An AI-Guided Framework for making TRIZ and C–K More Accessible

by

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Un Cadre Guidé par l'IA pour Rendre TRIZ et C–K Plus Accessibles

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RÉSUMÉ

TRIZ, méthode de résolution de problèmes structurée et créative bien connue, propose des approches structurées, mais sa mise en œuvre pratique peut s'avérer complexe. Le choix des outils requiert souvent de l'expérience, ce qui représente un défi pour de nombreux praticiens, notamment les débutants. Le manque de familiarité avec les outils, les lacunes dans les connaissances pertinentes et la tendance à privilégier des schémas de pensée familiers peuvent entraver l'exploitation optimale de cette méthode. De ce fait, les atouts de TRIZ ne se reflètent pas toujours dans le travail d'innovation quotidien.

Cette recherche explore comment le cadre développé utilise l'intelligence artificielle, en particulier les grands modèles de langage comme ChatGPT, pour surmonter ces difficultés en guidant les utilisateurs à travers TRIZ, puis la théorie C-K, de manière plus structurée et accessible. Au lieu de solliciter directement des solutions auprès de l'IA, ce qui conduit souvent à des idées génériques ou répétitives, l'approche proposée utilise une série de questions ciblées, basées sur la logique de TRIZ ou de C-K. Ces questions aident les utilisateurs à progresser étape par étape : définir plus clairement le problème, identifier les contradictions, rassembler les connaissances pertinentes et enfin évaluer les pistes possibles. Cette interaction leur permet de garder la maîtrise du processus, d’ajuster ou de rejeter les résultats de l’IA si nécessaire, et contribue à éviter l’homogénéisation souvent observée dans les résultats non structurés des modèles de langage.

Les quatre études présentées dans cette thèse appliquent cette idée dans différents contextes : de l’amélioration de la conception de chaussures antidérapantes au soutien au développement de concepts pour des systèmes d’assainissement compacts, en passant par l’exploration de solutions liées à la sécurité des conducteurs. Dans ces cas précis, les résultats démontrent que le cadre proposé facilite l'utilisation des principes TRIZ et C-K, notamment pour les utilisateurs peu familiers avec ces méthodes. Les utilisateurs sont également guidés vers une approche plus systématique des problèmes complexes et sont moins susceptibles de s'enfermer dans des schémas de pensée habituels.

Mots-clés : Intelligence Artificielle (IA), TRIZ Théorie de Résolution Inventive de Problèmes, Théorie de la Connaissance Conceptuelle (C-K), ChatGPT, Résolution Inventive de Problèmes, Techniques de Créativité et d'Innovation (CIT), 8 Tendances de l'Évaluation Technique

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ABSTRACT

TRIZ, as one of the well-known structured creative problem-solving methods, offers structured ways to approach problem-solving, but in practice it can be difficult to use. Its tool selection steps often require experience, which means many practitioners, especially beginners, find it challenging to apply. Issues such as unfamiliarity with the tools, gaps in relevant knowledge, and the tendency to fall back on familiar thinking patterns can make it hard to benefit fully from this method. Because of this, the strengths of TRIZ are not always reflected in everyday innovation work.

This research explores how the developed framework utilizes artificial intelligence, particularly large language models like ChatGPT, and eases these difficulties by guiding users through TRIZ and, later, C–K theory in a more structured and manageable way. Instead of asking the AI for direct solutions, which often leads to generic or repetitive ideas, the proposed approach uses a series of focused questions based on the logic of TRIZ or C–K. These questions help users move step by step from defining the problem more clearly, recognizing contradictions, gathering relevant knowledge, and finally evaluating possible directions. This interaction allows users to stay in control of the process, adjusting or discarding AI output when needed, and helps avoid the homogenization often seen in unstructured LLM outputs.

The four studies included in this thesis apply this idea in different contexts, from improving the design of non-slip footwear to supporting concept development for compact sanitation systems and exploring solutions related to driver safety. Across these cases, the findings proof that the suggested framework could make it easier to work with TRIZ and C–K principles, especially for users who are not deeply familiar with the methods. Users also are guided to approach complex problems more systematically and are less likely to get stuck in habitual thinking patterns.

Overall, the work shows that application of AI in the framework can play a practical supporting role. By helping clarify steps, surface relevant information, and structure the reasoning process, the proposed frameworks make TRIZ and C–K more accessible to a wider range of users.

Keywords: Artificial Intelligence (AI), TRIZ Theory of Inventive Problem Solving, Concept Knowledge Theory (C-K), ChatGPT, Inventive Problem Solving, Creativity and Innovation Techniques (CIT), 8 Trends of Technical Evaluation

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF ABREVIATIONS AND ACRONYMS

AI	Artificial Intelligence
ARIZ	Algorithm for Inventive Problem Solving
CIT	Creativity and Innovation Techniques
CK	Concept-Knowledge
C-space	Space of Concept
EVA	Ethylene-vinyl acetate
FEA	Finite Element Analysis
HUD	Head-Up Display
IFR	Ideal Final Result
K-space	Space of Knowledge
LLM	Large Language Model
NLP	Natural Language Processing
PE	Polyethylene
PLM	Product Lifecycle Management
PP	Polypropylene
PU	Polyurethane
R&D	Research and Development
Su-Field	Surface-Field
TPU	Thermoplastic Polyurethane
TPE	Thermoplastic Elastomers
TRIZ	Teorija Rezhenija Izobretatelskikh Zadach

LIST OF SYMBOLS

Xij	j-th generated answer related to i-th step
Qi	i-th Question
Ai,j	j-t answer related to i-th question

INTRODUCTION

By increasing the competitiveness in the market, companies which value and apply creativity and innovative activities have a better chance to increase their competitive advantages. Among many theories have been introduced to facilitate innovation within firms, TRIZ and concept-knowledge (CK) theories are selected in this research and their applications are facilitated through an AI-based framework. In this chapter the background of the study, project's objectives, expected outcomes, and significances of the study have been explained.

0.1 Background of the Study

The growing complexity of modern engineering and design problems has made the application of structured creative problem-solving methods such as TRIZ and C–K theory increasingly necessary, as these approaches provide systematic mechanisms to explore solution spaces beyond routine expertise. However, the effective use of these methods requires a substantial level of prior knowledge and experience. As a result, AI-driven tools like ChatGPT could be applied as supplementary tools to facilitate these methods effective implementation.

0.2 Problem Statement

The challenge lies in developing a systematic and effective framework that makes structured innovation methods like TRIZ and C-K theory more accessible.

0.3 Objectives of the Study

The general goal of this research is: **Increasing accessibility and simplifying the application of TRIZ and C–K theory even for individuals with limited prior expertise in using these methods.** To achieve this goal, the research follows the following interconnected objectives:

1. To develop a structured framework to facilitate problem-solving through a group of TRIZ tools (Hazard or cause of problem maps, Ideal outcome, Contradiction matrix, and 40 principles) and by using ChatGPT.
2. To test the applicability of suggested framework in addressing real engineering and design challenges through a practical case study
3. To expand the framework to cover another set of TRIZ tools (Hazard or cause of problem maps, Ideal outcome, and 8 trends of technical evaluation).
4. To explore how AI-assisted TRIZ tools (Hazard or cause of problem maps, Ideal outcome, and Su-Field analysis) could enrich both knowledge space and concept space within the C-K framework.

0.3 Expected Outcomes

The expected outcome of this research is to provide step-by-step guidance through targeted questions that make it easier for users to describe problems, define the ideal situation, explore relevant knowledge, and move toward possible solutions in a structured way. This is achieved by integrating ChatGPT as a supportive tool within the framework. Through practical case studies, the research aims to illustrate how the framework functions in real design and engineering contexts.

0.4 Significance of the Study

The study is relevant for both academic and practical contexts. For researchers, it offers a perspective on increasing the accessibility and ease of use of existing creativity and innovation theories. For practitioners, it provides an example of how guided, step-by-step interaction could make innovation tasks less overwhelming. Finally, organizations may use structured methods while still allowing flexibility and human insight in their decision-making processes.

0.5 Conclusion

This study develops and tests a framework that integrates ChatGPT with some of TRIZ tools and C–K theory. The framework applies some predefined questions to list hazards and causes of the problem, define ideal outcome, and move toward feasible solutions through TRIZ tools like 8 trends of technical evaluation and Su-field analysis. This research also highlights how AI application empowers both C-space and K-space and paves the way to reach feasible solutions. The framework was tested through three different case studies.

0.6 Organization of the Study

Following the introduction, this thesis is organized into six chapters. Chapter 1 represents a comprehensive literature review covering TRIZ and some of its selected tools, C–K theory, and the application of AI in creative design methods. Limitation of existing studies and open areas for future researches are highlighted through this review.

Chapter 2 highlights objectives, novel methodologies, and key contributions of the four studies that are the core of this research. The first study focuses on developing an AI-enhanced TRIZ framework to make creative problem-solving more accessible to practitioners. The second study retests the previous framework across a more complicated engineering and design challenges. The third study aims to expand the variety of TRIZ tools by adding 8 Trends of Technical Evolution to the developed framework. The fourth study explores the role of the developed framework in supporting both C-space and K-space.

Chapters 3 to 6 contain the journal articles corresponding to each study, presenting the research in detail. Chapter 3 describes an AI-enhanced framework to address challenges in TRIZ with the objective of facilitating problem-solving through TRIZ tools like Hazard or cause of problem maps, Ideal outcome, Contradiction matrix, and 40 principles. Chapter 4 named a TRIZ-based approach to reducing visibility issues and driver distraction, focuses on testing the suggested framework in addressing real engineering and design challenges. Chapter 5 represents the change in TRIZ tools within the framework where 8 trend of technical evaluation is used instead of contradiction matrix and 40 principles. Finally, chapter 6 presents how the proposed framework could benefits concept generation and user knowledge enrichment.

The overall conclusion of the research offers a broad discussion that brings together the key findings from Chapters 3 through 6. It reflects on the outcomes of the four studies as a whole, highlighting how suggested AI-integrated framework could open up creative problem-solving to a wider range of users. The final section outlines directions for future work, aimed at refining these AI-supported approaches and testing the framework in new industrial and design contexts.

CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Innovation considers as both mindset and process that results to new and valuable outcomes that gain successful acceptance and widespread use. These outcomes could be in different forms like products, process or even services. Creativity is a key component of innovation process and is defined as the ability to generate novel and appropriate ideas, concepts, and useful solutions to a given context by using existing knowledge (Gabriel, Monticolo, Camargo & Bourgault, 2016). To facilitate the innovation procedure, inventive and creative problem-solving methods like TRIZ have been applied in wide ranges of industrial problems.

1.2 TRIZ

TRIZ is the abbreviation of "teorija rezhenija izobreta- telskih zadach'' means theory of inventive problem solving developed by Genrich Altshuller. He and his colleagues reviewed and classified 400.000 inventions to reach a methodology or toolkit toward innovative problem solving. TRIZ was applied as a group of tools initially before being known as an organized method and finally concentrated as theory. TRIZ tools and techniques are developed based on the assumption that technology revolution and inventive products and processes could be gained according to certain laws and systematic way of thinking (Ilevbare, Probert, & Phaal, 2013).

Based on a survey of TRIZ applicants, Ilevbare categorized the ways in which TRIZ provides support as follows: helping to define problems, generating more innovative ideas, reaching innovative solutions in a shorter time, providing a common language for teams, and increasing teamwork performance (Ilevbare, Probert, & Phaal, 2013).

Although, TRIZ benefits from many tools and techniques, its acquisition and application are also challenging. First, understanding of TRIZ methodology is difficult that cause difficult adaptation in some contexts. Significant time requirement is another challenge when effective use of TRIZ typically demands both thorough theoretical comprehension and prior practical experience, which many potential users find difficult to attain. Finally, the lack of a standards to select best-practice framework causes uncertainty to choose among the wide range of tools. Consequently, some applicants may not accept TRIZ and have resistance against its useability (Ilevbare, Probert, & Phaal, 2013).

1.3 Ideality and the Ideal Final Result (IFR)

In TRIZ, Ideality is defined as the ratio between a system's useful functions (benefits) and its harmful functions (such as environmental impacts or negative side effects), including cost and waste (Dai & Ma, 2012). As a result, increasing ideality happens by improving system useful function (benefits) while (or) reducing resources cost or its harmful functions.

Ideality is considered one of the four basic theories of TRIZ by Mann and functions as a problem-definition tool that encourages problem solvers to move beyond the traditional approach of starting from the current situation. Instead, it promotes thinking from the perspective of the Ideal Final Result (IFR) which is a conceptual target and simply defined as a solution that delivers all the desired benefits while eliminating costs and harmful effects (Mann, 2001).

Ideality has several important applications in TRIZ. First, it provides a clear direction for innovation by guiding them toward the Ideal Final Result (IFR), thereby reducing the lack of focus often seen in traditional innovation approaches and improving innovation efficiency. Second, ideality is an important element to help formulate and analyze the original problem. Third, TRIZ assumes that technical systems evolve by resolving contradictions and increasing ideality; therefore, ideality also serves as a criterion for evaluating the evolutionary level of a technical system (Dai & Ma, 2012).

However, there are some challenges while IFR can sometimes feel too abstract or unrealistic for novice users. Moreover, translating a conceptual "ideal state" into actionable engineering steps requires experience and strong problem-framing skills (Cavallucci, 2017).

1.4 Contradiction Matrix and the 40 Inventive Principles

In TRIZ, a contradiction arises when an attempt to improve one parameter or characteristic of a system causes weakening in the same or another parameter (Savransky, 2000). To systematically address such contradictions, Genrich Altshuller developed the Contradiction Matrix, one of the most recognizable tools in TRIZ. This matrix was created after analyzing thousands of patents, which led Altshuller to conclude that many inventive breakthroughs occur when systems successfully resolve contradictions. The matrix helps practitioners identify which of the 40 Inventive Principles may be relevant to resolving a particular design conflict, such as increasing a system's strength without increasing weight. Because of its structured format, the matrix serves as a starting point for exploring conflicts within technical systems (Nakagawa, 2012).

From a functional perspective, the matrix has been widely acknowledged as an effective knowledge management framework that classifies problems in terms of feature conflicts and provides direction for inventive thinking. Researchers note that by selecting improving and worsening parameters, practitioners can quickly identify historically successful solution patterns, which can accelerate ideation and support systematic innovation processes (Murakami, 2019).

Despite its popularity, limitation concerns the completeness of the original parameter set. Because the matrix was derived from historical patent data belong to more than 20 years ago, it is argued that its fixed list of engineering features may not adequately cover emerging technologies or complex multidisciplinary problems. Additionally, the rigid pairwise structure assumes relatively simple conflicts, whereas many modern engineering problems involve multiple interacting contradictions and higher system complexity (Murakami, 2019).

1.5 Substance-Field (Su-Field) Analysis

Substance–Field (Su-Field) analysis is an important analytical tool in TRIZ that helps representing and studying problems in technological systems. It provides a structured way to describe interactions between system elements and supports the selection of appropriate solution strategies. In this approach, a technological situation is represented through an abstract graphical model composed of substances and fields. Substances represent material objects or components of a system, while fields represent the energy that enables interaction between these components, such as mechanical, electrical, thermal, chemical, or magnetic energy (Bukhman, 2021; Delgado-Maciel et al., 2025). Through this representation, problems and possible solutions can be expressed in a simplified and generalized form, which helps designers focus on the essential relationships within the system.

The basic structure of a substance–field model usually contains three elements: a first substance acting as a tool, a second substance representing the object or product, and a field that provides the energy for the interaction between them. The interaction between these elements may represent different types of system behaviour, such as useful actions, insufficient effects, excessive actions, or harmful interactions. By identifying these relationships, the Su-Field model helps clarify the core problem and guides the search for possible improvements or corrective actions (Bukhman, 2021).

Within TRIZ methodology, substance–field analysis is closely connected with the System of Standard Solutions. This system contains a collection of generic solution patterns developed by Genrich Altshuller and his research team to address recurring technical problems. The well-known set of 76 Standard Solutions is organized into several classes that address different types of technological situations, including creating or modifying substance–field models, developing existing systems, system transitioning to Supersystem and Microlevel, improving measurement and control processes, and finally simplification and improvement methods (Chen, Sheu, Sheu & Shi, 2025). Each standard typically describes a problem situation together with a recommended transformation that may lead to a possible solution. Because these standards are not linked to a specific technological domain, they allow knowledge and solutions to be transferred from one field of engineering to another (Bukhman, 2021).

The general problem-solving process in TRIZ often includes identifying the components of the system, constructing the substance–field model, linking the model with one of the standard solutions, and finally developing and validating a potential solution (Delgado-Maciel et al., 2025).

Despite their usefulness, Chen has noted that the traditional set of 76 Standard Solutions can be difficult to apply in practice. The standards are often presented mainly in textual form and are not always organized in a clear or systematic way, which may make them challenging for practitioners to understand and use effectively. In addition, some standards contain similar structural ideas, and the overall classification does not always provide a clear problem-solving procedure. To address these issues, developing simplified approaches to guide the application of Su-Field analysis in problem solving is also suggested (Chen, Sheu, Sheu & Shi, 2025).

1.6 The 8 Trends of Technical Evolution

The "8 Trends of Technical Evolution" sometimes called the "Laws of Technological Systems Evolution" forms one of the main foundations of TRIZ and offers a structured method for predicting how technological systems may grow or transform over time. These laws are considered as a heuristic and predictive toolkit that supports innovation and technology forecasting (Ghane et al., 2022). Because of its general structure, it has been applied in many engineering fields to support the development of new products and to anticipate future technological directions.

In TRIZ, technological systems are viewed as structures designed to perform specific functions. These systems are usually organized in hierarchical forms. A system often contains several subsystems that work together to perform required functions, while the system itself may also become a component of a larger and more complex system. This hierarchical view helps designers analyze system at different levels and better understand how improvements in one part may influence the overall system.

Technological systems are not static. They continuously change in response to evolving societal needs and increasing competition in global markets. The evolution of a technological system can be described as a sequence of changes appear as gradual improvements created through inventions. These incremental developments accumulate over time until the system reaches a new stage of evolution (Fey & Rivin, 2005). In another word, the laws of technical system evolution describe relationships between the elements of a system and their interaction with the surrounding environment. These relationships guide the gradual transition of a system from one state to another with the aim of improving its functionality (Chybowska & Chybowski, 2019).

The laws of technological system evolution provide useful guidance for engineering and business decision-making by providing a structured evaluation of the future potential of technical systems and provide them a vision of how a system may improve or transform in the future. This approach can support the development of new products and technologies and also help organizations estimate the potential value of technological solutions and better prepare for future competition (Chybowska & Chybowski, 2019).

Another important advantage of this method is its strategic value in product development and technology planning. By offering insights into possible future trends, it may help companies enhance existing products and develop new features that respond to emerging technological opportunities (Ghane et al., 2022).

Despite these benefits, several limitations have been reported. The trends and sub-trends are often broad and general, which may limit their direct application in specific design situations. Moreover, its application often requires significant manual interpretation, which can make the analysis process time-consuming (Ghane et al., 2022). Their application can be difficult in systems that experience sudden and highly dynamic technological changes, such as those influenced by breakthrough discoveries and the performance of individual trends may vary depending on the product type, technological maturity, and changing user needs (Chybowska & Chybowski, 2019). As a result, combination of this tool with other TRIZ tools or with additional sources of information such as patent analysis and its integration with computer-aided techniques are suggested to improve effectiveness and enhance the useability (Ghane et al., 2022). Below is an expanded explanation of each trend:

1.6.1 Increasing Ideality

This trend describes how technical systems tend to develop toward a higher level of ideality over time by delivering greater benefit with fewer drawbacks (complexity, cost, or negative effects). As examples, A system may improve its ability to perform existing functions with limited resources or perform additional functions without increasing resources. Because of this, systems with a higher level of ideality have a greater chance of succeeding in the market and remaining competitive for a longer period (Fey & Rivin, 2005).

Chybowska describes an ideal system as a system that technically does not exist but whose function is still achieved. In practice, this idea means improving system effectiveness, reliability and performance while requiring fewer resources (Chybowska & Chybowski, 2019).

1.6.2 Non-Uniform Development of System Components

The law of non-uniform evolution highlights that technological progress is not always smooth or balanced. Instead, it is often shaped by differences in the development speed of system components, as a result some components may improve rapidly, while others develop more slowly. As technological systems become more complex, this imbalance between their parts becomes more noticeable (Fey & Rivin, 2005); (Chybowska & Chybowsk, 2019).

This uneven development often leads to internal conflicts within the system. These conflicts create a need for new inventions or design changes to restore balance between the subsystems.

As a result, resolving such conflicts becomes an important driver of technological progress and helps guide the direction of future system development (Fey & Rivin, 2005). The analysis of system evolution through this law therefore provides useful insights for identifying possible directions for further technological improvement.

1.6.3 Transition to a Supersystem

When a technological system reaches the limits of its development at a certain level, its evolution may continue at the level of a supersystem. According to the law of transition to supersystems, technologies often evolve from simple mono-systems into more complex bi-systems or poly-systems (Fey & Rivin, 2005). A mono-system is typically designed to perform a single function, while bi- or poly-systems combine two or more systems. These combined systems may perform similar or different functions and may also have different physical properties.

The simplest way to create a more advanced system is to integrate previously independent mono-systems to share resources and expand their capabilities. When these systems are combined, the overall performance can improve and higher levels of functionality may achieve (Chybowska & Chybowsk, 2019). One benefit of this increased complexity is that the functional load can be distributed among different components of the system allowing the system to operate more efficiently and perform additional tasks (Fey & Rivin, 2005).

1.6.4 Increasing Dynamization

This trend suggests that technological systems evolve from rigid and fixed structures toward more dynamic ones. Greater flexibility allows systems to adjust to different performance requirements and environmental changes. Such adaptability helps technological systems remain effective as conditions change over time. In addition, systems that follow this evolutionary path often gain multifunctional capabilities, which increases their usefulness and efficiency (Fey & Rivin, 2005). This adaptability may also reduce the level of human intervention required to control or manage the system. As a result, technological systems gradually move toward higher levels of autonomy and efficiency (Chybowska & Chybowski, 2019).

The evolution toward greater dynamism can occur in several ways like increasing the degree of freedom of an object by adding joints, enhancing the flexibility of materials or substances used in the system through adopting deformable materials, and creating components that change shape or function depending on conditions. These developments contribute to making systems more responsive and versatile, which supports their long-term evolution and effectiveness (Chybowska & Chybowski, 2019).

1.6.5 Increasing System Completeness

This law explains the essential structure required for an autonomous technological system to operate effectively. According to this principle, every technical system should contain four main components: a working unit, an engine, a transmission, and a control unit. The working unit is the element that directly performs the main function of the system. The engine acts as the energy source, while the transmission transfers and transforms this energy so that it can be used by the working unit. The control unit regulates and adjusts the operation of these components, allowing the system to function properly and adapt to different conditions (Fey & Rivin, 2005); (Chybowska & Chybowski, 2019).

In the early stages of technological development, some of these functions are often performed by humans rather than by technical components. As the system evolves, these human roles are gradually replaced by technological elements. The system becomes more autonomous as control, operation, and coordination are increasingly handled by the technology itself (Fey & Rivin, 2005).

1.6.6 Transition from Macro to Micro Levels

According to this perspective, early technological solutions often rely on macro level such as visible mechanical elements. However, as technology develops, these functions are increasingly transferred to micro-level structures such as molecules, atoms, or other smaller physical elements. In many cases, conflicts or limitations that appear during system development can be resolved by moving toward micro-level solutions (Fey & Rivin, 2005).

The evolution toward micro-level structures is also related to the segmentation and transformation of system components. Such transformations illustrate how technological systems move from solid and rigid structures toward more advanced and distributed forms of operation. In practice, this means that solid objects may gradually be replaced by more flexible or dispersed forms such as granules, powders, gels, liquids, gases, or plasma (Chybowska & Chybowski, 2019).

1.6.7 Harmonization of Rhythms

Technological systems usually contain multiple interacting elements, and their performance depends not only on the design of individual parts but also on how these parts work together over time. According to this law, systems become more stable and productive when the periodic actions of their components are harmonized. If this coordination is not achieved, different elements of the system may disrupt each other, which reduces the overall performance (Fey & Rivin, 2005).

The application of this law in technology and product development can take different forms including alignment of system actions, and coordination in system shape or form. Designers may add periodic motions or operating parameters between system components, or reduce unwanted vibrations and repetitive motions that negatively affect system performance. Proper alignment of these actions can significantly improve system functionality and reliability (Fey & Rivin, 2005); (Chybowska & Chybowski, 2019).

1.6.8 Transition to Use of Fields (Field Evolution)

One of the important ideas in the evolution of technological systems is the law related to increasing substance–field interactions, sometimes also described as the law of increasing controllability. As the Su-Field model was discussed in detail in Section 1.5, its effects on technological systems are briefly presented in this section.

An incomplete system gradually develops into a minimal technical system that includes two substances and one field. Over time, these systems may expand further to form more complete and complex structures, such as chain substance–field systems or dual substance–field configurations, which increase the number of elements and interactions within the system (Chybowska & Chybowsk, 2019). As the system develops, this interaction between system elements and the fields inside a technological system becomes stronger, efficient, and more organized (Fey & Rivin, 2005). The system development may happen through different ways like replacing less controllable fields with fields that provide greater control. For example, gravitational effects may be replaced by mechanical actions, and mechanical systems may later be replaced by electrical fields that allow more precise control (Fey & Rivin, 2005).

1.7 ARIZ (Algorithm of Inventive Problem Solving)

ARIZ (Algorithm of Inventive Problem Solving) is considered one of the central methods within TRIZ for addressing complex engineering problems. It provides a structured and systematic procedure that guides users through a step-by-step problem-solving process. This method is especially useful for difficult and complicated problems where simple tools may not be sufficient, however it is known as a complex tool for simpler problems and novices (Ilevbare, 2013).

A key characteristic of ARIZ is its focus on problem reformulation. Instead of moving directly to a solution, the method repeatedly analyzes and reinterprets the problem. By doing so, an initial problem gradually transforms into a clearer and more structured problem model.

Through this process, the original situation can be generalized and represented in different forms such as contradictions, substance–field models, or functional requirements. By doing so, ARIZ removes preconceived solutions from the problem statement and allows designers to approach the situation more objectively (Cerit & Küçükyazıcı & Şener, 2014). The method relies on logical procedures that help users move from an initial description of the problem into a more precise formulation, often referred to as a mini-problem and finally toward effective and innovative solutions (Bukhman, 2021).

ARIZ also plays several important roles within the TRIZ methodology. It organizes specific TRIZ tools into a coherent system and guides users on when and how to apply them during problem analysis. In addition, ARIZ functions as a logical analytical procedure that helps the human mind move step by step from the initial problem statement toward innovative solutions (Bukhman, 2021). Bukham lists the ARIZ procedure into nine stages as briefly described as bellow (Bukhman, 2021):

1- Problem Analysis: The purpose of this stage is to transform the initial and sometimes vague problem statement into a clearly defined formulation often referred to as a “mini-problem.”

2- Problem Model Analysis: The next stage examines the resources like time, space, substances, and fields that exist within the system or its environment. By analyzing these resources, the designer gains a clearer understanding of how the system operates and what elements can be used to generate potential solution.

3- Determination of the Ideal Final Result and Physical Contradiction: At the most creative stage, different formulations of the ideal result may be proposed and available system resources are examined in order to explore alternative directions for the solution. At the same time, by clearly formulating contradictions, ARIZ helps focus the search for solutions that overcome the conflict rather than compromise between the two requirements

4- Utilization of Substance-Field Resources: As discussed in section 1.5, this stage develops the transition from problem understanding to potential answers by allowing visualization of possible system actions more freely.

5- Application of Standard Solutions, Separation Principles, and Scientific Effects: If a clear solution does not reach in the steps 3 and 4, ARIZ continues with the systematic use of additional mentioned TRIZ tools.

6- Problem Reformulation or Replacement: At this stage, the original formulation may be modified or replaced with a new perspective. This reformulation often helps remove hidden assumptions or limitations and update the problem definition continuously until a workable direction emerges.

7- Evaluation of the Solution: Once a possible solution has been generated, ARIZ requires an evaluation to verify that the solution removes the contradiction rather than simply reducing it.

8- Application of the Obtained Solution: After a solution is validated, ARIZ encourages its application beyond the original problem and reuse it in future problem-solving situations.

9- Analysis of the Problem-Solving Process: In the final stage the designers review the entire process to learn from each solved case and develop their inventive thinking skills as well as their ability to apply ARIZ in future problems.

Why ARIZ Was Not Used in This Research

Although ARIZ is one of the most comprehensive tools within TRIZ, it was not selected as the main approach in this research due to its level of complexity. For users without prior experience, following ARIZ can be difficult and time-consuming, which makes it less suitable for the main objective of this study which is to simplify the application of TRIZ and make it more accessible, especially for individuals with limited background in creativity and innovation methods. Even with AI support, guiding users through the full ARIZ process would likely remain challenging, as many of its steps involve abstract reasoning, problem reformulation, and the identification of physical contradictions that are not always straightforward.

Instead, this research focuses on selected set of TRIZ tools to be structured into guided interactions, such as contradiction analysis and the trends of technical evolution. These tools allow the development of a step-by-step, question-driven framework where users can interact with AI, evaluate intermediate results, modifying or filtering AI-generated outputs at each step, and gradually refine their solutions. This approach aligns better with the idea of using AI as a facilitator that supports structured thinking without requiring deep prior expertise.

For these reasons, ARIZ was not included as a core component of the methodology (however some TRIZ tools are applied in both methods). The focus was instead placed on more accessible TRIZ tools that could be effectively integrated with AI to support both novice and experienced users in a practical and manageable way.

1.8 C-K Theory

C-K theory is considered a design theory that explains how innovation and creative design processes can be structured and understood. It models design as an interaction between two different but connected spaces: the concept space (C) and the knowledge space (K). The concept space includes ideas or propositions that are not yet validated, meaning they are neither true nor false, while the knowledge space contains established and validated information that designers already know (Bordas & Pascal, 2026). These two spaces are interdependent but with different structures and logics. The C-space contains objectives and searching for new knowledge is required to find appropriate solutions. The acquired knowledge will be results to new concepts and this process continues so, CK is considered as a permanent creativity process (Hatchuel & Weil, 2009). This distinction helps designers clearly separate what is known from what still needs to be explored during the design process.

In this framework, design starts with an initial concept that is often incomplete or unclear. The goal of the process is to gradually transform this uncertain concept into validated knowledge by expanding both spaces. This is achieved through different design operators that allow movement between concept and knowledge, such as adding new attributes to concepts, generating new knowledge, or testing ideas through experimentation (Hatchuel & Weil, 2009). Through this interaction, both the concept space and the knowledge space grow together, supporting the development of innovative solutions.

Concept is not able to be searched or explored and the only operations are inclusion and partition. By adding new properties to concepts, a set will change to sub sets (partition). If a property from k-space is added to a concept (K→C), it is a restricting partition, while if the added property does not belong to K space (C→C) it is expansive partition. By removing partitions some subsets create another set (inclusion). Expansive partitions are the reason of dynamics in C-space as the modification in system objects are done in a way which is not exists in K-space. In a design procedure a concept will generate new concepts (C→C) or being transformed to knowledge (C→K). The last operation refers to transferring and reordering knowledge (K→K).

As is mentioned by Hatchuel and Weil, the design procedure needs at least one departure concept, one expansive partition that can be leads to another concept and knowledge expansions to validate the design solution as an acceptable one or generates new expansive partitions (Hatchuel & Weil, 2009).

To summarise, C-K theory emphasizes exploration as a key part of innovation. The concept space can be structured as a tree where an initial idea is expanded into several alternative concepts. Each branch represents a possible direction for new concepts, and some of them can later be connected to existing knowledge and transformed into feasible solutions. This continuous interaction between exploring new ideas and using existing knowledge allows designers to go beyond simply improving current solutions and instead generate more original and disruptive innovations (Kouassi & Gardoni, 2026).

Another important aspect of C-K theory is its ability to support knowledge expansion and creativity at the same time. By encouraging designers to question existing assumptions and explore unknown areas, the theory helps reveal gaps in knowledge and motivates further research. At the same time, it ensures that new ideas remain connected to reality by linking them back to validated knowledge. This balance between creativity and feasibility makes the approach useful in different contexts, including industrial design and innovation management (Kouassi & Gardoni, 2026).

The literature also highlights several strengths of C-K theory. It provides a structured yet flexible framework that supports collective creativity and helps teams explore ideas in a systematic way. It encourages open thinking, allows multiple innovation paths, and supports the gradual refinement of ideas into practical solutions. Because of its iterative nature, it also promotes continuous improvement and adaptation during the design process (Kouassi & Gardoni, 2026).

However, some limitations have been identified. The method can be complex and may require a strong understanding of both concepts and knowledge structures. It may also demand significant time and effort, especially when exploring multiple concept alternatives. In some cases, the iterative nature of the approach can lead to long cycles of idea refinement without clear stopping points. Additionally, the effective use of C-K theory often depends on expert knowledge, which can limit its accessibility for less experienced teams (Kouassi & Gardoni, 2026).

1.9 Integration of AI with Creative Design Methods

Recent studies highlight a growing interest in combining artificial intelligence (AI) with structured innovation methods such as TRIZ and C-K theory to overcome complex engineering challenges. One important direction is the development of hybrid methodologies that integrate data-driven AI capabilities with rule-based inventive reasoning. For example, a hybrid approach combining generative AI with TRIZ has been proposed to address engineering contradictions through a structured process that includes problem definition, idea generation, filtering, and iterative refinement. In this approach, AI recognizes patterns in complex data and explores a wide range of possible solutions, while TRIZ provides structured inventive principles which guide the selection and improvement of AI generated solutions, helping to balance conflicting requirements such as efficiency and simplicity (Brad et al., 2025).

This combination is particularly important because purely data-driven AI methods often depend on clearly defined objectives and constraints, which may limit their effectiveness in problems where contradictions are complex or not well defined. By integrating TRIZ and AI approaches, the framework enables a two-way exchange of information. On one hand, TRIZ principles guide and narrow the AI's search toward solution paths that have proven effective in past innovations. On the other hand, AI supports TRIZ by identifying the most relevant principles for a given problem and suggesting practical ways to apply them. This combination helps overcome key limitations of both methods, including the lack of structured guidance in AI-based exploration and the difficulty of fully exploring solution spaces when TRIZ is applied manually (Brad et al., 2025).

In addition to design generation, AI has also been explored as a supportive tool in innovation processes. Studies using AI-based TRIZ chatbots show that AI can complement human problem-solving by validating results and suggesting new directions for exploration. Although AI does not yet match the depth of human creativity and contextual understanding, it can support post-analysis, enriching ideation sessions, improve decision-making, and enhance the robustness of innovation outcomes. This suggests a future where human designers and AI systems collaborate more closely throughout the innovation process rather than working separately (Tatti, 2025).

Another important contribution in this field focuses on extending traditional TRIZ tools using AI. For instance, limitations in the classical contradiction matrix, especially in handling self-contradictory parameters, have led to the introduction of new types of contradictions and solution strategies. By combining semantic AI models with case-based reasoning, researchers have shown that AI can identify new inventive patterns, refine existing TRIZ principles, and adapt them to specific domains such as energy, information technology, and biomedical systems. This approach also supports the continuous evolution of TRIZ by creating dynamic and adaptable knowledge bases that can grow with new data and technological developments (Brad, Cîrlejan, Brad, & Chiş, 2025).

Beyond TRIZ, the integration of AI with broader design theories such as C-K theory has also been explored. These approaches aim to unify different creativity methods into a single framework where AI acts as a catalyst for innovation. By analyzing large amounts of data, AI can assist in multiple stages of the design process, including pattern identification, problem formulation, knowledge organization, and new concepts generation, while methods like TRIZ and C-K provide structure and reasoning to guide this process. This integration enables designers to develop data-driven solutions while maintaining a systematic approach to creativity (Senghor, 2024).

Overall, the literature shows that combining AI with TRIZ and C-K creates a more powerful and flexible innovation framework. AI contributes strong capabilities in data analysis, pattern recognition, and exploration, while TRIZ and C-K provide structured reasoning and problem-solving logic. Together, they support more efficient and adaptive design processes and open new possibilities for innovation across different industries.

1.10 Research Gap and Contribution of the Study

Although recent studies show strong potential in combining artificial intelligence with TRIZ and design methodologies, they still have several limitations that reduce their practical usability, especially for non-expert users. Many existing works focus on integrating AI with only a single TRIZ tool or a limited part of the methodology. For example, some studies mainly use AI for contradiction resolution or idea generation, without covering the full problem-solving process from problem definition to final solution development. As a result, these approaches remain fragmented and do not provide a complete and coherent framework that users can easily follow in real design situations (Brad et al., 2025; Tatti, 2025).

Another important limitation is how AI is typically used in these studies. In many cases, AI is applied as a direct solution generator, where the system produces final answers with limited user involvement. This reduces the role of the user in the reasoning process and may lead to solutions that are not fully realistic or well-evaluated. Users often do not have a clear opportunity to analyze, filter, or refine the generated ideas step by step. As a result, the process may lack transparency and control, especially for complex engineering problems (Brad, Cîrlejan, Brad, & Chiş, 2025; Tatti, 2025).

In addition, previous studies rarely provide a structured pathway that connects different stages of TRIZ problem solving. Important steps such as problem analysis, defining the Ideal Final Result, and exploring solutions using different TRIZ tools are often treated separately rather than as part of an integrated process. This makes it difficult for users, particularly those with limited experience, to understand how to move from one stage to another in a logical and systematic way (Brad et al., 2025; Tatti, 2025). Furthermore, while some research explores the integration of AI with TRIZ, the connection between AI-assisted TRIZ tools and C–K theory has not been sufficiently studied, leaving a gap in understanding how knowledge and concept spaces can be jointly expanded in an AI-supported environment (Senghor, 2024).

To address these gaps, the present research proposes a more comprehensive and user-oriented framework. Instead of relying on a single TRIZ tool, this study integrates several key tools, including hazard or cause of problem maps, Ideal Final Result, contradiction matrix, 40 inventive principles, Su-Field analysis, and trends of technical evolution. This combination allows the framework to cover different stages of the problem-solving process, from problem understanding to solution exploration, creating a more complete and structured approach.

Another key contribution of this study is the way AI is used within the framework. Rather than generating final answers directly, ChatGPT is integrated as a supportive tool that guides users through a step-by-step process based on targeted questions. At each stage, users are able to review, evaluate, and refine the AI-generated outputs before moving forward. This interactive process increases user involvement and control, and it improves the feasibility and practicality of the final solutions.

Moreover, this research extends beyond TRIZ by exploring the integration of AI-assisted TRIZ tools within the C–K theory framework. By linking problem-solving tools with the expansion of knowledge and concept spaces, the study provides a deeper understanding of how AI can support both idea generation and knowledge development simultaneously. This connection represents a novel contribution and opens new directions for combining structured innovation methods with AI technologies.

Overall, the added value of this research lies in developing a structured, step-by-step, and accessible framework that simplifies the application of TRIZ and C–K theory. By combining multiple TRIZ tools, enabling active user participation, and integrating AI in a controlled and interactive way, the proposed approach aims to make systematic innovation more practical, understandable, and effective, even for users with limited prior experience.

CHAPTER 2

RESEARCH OBJECTIVES, METHODOLOGIES, AND CONTRIBUTIONS

This research began with a persistent observation: although TRIZ offers one of the most comprehensive and structured approaches to inventive problem-solving, its application in industry remains limited specially for practitioners without formal TRIZ training. At the same time, artificial intelligence has matured into a conversational, reasoning partner capable of assisting human cognition in real time. This convergence raised a fundamental question could AI make TRIZ more accessible?

The answer to the research question developed through four consecutive studies, each shaped by the insights and limitations identified in the previous one. What began as an effort to make TRIZ easier to apply gradually expanded into a broader investigation of how AI can support the practical use of structured innovation methods. The research progressed from developing a general, guided procedure for applying TRIZ, to applying the approach in concrete engineering contexts, then to exploring how other selected TRIZ tools can be used more effectively with AI support, and finally to examining how TRIZ-based reasoning can be aligned with the conceptual structure of C–K theory. Together, these studies reflect a step-by-step exploration of how AI can facilitate the implementation of the established creativity and innovation methodologies.

2.1 Creating Procedural Clarity and Universal Accessibility

The first study focused on a well-known challenge in using TRIZ. The method itself is strong and well structured, and it offers clear principles for solving inventive problems. However, even though the theory can be learned, applying TRIZ in real situations often takes a lot of time and experience. Many practitioners struggle not because they do not understand TRIZ concepts, but because they are unsure where to start, which tools to use, or how to interpret and work through contradictions in practical design problems. To address this issue, the study developed a general AI–TRIZ framework that turns TRIZ from a static method into an interactive process between the user and the system.

In this framework, ChatGPT was used as a conversational guide. It responded to structured questions, helped users clarify the problem, and apply defined TRIZ tools at each step. In this way, the logic of TRIZ was expressed through a natural dialogue rather than technical instructions. The approach was tested through a case study on non-slip shoe outsole design. The results showed that users with no prior TRIZ background could be benefited from the full innovation process. But the applicability of the suggested framework needs to be tested in real engineering and design challenges through a practical case study. This led to the second phase of the research.

2.2 TRIZ in Engineering Applications

The second study marked a turning point. Having validated that an AI embedded TRIZ tool could be more accessible for both novice and professional users, the focus now shifted toward practical application of it in engineering contexts. The goal was to see whether the AI–TRIZ integration could support not only idea generation but also the full innovation cycle.

It incorporated three main elements: problem definition to clarify the core technical contradictions, explore relevant scientific and engineering principles, and establishing criteria for solution evaluation and assess alternatives in terms of safety, performance, and feasibility.

A case study in automotive design, specifically on reducing driver distraction and improving visibility, demonstrated how the framework could guide engineers from problem identification to concrete, validated solutions.

While this framework helped improve clarity and ease of use in the studied case, it also raised a further question. If AI could support the procedural steps of TRIZ, could it also engage with other TRIZ creative tools? This question guided the next stage of the research and shaped the direction of the third study.

2.3 AI and the 8 Trends of Technical Evolution

Having demonstrated that AI could guide users through TRIZ processes, the next challenge was to explore whether AI could support specific TRIZ tools, especially those that demand interpretive skill and creative reasoning. The "8 Trends of Technical Evolution" represents the evolution of technical systems through distinct stages, but in practice, its complexity often limits its use.

The third study thus focused on embedding AI within the 8 Trends framework. By integrating ChatGPT and through structured questioning and guided prompts, users explore analogies, rethink trends, and forecast new directions of system development.

Once again, the non-slip outsole design served as a case example, allowing direct comparison with the earlier framework. This time, however, the system not only organized the process, it actively stimulated new ideas, helping users to overcome mental blocks. The study demonstrated that application of AI in 8 trends of technical evaluation, could act as a creative catalyst**,** transforming TRIZ from an expert's toolkit into an accessible creativity assistant**.**

The studies so far had proven the efficiency of proposed framework, but they had not yet explained why AI-TRIZ combination worked so powerfully. To address that, the research turned to theory.

2.4 Integrating C–K Theory with AI–TRIZ

The final article illustrates the cognitive structure of the AI–TRIZ interaction. Here, Concept–Knowledge (C–K) theory provided the missing link by explaining how innovation emerges from the dynamic interplay between the concept space (C), where new ideas are imagined, and the knowledge space (K), where existing knowledge resides. By embedding AI into this model, the study revealed a more general cognitive architecture of innovation: AI application expands the K-space by gathering diverse knowledge, while TRIZ structures the exploration of the C-space by guiding idea evolution.

The resulting AI–TRIZ–C–K hybrid framework demonstrated the role of AI application in assisting and even amplifying human inventiveness. The case of the automated sanitation system illustrated this theoretical model in action, showing how the interaction between AI and TRIZ fosters both structured reasoning and improved creativity.

This final study thus reframed the entire research program: what began as a procedural improvement ended as a conceptual synthesis, articulating how AI, TRIZ, and C–K theory converge into a new intelligent innovation system.

2.5 A Coherent Framework

Taken together, the four studies are connected where each one builds on the questions and limitations identified in the previous one. Their relationship and progression are illustrated in Figure 2.1. The focus gradually shifts from improving practical accessibility, to applying the approach in engineering-related cases, then to examining the use of specific tools, and finally to considering how these methods can be positioned within the structure of C–K theory. Rather than presenting separate contributions, the studies collectively support a clearer understanding of how AI can be integrated in problem solving methods to assist human creativity in a structured and controlled manner.

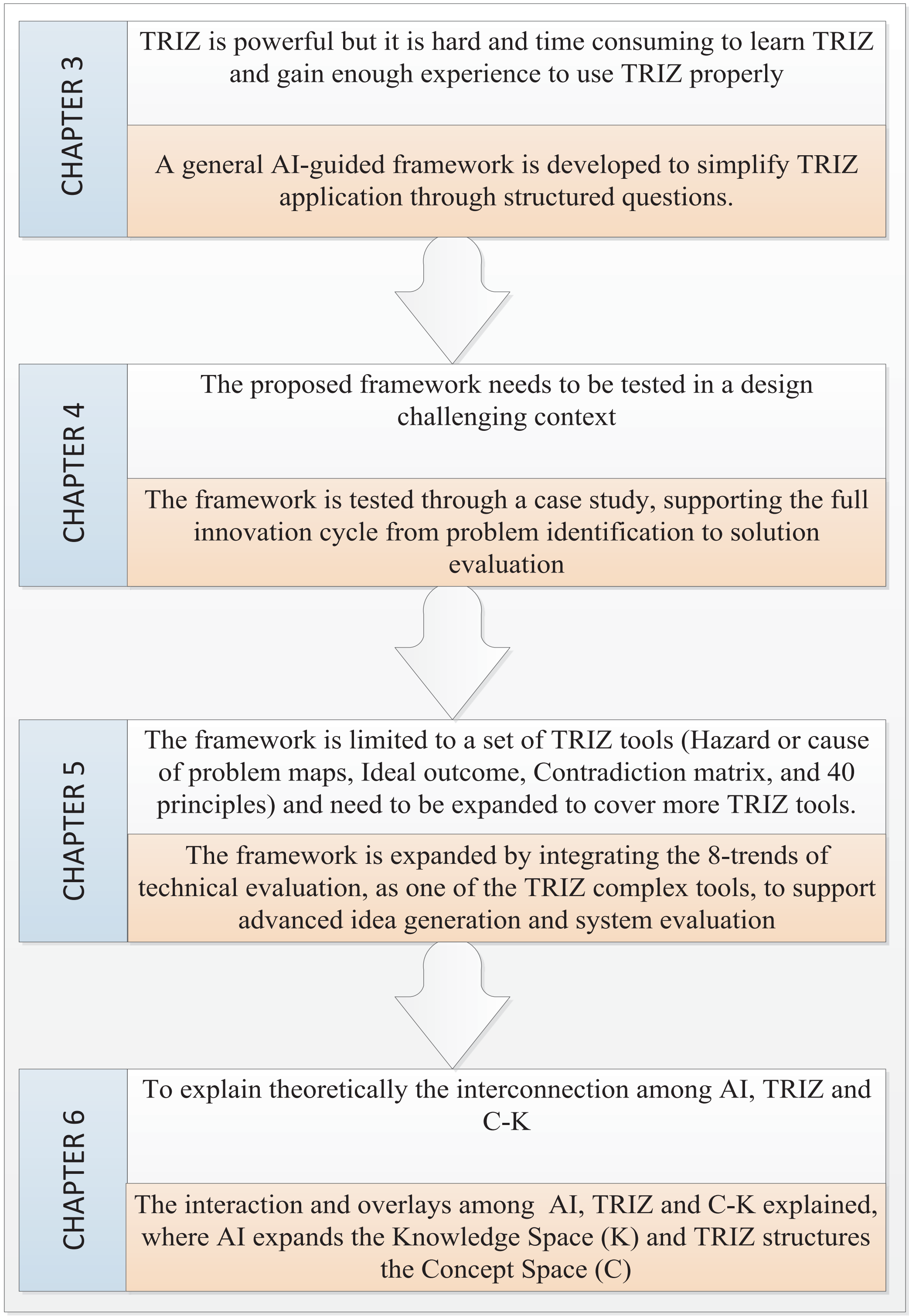

Figure 2.1 Logical evaluation across the four articles

CHAPTER 3

NEXT-GEN INNOVATION: A HOLISTIC AI-ENHANCED FRAMEWORK TO ADDRESS CHALLENGES IN TRIZ AND CIT CREATIVE PROBLEM-SOLVING PROCEDURES

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Résumé

Dans un contexte économique en constante évolution, la recherche d'un avantage concurrentiel est essentielle à la réussite d'une entreprise, en privilégiant les activités de recherche et développement (R&D) étroitement liées aux techniques de créativité et d'innovation. Malgré l'application généralisée des techniques de créativité et d'innovation (TCI) dans divers domaines, des obstacles entravent leur mise en œuvre efficace. L'IA apparaît comme une solution prometteuse pour accélérer les procédures de TCI, réduisant ainsi les risques et les coûts liés à l'innovation. Cependant, notre compréhension du rôle de l'IA dans la gestion de l'innovation et de ses limites potentielles reste particulièrement limitée par rapport à d'autres domaines de gestion traditionnels où l'IA se substitue aux rôles humains. Cet article propose un modèle combiné universel, s'appuyant sur des cadres basés sur l'IA comme ChatGPT, pour accélérer la théorie de la résolution créative de problèmes TRIZ et fournir aux décideurs des connaissances et des données diversifiées, tout en proposant des solutions potentielles qui élucident les contradictions et les paramètres d'évaluation.

Abstract

In the rapidly evolving business landscape, the pursuit of competitive advantage is crucial for a company's success, focusing on Research and Development (R&D) activities intertwined with creativity and innovation techniques. Despite the widespread application of creativity and innovation techniques (CIT) across diverse fields, barriers impede their effective implementation. AI emerges as a promising solution to expedite CIT procedures, reducing the risks and costs associated with innovation. However, our understanding of AI's role in innovation management and its potential limitations remains notably limited compared to other traditional management domains where AI serves as a substitute for human roles. This article proposes a universal combined model, leveraging AI-based frameworks like ChatGPT to accelerate TRIZ creative problem-solving theory, and provide decision-makers with diverse knowledge and data and offering potential solutions that elucidate contradictions and evaluation parameters.

3.1 Introduction

Although the significant role of CIT is widely accepted in a company's continuous development (Rumanti, Rizana, & Achmad, 2023), the application of creativity and innovation techniques (CIT) extends beyond the business domain and spans various fields today. Regrettably, the implementation of CIT faces substantial barriers. Firstly, the selection and application of suitable tools demand considerable knowledge and experience, thereby limiting the accessibility to a diverse range of users. Secondly, traditional CIT techniques are inherently human-centered, and their efficacy diminishes due to constraints associated with applicants' knowledge and experiences. Lastly, a comprehensive guideline is lacking to delineate the initiation and conclusion, thereby impeding the progression of CIT activities.

Amidst the array of available CIT tools and techniques, the utilization of creative problem-solving theories, such as TRIZ, is proposed to streamline innovation procedures. TRIZ, a well-known human-centered creative problem-solving theory, regards design as a cognitive activity inherently tied to human thinking, requiring users to possess an engineering background.

Consequently, the pivotal role of users' knowledge emerges as a critical factor in fostering creativity and contributing to the success of CIT activities.

TRIZ does not explicitly outline a precise perspective on the problem space, encompassing evaluation parameters and contradictions, or the solution space, which entails a specific set of contradictions to meet evaluation criteria. Thus, enhancing these methodologies with a framework that elucidates the problem space and streamlines knowledge generation will lead to more effective innovative solutions.

Based on the interesting results of each TRIZ tool in specific fields, a universal combined model is suggested to find innovative solutions for wide areas of problems. In this point, the role of AI-based framework could be critical to facilitate think out of the box procedures and speed up innovation procedures by feeding users with related knowledge and data from a variety of areas.

The framework also expands the solution selection procedure beyond available knowledge and experience inside the company. In other words, applying AI systems like ChatGPT in combination with TRIZ tools not only facilitates innovation by supporting decision-makers with sufficient related knowledge but also speeds up the knowledge discovery procedure. Overall, this research culminates in a machine learning-driven framework aimed at offering prospective solutions that delineate contradictions and evaluation parameters.

3.2 Literature review

Creativity is characterized as the capacity of an individual or a group to put forward or generate an original concept, while innovation entails the implementation of these concepts via an organizational procedure that results in a technically and economically viable resolution to a problem (Gabriel et al., 2016).

Innovation hinges on the utilization of Creativity and Innovation Techniques (CITs), a term formalized by Foster and Broco as an embodiment of empirical practices leading to successful creative endeavors (Forster & Brocco, 2008). By employing CITs, encompassing methods, frameworks, procedures, or even systems, creative teams are supported in the creative process to generate more ideas and attain superior solutions at an earlier stage (Forster & Brocco, 2008), (Teza et al., 2016), (Bertoncelli et al., 2016). Typically, numerous CITs are available for a given problem, necessitating the evaluation of various criteria such as team dynamics, desired innovation level, and associated challenges for the selection of one or more CITs. Consequently, the judicious choice of CITs, aimed at meeting organizational requirements or enhancing goal attainment, demands substantial expertise (De Carvalho Botega & Da Silva, 2020).

3.2.1 TRIZ

TRIZ stands for "teorija rezhenija izobretatelskih zadach," which translates to the theory of inventive problem-solving (Ilevbare et al., 2013). Originating in Russia and developed by Genrich Altshuller post-World War II, a time when manufacturing industries held strategic importance, TRIZ emerged as a systematic approach. Altshuller and his colleagues meticulously reviewed and categorized 400,000 inventions, leading to the formulation of a methodology or toolkit for innovative problem-solving. The tools and techniques of TRIZ are grounded in the belief that technological revolutions and inventive products and processes do not occur randomly; rather, they follow specific laws and a systematic mode of thinking (Savranksy, 2000), (Eversheim, 2008).

Initially applied as a set of tools, TRIZ evolved from a group of tools to a recognized method and eventually consolidated into a formal theory (Benmoussa et al., 2019). While TRIZ is now acknowledged as a knowledge-based methodology for problem-solving with an expanded scope (Savranksy, 2000), it is essential to note that it is most effective for addressing standard types of problems (Altshuller, 2000).

To derive a solution using TRIZ, the initial stage involves deconstructing a tangible technical issue into its fundamental elements, referred to as a conceptual problem. Subsequently, one or more conceptual solutions are aligned with the conceptual framework. These solutions may take various forms, such as inventive principles, standard solutions, or technical improvements, and are then translated into practical solutions for the factual problem (Ilevbare et al., 2013), (Gadd, 2011). In essence, TRIZ encompasses two primary processes: problem formulation and problem solving. In the former, the problem must be precisely defined, and goals and constraints are articulated as a set of assessment parameters, forming the basis for establishing a system of contradictions. This amalgamation of assessment parameters and contradictions constitutes the problem space. The solution space, on the other hand, represents a specific system of contradictions that aligns with fulfilling the defined assessment parameters. Progressing from problem identification to solution is a systematic process involving the stepwise formulation of contradictions within TRIZ. In simpler terms, a TRIZ-based assessment is imperative for recognizing disparities between technological capabilities and an organization's compatibility with its environment. Consequently, achieving harmony between available resources and the optimal resolution is crucial for addressing these contradictions (Benmoussa et al., 2019).

TRIZ remains a highly comprehensive toolkit for fostering industrial creativity, experiencing growing popularity in both educational and industrial realms. According to a survey conducted among TRIZ enthusiasts by Ilevbare, the benefits of TRIZ can be categorized as follows: offering guidance in approaching problems to uncover solutions, fostering the generation of innovative ideas, swiftly identifying problems and arriving at innovative solutions, providing a common language for teams, and enhancing teamwork performance, as well as elucidating technical systems and technological developments (Ilevbare et al., 2013). On the flip side, the adoption and application of TRIZ pose challenges. Firstly, there is a lack of standardized guidelines for identifying problem-solving methodologies and selecting the most suitable tool. Secondly, the comprehension and application of this method are complicated by its intricate methodology, as well as cultural and organizational issues. Thirdly, it is a time-consuming process that demands implicit understanding of the method and practical experience in its application. Lastly, the TRIZ matrix has remained unchanged since the 1970s. Consequently, TRIZ may not yield satisfactory results for non-technical issues or objectives related to emerging technologies such as Astronautics and Nano technologies (Ilevbare et al., 2013), (Brunet, 2012). This situation also gives rise to the potential for misuse and misinterpretation of the method, emphasizing the necessity for a profound understanding and standardization in the fields from which it originated.

To surmount these challenges, there has been a concerted effort to categorize problems differently, crafting a framework that recommends appropriate tools based on problem specifications. For instance, Zlotin et al. have classified tools into three distinctive categories (Zlotin et al., 2001):

I. Analytical tools for problem modeling and definition, such as ARIZ.

II. Knowledge-based tools, well-suited for problem-solving, exemplified by the 76 standard solutions.

III. Psychological tools that facilitate the creative process.

But the importance of selecting the appropriate tool is still significant to avoid waste of time and effort (Rutitsky, 2010).

3.2.2 AI

Several compelling reasons drive businesses toward incorporating AI into their innovation processes. These reasons include a substantial surge in innovation costs and the rapid, continuous shifts in critical variables like the competitive market landscape, available information, political dynamics, and accessible technologies (O'Cass & Wetzels, 2018), (Schilling & Shankar, 2019). Consequently, AI not only furnishes firms with a structured framework to confront and respond to these dynamic changes but also diminishes both the risks and costs associated with the innovation process (Haefner et al., 2021).

Despite these advantages, our understanding of AI's use in innovation management and its potential limitations remains notably limited compared to other traditional management domains where AI serves as a substitute for human roles (Chui, Henke, & Miremadi, 2018).

In the realm of innovation, the effectiveness of decision-makers faces a duo of constraints. The first, termed information processing constraints, stems from the managers' struggle to handle vast amounts of information due to human limitations in absorbing and processing data (Williams & Mitchell, 2004). Secondly, many managers may lack access to all the necessary information or operate in fields unrelated to the information they pursue. In simpler terms, numerous managers confine themselves to inefficient or localized search routines, seeking solutions within their or their firms' knowledge domain (Katila & Ahuja, 2002).

Enter AI, presenting the potential to assist with, and possibly supplant, the processing of organizational information. AI offers the opportunity to sift through copious amounts of information, streamlining the myriad of available solutions and enabling decision-makers to transcend their existing knowledge (Von Krogh, 2018). To acquire relevant information and insights in a specific problem domain, exploring various data sources such as articles, patents, and so on is required. The subsequent action to present a clear understanding to users involves condensing this information by highlighting the identified contradictions and their resolutions. Pinpointing these contradictions and their associated solutions from the corpus of resources is a crucial task, as providing precise solutions to contradictions serves as a key indicator of the level of invention in a patent or article. Nevertheless, acknowledging that AI may not always yield the optimal solution, and recognizing the impossibility of excluding the human factor from the innovation process, innovation managers and decision-makers must vigilantly oversee AI algorithms to discern the best opportunities and secure organizational competitive advantages (Haefner, Wincent, Parida, & Gassmann, 2021).

Contrary to common assumptions, contemporary research reveals a significant connection between creativity and AI (Chen et al., 2019). Achieving innovative solutions necessitates robust creative abilities and proficiency in navigating intricate creative thought processes (Anderson, Potočnik, & Zhou, 2014). While an AI-based support system emerges as a potential remedy for this complexity, there exists a paucity of exploration into the integration of AI in creative design. Despite certain prior studies focusing on singular applications of Creative and Innovation Techniques (CIT), there arises a necessity to formulate and affirm a CIT approach that not only addresses the needs of design teams but also enhances the overall design process. As a result, there is a need for further empirical research to explore the interaction between these techniques in various academic disciplines and real-world settings (De Carvalho Botega & Da Silva, 2020).

3.2.3 Application of AI in TRIZ

The recent years have witnessed a burst of research activity involving applying large language models (LLMs) and generative AI within TRIZ-based creative problem-solving. For instance, Jiang and Luo introduced AutoTRIZ, an LLM-powered program that can carry out TRIZ reasoning steps and generate structured solution reports (Jiang & Luo ,2024). While promising, their study is limited to textbook problems and provides no evaluation framework for novice users. Similarly, Chen proposed TRIZ-GPT, demonstrating that GPT-4 could replicate contradiction-solving processes, yet their approach depends heavily on handcrafted prompts and a small case library (Chen et al., 2024). Beyond these, Shin found that ChatGPT integration improved solution quality for developers with little TRIZ knowledge, though their results were confined to a few qualitative cases (Shin, Lee, & Sue, 2024). Extending the methodological scope, Mohammadi and Zeng combined TRIZ with Environment-Based Design supported by an LLM, achieving novel ideas but without usability testing among novices. A different approach by Szczepanik and Chudziak framed TRIZ as a multi-agent system of LLMs, but their design lacked iterative refinement and practical testing (Szczepanik & Chudziak, 2025). Meanwhile, Čok compared TRIZ, ChatGPT, and hybrid methods in industrial contexts, observing complementary strengths but offering no clear framework (Čok, Samsa, Brojan, Tavčar & Vukašinović, 2025). Finally, Phadnis and Torkkeli examined AI-TRIZ integration in consulting practice, showing efficiency gains but based on a single limited case (Phadnis & Torkkeli, 2024). Taken together, these studies highlight substantial progress but also reveal a persistent gap: none provide a replicable, user-friendly framework accessible to practitioners without prior TRIZ expertise. The present research addresses this shortcoming by offering a holistic, AI-enhanced TRIZ framework designed for both expert and novice users.

3.3 Methodology

The proposed framework was deployed using ChatGPT as the primary AI model, chosen for its reasoning ability and alignment with structured problem-solving tasks. Each stage of the process was supported through carefully engineered prompts reflecting TRIZ principles: from problem framing and contradiction identification to inventive principle suggestion and solution generation. Importantly, outputs were not derived from a single attempt; multiple solution candidates were generated, compared, and filtered to ensure reliability and novelty. This iterative process improves transparency and helps distinguish between AI hallucinations and meaningful insights.

To evaluate the framework, AI effectiveness was disentangled at each stage: In Step 1 (Problem Definition), GPT-4 reformulated problems, which were validated against human understanding. In Step 2 (Contradiction Identification), it consistently surfaced contradictions when guided by structured prompts. In Step 3 (Principle Suggestion), the model provided inventive principles with notable accuracy, though occasional irrelevant outputs were discarded. Finally, in Step 4 (Solution Generation), multiple candidate solutions were produced and qualitatively assessed by domain experts for feasibility and creativity. This stepwise evaluation confirms the added value of AI support across the process.

The proposed hierarchical framework comprises interconnected TRIZ tools. The model's significance lies in its accessibility for a wide range of users, as no prior knowledge of TRIZ or its tools is required. The framework incorporates specific questions for each route, prioritized and asked to ChatGPT, a robust AI-based chatbot. This tool offers customizable responses; users can control factors such as the number of generated answers, and they can request either summarized or expanded responses. The responses to each question serve as inputs for the subsequent query. The framework, benefiting from human user supervision, ensures that unrelated or unjustified answers are erased or modified before progressing to the next step. This approach enhances the likelihood of attaining more feasible solutions in the final steps, ensuring a more effectiveness and adaptability of the proposed model.

3.3.1 Hierarchical procedure based on contradiction matrix and 40 principles tools

This part of the framework combined four TRIZ tools named Hazards or cause of the problem map, ideal outcome, contradiction matrix, and 40 principles to recognize the main contradictions that should be solved to reach an ideal situation.

3.3.2 Understanding and Scoping the Problem

One of the crucial initial steps in the TRIZ process is to thoroughly understand and scope the problem at hand. This involves defining the boundaries of the problem, identifying its key components, and discerning the inherent contradictions that hinder optimal solutions. By clearly defining the problem, TRIZ practitioners can focus their efforts on the most critical aspects, facilitating a more efficient and effective problem-solving process. This step aligns with the TRIZ principle of "problem formulation," which stresses the importance of articulating the problem in a comprehensive and unambiguous manner. Proper problem scoping lays the foundation for subsequent stages in the TRIZ process, such as identifying inventive principles and generating innovative solutions. As Altshuller, the founder of TRIZ, highlighted, a well-defined problem is essential for uncovering inventive solutions and breaking through the barriers that limit conventional problem-solving approaches (Altshuller, 1999).

3.3.3 Navigating the Problem Space

In the first step, a comprehensive problem description is supplied to ChatGPT, followed by posing the question, "What are the main challenges related to the mentioned problem?". The procedural hierarchy entails the generation of multiple answers at each step, creating a structured framework where the selection of one answer determines the subsequent question. This hierarchical approach, denoted as X_{ij}, signifies the i-th step and the j-th generated answer. For instance, X_{12} corresponds to the second generated answer in response to the first question.

Consider the example of Xij where i=1 and j=2, signifying the second answer in the initial step. Following this selection, the user can progress through subsequent steps based on this specific answer, exploring potential solutions. However, the methodology allows flexibility, enabling the user to choose a different answer, such as X_{13}, in a subsequent run to reiterate the process and explore alternative feasible solutions.

To illustrate, let's consider a mathematical model: suppose Xij represents a solution space, and the user aims to maximize a specific objective function within this space. Each run through the procedure with different Xij values corresponds to exploring different regions of the solution space. The iterative nature of this methodology allows users to navigate through various combinations of generated answers, refining their approach with each iteration.

3.3.4 Utilizing ChatGPT Capabilities

To streamline the problem-solving process and avoid overwhelming complexity, users are encouraged to leverage ChatGPT's capabilities to limit the number of generated answers. This restriction ensures a more manageable and focused exploration of the solution space. In essence, the methodology offers a dynamic and iterative problem-solving process, empowering users to systematically navigate the hierarchy of generated answers in pursuit of the most viable and innovative solutions.

3.3.5 Analyzing Problem Aspects and Constraints

The process follows through the next two questions: “Which aspects of the problem must be improved to solve X_{ij}” and “Are there any specific constraints or requirements for each aspect” which analyze the problem and affecting criteria by recognizing the main challenges of the mentioned problem, recognizing those aspects of problem that need to be solved as well as problem constraints and requirements.

3.3.6 Formulating Simply-Stated Mini-Problems

To delve deeper into problem analysis, the identification of simply-stated mini-problems becomes pivotal through this command “Based on the previous answers provide a simply state mini-problem that addresses solving constraints of this aspect and mention related desired outcomes based on TRIZ ideal outcome and ideal system concepts”. These mini-problems are crafted to highlight specific contradictions within the larger problem context. TRIZ emphasizes the need to articulate these contradictions clearly and succinctly. This involves defining the conflicting elements within the system and specifying what the ideal situation would be if these contradictions were effectively resolved. TRIZ introduces the concept of an "Ideal Final Result" (IFR), which represents the ultimate objective or state without the existing contradictions. The IFR serves as a guiding principle for problem resolution, pushing innovators to envision an ideal system where conflicts are eliminated or harmoniously coexist. The TRIZ process encourages problem solvers to aim for this ideal state, stimulating creative thinking and guiding the development of inventive solutions. The consideration of the ideal outcome and ideal system concepts aligns with TRIZ principles, fostering a systematic approach to innovation that goes beyond incremental improvements. These two steps are the base of the framework and are repeated for the other three roots.

3.3.7 Identifying Contradictions

Within the formulated mini-problems, contradictions are identified using the TRIZ contradiction matrix by asking “Which contradictions from TRIZ contradiction matrix are involved in the mini-problem X_{ij}?” and potential solutions are suggested by applying the TRIZ 40 inventive principles. This step prompts innovators to explore inventive solutions by asking, "What are the potential solutions for the identified contradictions based on the TRIZ 40 inventive principles?". The 40 inventive principles encapsulate a wide array of engineering strategies that have historically proven effective in resolving conflicts and promoting innovation.

By aligning the specific contradictions with the corresponding inventive principles, TRIZ provides a structured framework for ideation. For example, if the identified contradiction involves a trade-off between strength and flexibility, the TRIZ matrix can guide the application of principles such as "Segmentation" or "Use of Pneumatics and Hydraulics" to explore novel solutions. This process leverages the collective wisdom distilled from diverse problem-solving scenarios across various industries.

3.3.8 Structured Ideation and Solution Development

Systematic application of inventive principles to identified contradictions enables problem solvers to break free from conventional thinking and discover inventive and often unexpected solutions. The application of the TRIZ 40 inventive principles aligns with the overarching goal of TRIZ to enhance creativity, efficiency, and effectiveness in problem-solving within various domains of engineering and innovation (Koltze & Souchkov, 2017). Figure 1 summarizes all mentioned steps.

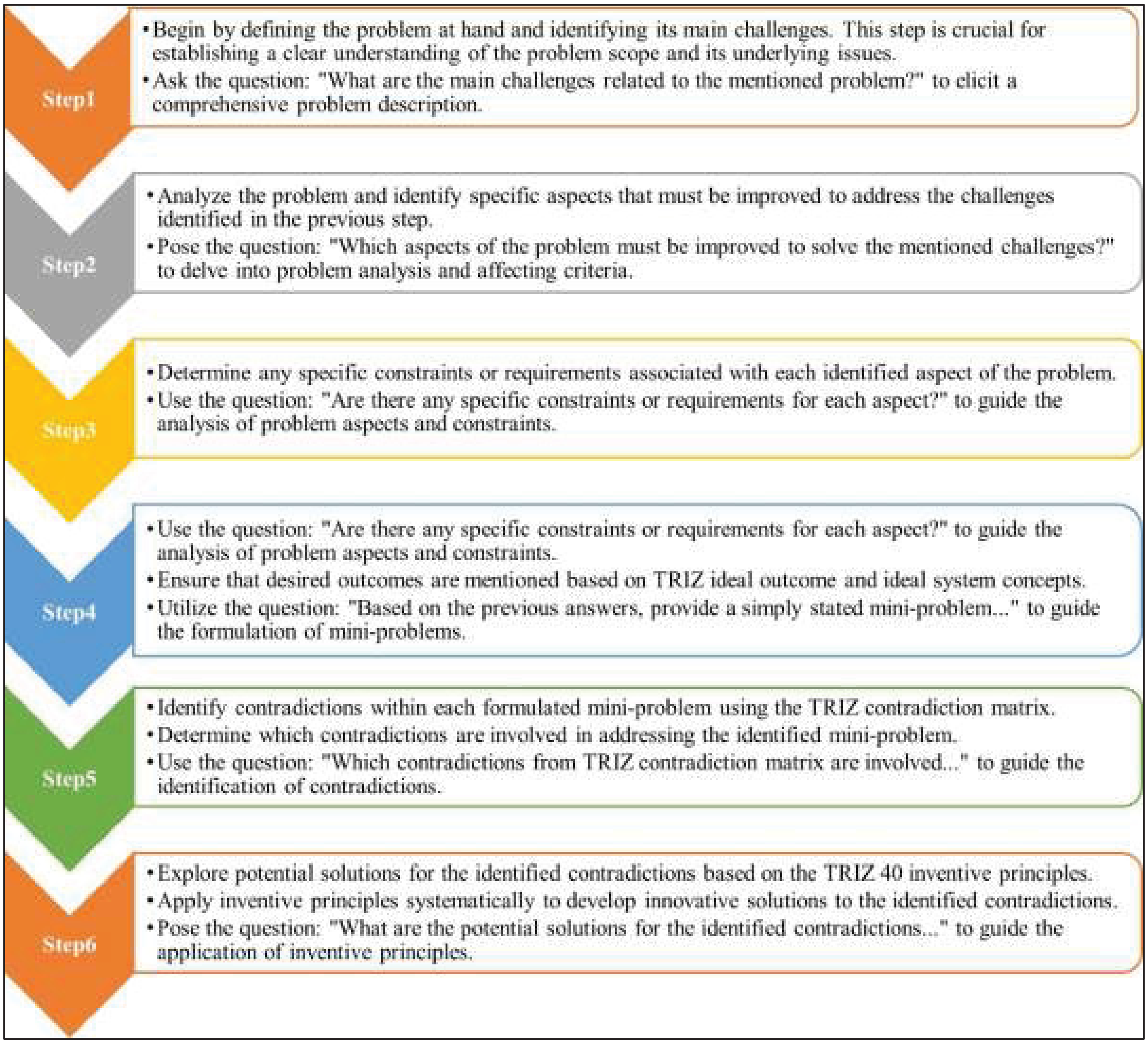

Figure 3.1 A summary of required steps from problem identification to potential solution generation

All in all, the application of TRIZ tools offers a structured framework for ideation and problem-solving, empowering users to break free from conventional thinking and discover inventive solutions. By aligning specific contradictions with corresponding inventive principles, TRIZ enables problem solvers to enhance creativity, efficiency, and effectiveness in problem-solving within various domains of engineering and innovation.

3.4 Case study

Non-slippery shoes are crucial for ensuring user safety in various environments, including workplaces and outdoor settings, particularly during winter when icy conditions pose a significant risk of slipping and injury. Despite numerous shoes being marketed as non-slippery, none of them are entirely devoid of slipperiness. This limitation necessitates users resorting to additional measures such as crampons and ice cleats when navigating icy or slippery surfaces. Recognizing the need for innovation in this area, a research initiative has been undertaken through the proposed framework. The primary goal is to develop an outsole that not only provides exceptional traction on ice and slippery surfaces but is also characterized by durability, comfort, and suitability for everyday use. The research aims to address the existing limitations in current footwear options and pave the way for a more reliable and versatile solution, enhancing user safety and comfort in challenging conditions.

To arrive at a viable solution, researchers must possess extensive knowledge of material selection and the footwear industry. Fortunately, the proposed framework addresses this challenge, bridging the gap and dismantling barriers for the development of new ideas and designs.

Upon consulting ChatGPT for insights, the three primary challenges related to creating non-slippery shoes for icy and slippery conditions were identified as Inadequate Traction of Existing Footwear, Dependence on Additional Measures, and Lack of a Comprehensive Solution. In this progression, Inadequate Traction of Existing Footwear was singled out for further exploration. Despite being marketed as non-slippery, shoes with insufficient traction fail to completely mitigate the risk of slipping, posing a safety concern, especially in environments where slipping can result in injuries.

Subsequently, three key aspects requiring improvement to address the inadequate traction issue were identified as Testing and Performance Standards, Traction Technology and Innovation, and Material and Outsole Design. Among these, the incorporation of advanced traction technologies and innovative features emerged as more crucial. This could involve integrating micro-spikes, nano-textures, or other cutting-edge technologies into the outsole to enhance grip. Research and development in this domain have the potential to revolutionize the effectiveness of footwear in preventing slips and falls on slippery surfaces. However, this solution faces challenges and requirements such as Durability and Wear Resistance, Adaptability to Diverse Environments, and Comfort and Flexibility.

While improving traction, it's essential to maintain a focus on user comfort and flexibility. The added traction features should not make the footwear rigid or uncomfortable to wear. Innovations should be designed to seamlessly integrate with the overall structure of the shoe, providing the necessary grip without sacrificing comfort. This requirement is crucial for ensuring that the footwear is suitable for everyday use in different settings. So, the main mini-problem statement is expanded based on that as <u>Enhancing Traction Without Compromising Comfort and Flexibility in Footwear</u> with the related desired outcome:

(1) Increased Friction Without Bulk:

Ideal Outcome: Increase the friction between the outsole and slippery surfaces without adding bulk or rigidity to the footwear.

Ideal System Concept: Introduce a nanomaterial coating or microstructure on the outsole that enhances grip without altering the overall flexibility and weight of the shoe.

(2) Dynamic Adaptability to Surface Changes:

Ideal Outcome: Develop a dynamic traction system that adapts in real-time to changes in surface conditions, providing optimal grip without sacrificing flexibility.

Ideal System Concept: Implement a responsive technology that adjusts the outsole's grip pattern or properties based on temperature, surface texture, or moisture, ensuring continuous adaptability.

(3) Seamless Integration of Traction Features:

Ideal Outcome: Integrate traction-enhancing features seamlessly into the shoe design, ensuring that the wearer experiences comfort and natural movement.

Ideal System Concept: Explore design solutions such as embedded micro-spikes that retract when not needed, allowing the outsole to maintain flexibility during regular walking but deploy when encountering slippery conditions.

By addressing these desired outcomes based on TRIZ (Theory of Inventive Problem Solving) concepts, the mini-problem aims to find innovative solutions that simultaneously improve traction on icy surfaces while maintaining the comfort and flexibility expected in everyday footwear. Recognizing and solving the following contradictions is a major step to reaching the desired outcome:

(1) Contradiction 1: Weight of Moving Object vs. Reliability:

In the context of footwear, the contradiction arises between the desire to increase the reliability of traction (improving grip on slippery surfaces) and the potential increase in weight due to additional traction features. The challenge is to enhance reliability without adding excessive weight, ensuring the footwear remains comfortable and flexible.

(2) Contradiction 2: Hardness vs. Elasticity:

There is a contradiction between the need for the outsole to be hard enough to provide effective traction (hardness) and the desire for the footwear to remain elastic and flexible (elasticity). Balancing these factors is crucial to achieving a comfortable and flexible shoe that still offers enhanced traction.

(3) Contradiction 3: Simplicity vs. Effectiveness:

The challenge involves finding a balance between the simplicity of the footwear design (maintaining comfort and flexibility) and the need for an effective traction solution. The goal is to introduce innovative technologies without making the shoe overly complex, ensuring ease of use and wearability.

(4) Contradiction 4: Wear Resistance vs. Flexibility:

There is a contradiction between the desire for the outsole to be wear-resistant (durable for long-term use) and the need for the footwear to remain flexible. Addressing this contradiction involves developing materials or technologies that enhance wear resistance without compromising flexibility.

Recognizing and resolving these inherent contradictions is paramount in formulating inventive solutions that significantly improve traction in footwear while preserving comfort and flexibility. The utilization of TRIZ principles proves instrumental in guiding the generation of innovative ideas that effectively reconcile these conflicting factors. In the initial phase, the selection of the first two contradictions aims to gauge the feasibility of extracting sufficiently innovative ideas. Should this effort fall short, researchers may pivot to alternative contradictions and branches explored in earlier stages for further investigation.

Examining the specific contradiction of "Weight of Moving Object vs. Reliability," ChatGPT has proposed potential solutions grounded in the TRIZ 40 inventive principles.

(1) Principle 1: segmentation:

Idea: Divide the traction enhancement mechanism into smaller, lightweight segments.

Material/Design: Utilize lightweight yet durable materials like composite alloys or high-strength plastics. Design the outsole with segmented components that collectively enhance traction without significantly increasing overall weight.

(2) Principle 12: Equipotentiality:

Idea: Distribute the traction enhancement features more evenly across the sole to prevent localized weight increase.

Material/Design: Use materials that evenly distribute weight, such as advanced foams or lattice structures. Design the outsole with a uniform distribution of traction elements to ensure reliable grip without creating localized heavy spots.

(3) Principle 8: Anti-weight:

Idea: Introduce anti-weight materials or structures to offset the added weight of traction features.

Material/Design: Incorporate lightweight, aerogel-like materials in non-traction areas of the footwear to counterbalance the weight of the traction-enhancing components. This helps maintain overall comfort and flexibility.

As a result, Figure 3.2 illustrates a conceptual idea that incorporates composite alloys or high-strength plastic materials into specific sections of the outsole, strategically placing them where the center of gravity aligns and ensures maximum ground contact during each step. This design not only facilitates the even distribution of weight for traction enhancement materials but also guarantees a uniform dispersion of these materials, ensuring a reliable grip. Additionally, Aregel and advanced foams can be utilized in other regions of the outsole for weight reduction.

In a different attempt, ChatGPT has presented potential solutions addressing the contradiction of "Hardness vs. Elasticity" within the context of enhancing traction in footwear. These suggestions are grounded in the TRIZ 40 inventive principles:

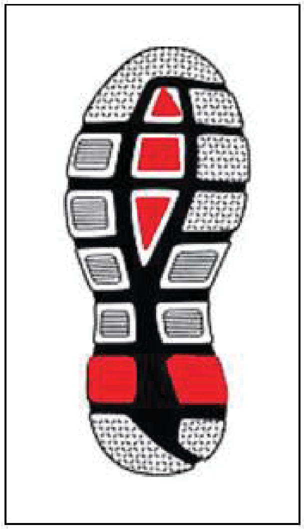

Figure 3.2 The suggested design based on segmentation and anti-weight principles

(4) Principle 5: Merging:

Idea: Develop a material or composite that naturally combines both hardness and elasticity.

Material/Design: Explore advanced polymer blends or composite materials that inherently possess both hardness for traction and elasticity for flexibility. This could involve combining rubber-like materials with rigid elements in a way that optimizes both properties.

(5) Principle 7: Nested Doll:

Idea: Create nested layers within the outsole, each with different hardness and elasticity characteristics.

Material/Design: Design the outsole with layers of materials, each contributing to a specific aspect of hardness or elasticity. This allows for a tailored combination of properties, ensuring effective traction while maintaining overall flexibility.

These inventive solutions for both contradictions “Hardness vs. Elasticity” and “Weight of Moving Object vs. Reliability", offering practical ideas, suggested materials, and designs to enhance traction while maintaining comfort and flexibility in footwear. Balancing these factors is crucial to achieving a comfortable and flexible shoe that still offers enhanced traction. Table 3.1 represents the list of materials or composites that naturally combine both hardness and elasticity for a non-slippery outsole involves selecting advanced polymer blends or composite materials that offer a balance between these properties.

Table 3.1 Suggested materials for shoe outsole manufacturing

Material	Specification
TPU (Thermoplastic Polyurethane) Blends	Combine TPU with a reinforced rigid polymer or filler material. TPU is known for its elasticity, flexibility, and wear resistance, and blending it with a rigid filler can enhance hardness without sacrificing overall flexibility.
Elastomer-Ceramic Composites	Integrate elastomeric polymers, such as silicone or polyurethane, with ceramic nanoparticles. The ceramic nanoparticles provide increased hardness while the elastomeric component maintains flexibility. This combination can offer improved wear resistance and traction.
Polymer-Graphene Nanocomposites	Create a nanocomposite by incorporating graphene into a polymer matrix. Graphene, a two-dimensional material, adds hardness and strength to the polymer, enhancing traction, while the polymer component ensures flexibility. This combination can result in a lightweight and durable outsole
Silicone-Rubber Hybrid Materials	Blend silicone rubber with a reinforcing rigid polymer or nanostructured materials. Silicone rubber provides excellent elasticity, and the addition of rigid elements enhances hardness, making it suitable for traction on slippery surfaces.
Polyurethane-Polyamide Blends:	Combine polyurethane with polyamide (nylon) to achieve a balance between hardness and elasticity. Polyurethane contributes flexibility and impact resistance, while polyamide provides increased hardness and strength, creating a well-rounded material for a non-slippery outsole.
Elastomeric Copolymers with Thermosetting Resins	Develop copolymers containing elastomeric segments combined with thermosetting resins. The elastomeric segments contribute flexibility, while the thermosetting resins enhance hardness and abrasion resistance, resulting in a durable and non-slippery outsole.
Polyethylene-Modified Elastomers	Modify elastomers like ethylene propylene diene monomer (EPDM) with polyethylene. The addition of polyethylene can increase hardness, making the material more suitable for providing traction on slippery surfaces, while retaining the elastomeric properties.

TPU, is a prevalent material in the footwear outsole industry and has been selected as the base material for enhancement through reinforced rigid polymers or filler materials. Achieving the desired balance of flexibility, durability, and cost-effectiveness in a non-slip outsole involves the critical choice of the appropriate reinforced rigid polymer or filler material when combined with TPU. While options such as Nylon (Polyamide), Glass Fiber Reinforcement, and Carbon Fiber Reinforcement exist for this purpose, the integration of silica nanoparticles into TPU emerges as a promising solution, particularly for creating a highly effective non-slip outsole on icy surfaces. Silica nanoparticles contribute to increased hardness, wear resistance, cost-effectiveness, and improved traction, owing to their unique surface characteristics. It is crucial, however, to ensure the careful dispersion of nanoparticles to prevent agglomeration, thereby guaranteeing uniform properties in the outsole. Further studies and experiments are imperative to elucidate the precise dispersion characteristics. Figure 3.3 summarizes these steps:

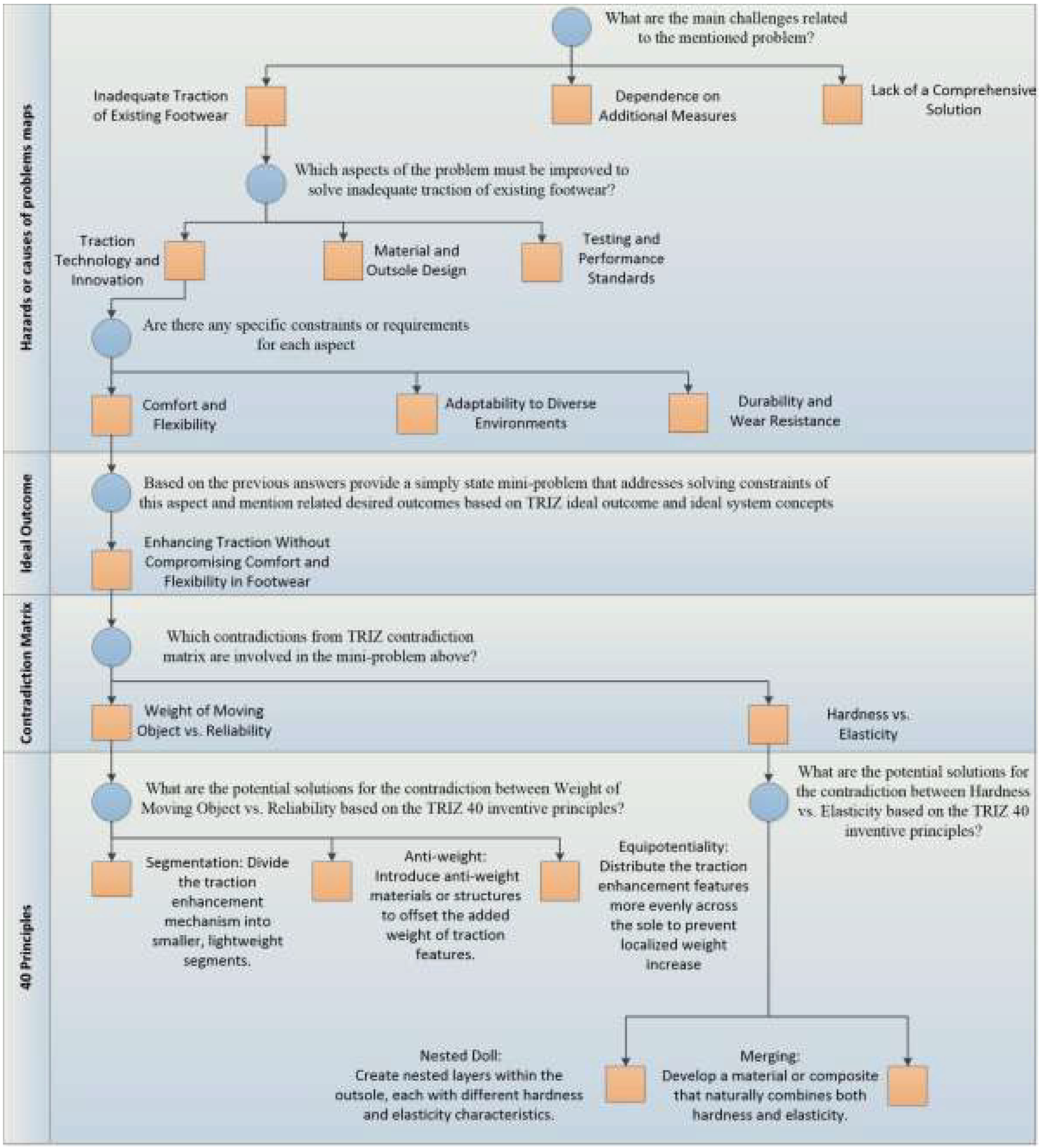

Figure 3.3 A visual diagram of passed steps in the framework

3.5 Discussion

Our proposed framework encompasses both TRIZ problem formulation, involving the analysis of assessment parameters and contradictions within the problem space, and problem-solving processes, which suggest solutions aligning with defined parameters. This framework enhances TRIZ advantages by providing comprehensive guidance for approaching problems through various tools, fostering innovative idea generation with a range of suggested solutions, and establishing a common language for teams by offering advanced knowledge from different scopes, thereby eliminating the need for specific domain expertise.

In addition, our framework significantly mitigates the challenges associated with adopting and applying TRIZ. Firstly, it offers standardized guidelines based on a combination of tools, removing the burden on users to identify problem-solving methodologies and select the most suitable tool. Secondly, the comprehension and application of TRIZ methods become more accessible. Thirdly, ChatGPT expedites the innovation process by providing required information swiftly. Lastly, leveraging the boundless data source of ChatGPT, the application of TRIZ methodology could also extend beyond technical issues to encompass non-technical objectives.

3.6 Conclusion

Future work should extend validation of the framework across diverse case studies, beyond the current demonstration. Particularly, comparative studies contrasting framework-guided outcomes with those produced by human design teams without AI-TRIZ support are necessary. Such studies would clarify whether the framework not only accelerates ideation but also enhances novelty and feasibility. Additionally, investigating the framework’s transferability to industries outside automotive and engineering could further establish its generalizability and practical relevance.

AI presents an opportunity to navigate extensive information, streamlining solutions and empowering decision-makers to surpass their existing knowledge. To acquire insights in a specific problem domain, exploring diverse data sources, extracting information, and highlighting identified contradictions and their resolutions are necessary. However, recognizing that AI may not always yield optimal solutions and the necessity of human involvement, innovation managers must oversee AI algorithms for discerning the best opportunities.

In the proposed framework, overcoming TRIZ limitations and facilitating CIT procedures is the primary goal. A case study evaluating the effectiveness of the proposed framework was conducted, focusing on an innovative non-slip shoe outsole. The results underscore those individuals lacking prior TRIZ knowledge should successfully employ this framework by following a set of guided questions, obviating the necessity for extensive expertise. The AI-based process transforms knowledge into a human-machine procedure, providing a comprehensive guideline for the entire CIT procedure from initiation to conclusion. The model clarifies both problem and solution spaces by presenting evaluation parameters, a system of contradictions, and selecting specific contradictions to fulfill those parameters.

CHAPTER 4

INNOVATIVE SOLUTIONS FOR ENHANCED DRIVING SAFETY: A TRIZ-BASED APPROACH TO REDUCING VISIBILITY ISSUES AND DRIVER DISTRACTION

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Résumé

Les techniques de créativité et d'innovation (CIT) jouent un rôle essentiel dans le développement continu de tous les secteurs, mais leur mise en œuvre pratique reste complexe. Les méthodes CIT traditionnelles requièrent souvent une expertise approfondie, sont limitées par les connaissances humaines et manquent de directives procédurales claires. TRIZ, une méthodologie de résolution créative de problèmes bien établie, propose une approche structurée, mais n'aborde pas pleinement la définition des problèmes et la génération de solutions. Cette recherche explore comment l'intégration de cadres d'IA, tels que ChatGPT, à TRIZ peut stimuler l'innovation en élargissant le processus de découverte de connaissances et en favorisant la sélection de solutions au-delà de l'expertise conventionnelle. Le cadre proposé s'appuie sur l'apprentissage automatique pour définir les contradictions, établir des critères d'évaluation et rationaliser l'innovation. Une étude de cas démontre son efficacité pour résoudre les défis d'ingénierie, soulignant son potentiel pour améliorer la prise de décision et la résolution de problèmes dans divers domaines.

Abstract

Creativity and Innovation Techniques (CIT) play a vital role in fostering ongoing development across industries, yet their practical implementation remains challenging. Traditional CIT methods often require substantial expertise, are limited by human knowledge, and lack clear procedural guidelines. TRIZ, a well-established creative problem-solving methodology, offers a structured approach but does not fully address problem definition and solution generation. This research explores how integrating AI-driven frameworks, such as ChatGPT, with TRIZ can enhance innovation by expanding the knowledge discovery process and supporting solution selection beyond conventional expertise. The proposed framework leverages machine learning to define contradictions, establish evaluation criteria, and streamline innovation. A case study demonstrates its effectiveness in solving engineering challenges, highlighting its potential to improve decision-making and problem-solving across diverse fields.

4.1 Introduction

The importance of Creativity and Innovation Techniques (CIT) in a company's ongoing development is well-established (Rumanti et al., 2023), but their application extends far beyond the business world and now spans various fields. Despite this, the implementation of CIT faces significant challenges. First, the selection and application of the right tools require substantial expertise, limiting accessibility for a wide range of users. Second, traditional CIT methods are inherently human-centered, which means their effectiveness is diminished by the limitations of the users' knowledge and experience. Third, there is a lack of clear guidelines on how to initiate and conclude CIT processes, hindering their progress.

Among the many CIT tools available, applying creative problem-solving theories, such as TRIZ, can help streamline innovation. TRIZ, a well-established human-centered theory, views design as a cognitive process closely tied to human thinking and requires users to have an engineering background. As a result, the knowledge of the user plays a crucial role in fostering creativity and ensuring the success of CIT activities.

However, TRIZ does not provide a clear framework for defining the problem space (including evaluation criteria and contradictions) or the solution space (a set of contradictions needed to meet those criteria). Improving these methodologies with a framework that clarifies the problem space and supports knowledge generation will lead to more effective solutions.

Based on the promising outcomes of specific TRIZ tools in various fields, a unified model is proposed to address a broad range of problems. At this stage, the role of an AI-driven framework becomes critical in facilitating "out-of-the-box" thinking and accelerating the innovation process by providing users with relevant knowledge and data from multiple domains.

Furthermore, this framework expands the solution-selection process beyond the existing knowledge and experience within the company. By integrating AI systems like ChatGPT with TRIZ tools, innovation is enhanced not only by supplying decision-makers with relevant knowledge but also by expediting the knowledge discovery process. Ultimately, this research introduces a machine-learning-driven framework designed to provide solutions that define contradictions and evaluation parameters, thereby streamlining innovation. While TRIZ has demonstrated value in structured problem-solving, it remains limited by users' domain expertise and lacks clarity in defining and navigating problem spaces. At the same time, AI's ability to expand information access and support decision-making is underutilized in structured innovation contexts. Prior attempts at merging AI and problem-solving frameworks have not fully integrated analytical reasoning with human creativity in engineering settings.

This study seeks to address the limited accessibility and adaptability of TRIZ by asking: How can AI be meaningfully integrated into TRIZ to accelerate and enhance innovation outcomes, particularly for connected digital systems such as driver safety features in digital twins?

4.2 Literature review

4.2.1 Creativity and Innovation

Creativity refers to the ability of an individual or group to generate novel ideas, while innovation involves transforming these ideas into tangible solutions through organizational processes, resulting in technically and economically viable outcomes (Gabriel et al., 2016). Innovation relies heavily on Creativity and Innovation Techniques (CITs), a term introduced by Foster and Broco (2008) to describe practical methods that foster successful creative outcomes. These techniques, which encompass frameworks, methodologies, and systems, aim to help teams generate more ideas and achieve better solutions early in the creative process (Foster & Brocco, 2008); (Teza et al., 2016); (Bertoncelli et al., 2016).

Given the variety of CITs available, factors such as team dynamics, desired innovation levels, and associated challenges must be carefully considered to select the most suitable technique. Consequently, selecting CITs that align with organizational objectives or enhance goal achievement requires substantial expertise (De Carvalho Botega & Da Silva, 2020).

4.2.2 TRIZ

TRIZ, an acronym for teorija rezhenija izobretatelskih zadach (the theory of inventive problem-solving), was developed by Genrich Altshuller in post-World War II Russia, during a critical era for manufacturing. This methodology emerged as a systematic approach to solving complex problems. Altshuller and his team analyzed over 400,000 inventions to devise tools for innovative problem-solving, based on the premise that technological advancements follow specific patterns rather than arising randomly (Savranksy, 2000) ; (Eversheim, 2008).

Initially a collection of tools, TRIZ has evolved into a comprehensive methodology and formal theory (Benmoussa et al., 2019). It is now regarded as a knowledge-based approach with wide applicability, though it is particularly effective for addressing standard problem types (Altshuller, 2000).

The TRIZ process begins by breaking down a tangible technical problem into fundamental elements—referred to as a conceptual problem. These elements are then aligned with conceptual solutions, which may include inventive principles, standard solutions, or technical improvements, ultimately translating into practical outcomes (Ilevbare et al., 2013); (Gadd, 2011). TRIZ consists of two key stages: problem formulation and problem-solving. During formulation, the issue is clearly defined, and parameters such as goals and constraints are established to delineate the problem space. The solution space encompasses contradictions that need resolution to meet these parameters. TRIZ emphasizes resolving these contradictions systematically, facilitating progression from problem identification to solution (Benmoussa et al., 2019).

Despite its effectiveness, TRIZ faces challenges such as the absence of standardized guidelines for tool selection, methodological complexity, cultural and organizational barriers, and the outdated TRIZ matrix, which has not been revised since the 1970s. These limitations are especially evident in non-technical problems or emerging technologies like astronautics and nanotechnology, where TRIZ may be less effective (Ilevbare et al., 2013); (Brunet, 2012).

Efforts to overcome these challenges include Zlotin et al. (2001) classification of TRIZ tools into three categories: analytical tools for problem modeling (e.g., ARIZ), knowledge-based tools for problem-solving (e.g., 76 standard solutions), and psychological tools to support creativity. However, selecting the right tool remains critical to avoid inefficiency (Rutitsky, 2010); (Zlotin et al., 2001).

4.2.3 AI

There is growing interest in the potential of AI to replace human roles, particularly in traditional tasks (Von Krogh, 2018). However, incorporating AI into innovation management—a complex process crucial for achieving long-term competitive advantages—requires careful assessment. It is essential to determine whether AI, when combined with human expertise, can enhance the quality, performance, and outcomes of innovation (Porter & Stern, 2001); (Bughin et al., 2018).

Several factors drive organizations to adopt AI in innovation processes, including rising innovation costs and rapid, continuous shifts in market dynamics, information availability, political contexts, and technological advancements (O'Cass & Wetzels, 2018); (Schilling & Shankar, 2019). AI offers a structured approach to addressing these challenges while reducing risks and costs associated with innovation (Haefner et al., 2021). However, its role in innovation management is less understood compared to its applications in other domains, where it often replaces human roles (Chui et al., 2018).

In innovation, decision-makers face two primary constraints. The first is information-processing constraints, where cognitive limitations hinder managers from processing large volumes of data effectively (Williams & Mitchell, 2004). The second involves limited access to necessary information or a tendency to focus on familiar domains of knowledge, potentially overlooking relevant insights (Katila & Ahuja, 2002). AI can alleviate these challenges by processing vast amounts of data, streamlining available solutions, and expanding decision-makers' knowledge base (Von Krogh, 2018).

AI must aggregate and condense information from diverse sources, such as articles and patents, identifying contradictions and their solutions—a critical step for determining the level of invention in a given patent or article. However, AI might not always yield the best solutions, necessitating oversight by innovation managers and decision-makers to ensure optimal outcomes and maintain competitive advantages (Haefner et al., 2021).

Contrary to common assumptions, recent research highlights a strong connection between creativity and AI (Chen et al., 2019). Achieving innovative solutions requires advanced creative skills and effective navigation through complex thought processes (Anderson et al., 2014). While AI-based systems hold promise, their integration with creative processes remains underexplored. Although earlier studies have examined specific applications of CITs, further empirical research is needed to understand their broader interactions across various academic and practical contexts (De Carvalho Botega & Da Silva, 2020).

4.3 Methodology

This methodology provides a structured approach for enhancing creative problem-solving by integrating AI with TRIZ tools. AI helps filter information, personalize assistance, and expand the knowledge base, making the application of TRIZ principles more effective in innovation.

4.3.1 Defining the Problem

To begin, use AI tools like ChatGPT to analyze the problem by asking:

"What are the main challenges related to this problem?" This helps clearly define the scope of the problem, identifying key components and contradictions. Break the problem down into smaller sub-problems to ensure a deeper understanding of each aspect. The process generates multiple responses at each stage, and each selected answer guides the subsequent question. j (j = 1, 2, …, n) refers to a number of answers generated in each step. For example, X12 refers to the second answer to the first question. This process can be compared to navigating a solution space, where each step through the procedure represents an exploration of different regions. The iterative nature allows users to refine their approach with each run, leading to more viable solutions.

4.3.2 Identifying Key Issues and Constraints

Once the AI provides responses, review them carefully to extract key issues that need deeper analysis. To pinpoint constraints and areas for improvement, ask: "Which aspects require improvement to solve X1j?” This iterative approach helps refine the understanding of the problem and ensures focus on the most critical challenges.

4.3.3 Isolating Core Challenges

Narrow down the main challenges and contradictions. To do this, ask AI: “What are the constraints and requirements for aspect X2j?” This step helps define the core obstacles that must be overcome to develop an effective solution.

4.3.4 Generating Mini-Problems

To make problem-solving more structured, break the issue into mini-problems. Use AI to generate a focused problem statement by asking: “Based on answer X3j, provide a mini-problem statement outlining constraints and ideal outcomes.” Each mini-problem should highlight a specific contradiction to help guide further analysis and solution development.

4.3.5 Identifying and Resolving Contradictions

In the next step, apply TRIZ principles to tackle contradictions systematically. Identify contradictions by asking: “Which contradictions from the TRIZ matrix are involved in mini-problem X4j?” Once the contradictions are mapped, the TRIZ Contradiction Matrix will help identify suitable problem-solving strategies.

4.3.6 Exploring Solutions with TRIZ

Now that the contradictions are clear, apply the TRIZ 40 Inventive Principles to generate creative solutions. Use AI to explore these principles by asking: “What are the solutions for X5j based on the TRIZ 40 Inventive Principles?” This step allows AI-generated insights to refine and expand on potential solutions.

4.3.7 Evaluating and Refining Solutions

Once solutions are generated, compare and refine them based on their effectiveness. The goal is to ensure they align with the Ideal Final Result (IFR)—a solution that resolves contradictions while maintaining desired outcomes. Evaluate how well each inventive principle addresses the contradiction. Iterate and improve potential solutions for better results.

4.3.8 Documenting and Implementing the Final Solution

After selecting the best solution, document the approach, including any key insights and areas for potential improvement. Implementation: Apply the most effective solution in a real-world scenario. Evaluation: Assess its impact and effectiveness.

4.3.9 Summary

This AI-enhanced TRIZ methodology provides a systematic framework for structured and innovative problem-solving. It enables users to: Clearly define and analyze problems, Identify contradictions and constraints, Apply TRIZ principles effectively, and Generate and refine innovative solutions.

By leveraging ether, this approach ensures continuous learning, refinement, and optimization, making it a powerful tool for engineers, designers, and innovators in various industries.

4.4 Case study

4.4.1 Case Study Overview: Addressing Reduced Visibility and Driver Distraction

This case study addresses two critical challenges encountered by drivers: reduced visibility and driver distraction. These challenges arise in varying driving conditions, such as inadequate lighting at night, blinding headlights, adverse weather conditions (rain, snow, fog), and navigation system usage like GPS. Additionally, limited rear visibility due to small screens in modern vehicles exacerbates the problem, compromising both safety and driving efficiency.

4.4.2 Problem Description and Analysis

The problem at hand was thoroughly analyzed, taking into account different factors contributing to poor visibility. These factors include environmental conditions like bad weather or direct sunlight, as well as internal distractions resulting from the need to divide attention between the road and navigation systems. The inability to simultaneously view both the road and GPS instructions leads to driver distraction and escalates the risk of accidents. Upon analysis, two main aspects requiring enhancement were identified:

Improved Lighting and Visibility Aids: This aspect concentrates on improving the road's lighting and utilizing technologies to mitigate external visibility barriers, such as glare from headlights or sun.

Integrated Navigation Systems: This aspect aims to create a more efficient and less distracting navigation system, ensuring that the driver can receive guidance without diverting attention from the road.

4.4.3 TRIZ Methodology Applied

To tackle the issue at hand, the TRIZ (Theory of Inventive Problem Solving) methodology was employed. This systematic approach to innovation centers on identifying contradictions impeding progress and offering inventive principles to resolve these contradictions. The main contradictions pinpointed in this case study were:

Visibility vs. Distraction: Balancing the need for visible navigation information with the risk of distraction from the road. The solution necessitated ensuring accessible information without compromising safety.

Functionality vs. Safety: Ensuring the navigation system is effective and easily comprehensible without obstructing the driver's view or compromising safety.

4.4.4 TRIZ Solutions

To overcome these contradictions, several TRIZ inventive principles were explored:

Segmentation (Principle 1): The navigation information was divided into small, localized cues to reduce the visual clutter. For example, key instructions could be displayed in the peripheral view or on the dashboard, avoiding the need for a large central display.

Preliminary Action (Principle 10): Navigation instructions could be preloaded before the drive, showing only key updates as necessary. This minimizes real-time interference, reducing the driver’s distraction.

Dynamicity (Principle 15): Adaptive displays were considered to adjust the visibility of the navigation cues based on external factors like light conditions, ensuring that the display was always clear without obstructing the driver’s view.

Merging (Principle 5): The use of existing vehicle components, like the windshield or dashboard, to display navigation instructions without adding additional devices or interfaces. This reduced complexity and minimized potential distractions.

Feedback (Principle 23): Instead of relying solely on visual displays, feedback mechanisms like vibrations in the steering wheel or seat were proposed to signal navigation cues, reducing the need to divert the driver’s attention to the screen.

4.4.5 Final Approach and Implementation

Following the application of TRIZ principles, the final solution involved integrating an advanced HUD (Head-Up Display) system that projects navigation cues directly onto the windshield, enabling the driver to access information without shifting focus from the road. The system also incorporated vibrations for important navigation signals, aiding the driver in staying informed through tactile feedback and reducing reliance on visual cues.

Furthermore, adaptive lighting and visibility aids such as glare-reducing technology in the windshield and advanced wiper systems for rain or snow were integrated into the solution. These enhancements ensured improved visibility while driving under varying conditions such as night time, sunlight, or adverse.

The methodology directly linked the identified mini-problems to the corresponding inventive principles. This mapping was essential in selecting appropriate TRIZ principles, such as Segmentation, Preliminary Action, and Dynamicity, to resolve the contradictions. Each question, therefore, served a distinct purpose in progressively refining the problem space, and the entire process is visually encapsulated in Figure 6.1, which illustrates the iterative progression from problem identification to the final solution.

The HUD-based navigation enhancement serves as a component of a connected digital twin. Such twins simulate real-time driving scenarios, and the AI-TRIZ framework enables modelling contradictions e.g., between visibility and distraction—in virtual environments. This not only supports predictive design optimization but also links engineering decisions with behavioural simulation data within PLM ecosystems.

The effectiveness of the solution could be further validated by empirical metrics such as: average driver attention retention, reduced glance time, expert review scores, or simulation-derived safety incident likelihood reductions.

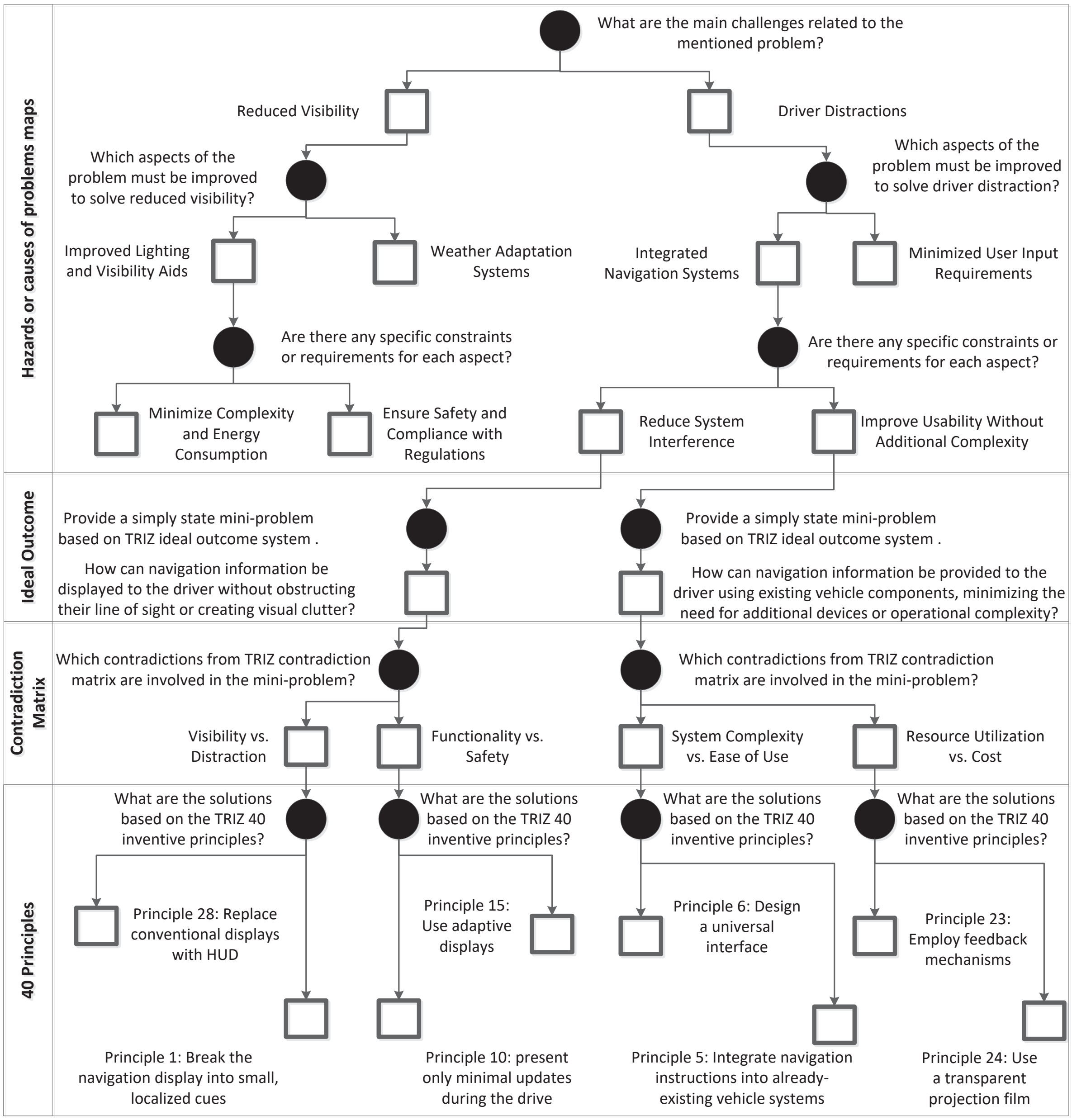

Figure 4.1 The summary of questions and AI generated answers

4.5 Conclusion

By applying the TRIZ methodology, the two major problems—reduced visibility and driver distraction—were resolved in this case study. This innovative solution not only enhanced the overall driving experience but also improved safety by minimizing distractions and ensuring the driver's focus remained on the road. The case study highlights the effectiveness of systematic problem-solving techniques, like TRIZ, in addressing complex engineering challenges.

CHAPTER 5

A STRUCTURED APPROACH INTEGRATING ARTIFICIAL INTELLIGENCE AND THE 8 TRENDS OF TECHNICAL EVOLUTION FOR INNOVATIVE SOLUTIONS

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Résumé

L'intégration des Techniques d'Innovation Créative (TICE) et de la théorie de la résolution inventive de problèmes (TRIZ) dans la quasi-totalité des secteurs d'activité a durablement contribué à l'avancement des technologies et des processus. Cependant, la complexité et les connaissances spécifiques au domaine associées aux méthodologies TRIZ limitent intrinsèquement leur utilisation par les praticiens débutants. Cet article vise à améliorer l'ergonomie et l'efficacité d'un outil TRIZ, baptisé « 8 Tendances de l'Évolution Technique », en l'intégrant à des outils d'IA tels que ChatGPT. Ce nouveau cadre vise à rationaliser le processus d'innovation et à générer des solutions plus pratiques et innovantes, en s'attachant notamment à surmonter l'inertie psychologique lors des processus créatifs comme le brainstorming. Ce dernier permet aux utilisateurs de résoudre les problèmes les plus complexes et de proposer des solutions innovantes en les guidant à travers des questions bien structurées.

Abstract

The infusion of Creative Innovation Techniques, along with TRIZ, the Theory of Inventive Problem Solving, into almost every industry, has had long-standing effects on the advancement of technology and process. However, the very complexity and domain-specific knowledge attached to TRIZ methodologies inherently limit their use by practitioners at the novice level. The objective of this paper is to enhance the usability and effectiveness of a TRIZ tool named the 8 Trends of Technical Evolution by integrating it with AI-driven tools, such as ChatGPT. The new framework aims to streamline the innovation process and generate more practical and innovative solutions, particularly focusing on overcoming psychological inertia during creative processes like brainstorming. The latter enables the users to solve the most complicated issues and come up with innovative solutions by leading them through well-structured questions embedding TRIZ principles and the 8 Trends of Technical Evolution. To demonstrate this approach, a case study on the development of Non-Slippery Shoe Outsole Design and Material Selection is presented. The results reveal how the integration of AI with TRIZ significantly enhances innovation practices, increasing the potential for broader adoption across industries.

5.1 Introduction

Innovation is the cornerstone of progress across all areas, whether in technology, products, or processes, and it often stems from the application of Creative Innovation Techniques. Among these, TRIZ (Theory of Inventive Problem Solving) stands out for its systematic approach and extensive set of inventive principles (Altshuller, 1999); (Mann, 2002). TRIZ offers various techniques, such as Hazard and Cause of Problem Maps, Ideal Outcome, and Trends of Technical Evolution, which provide structured methods to identify, analyze, and resolve complex challenges in product and process development.

Despite TRIZ's proven effectiveness in generating breakthrough solutions within a well-structured framework, it has inherent weaknesses that can limit its application in real-life scenarios, particularly for novice users who may not be familiar with its methodologies

(Ilevbare et al., 2013). TRIZ, known for its adaptability across various domains, relies heavily on the user's expertise within a specific field, which is not always guaranteed. This is where AI becomes particularly valuable. AI-driven tools, such as ChatGPT, can bridge this gap by tailoring TRIZ's general principles to the specific needs of a domain, thereby providing more contextually relevant and adaptive solutions. This integration not only enhances the usability of TRIZ but also amplifies its effectiveness in product and process improvement initiatives, demonstrating the significant potential of combining these two powerful methodologies.

AI tools, particularly those based on natural language processing (NLP) like ChatGPT, align closely with the goals of Creative Innovation Techniques (CIT) methodologies. By leveraging vast amounts of data and advanced pattern recognition algorithms, ChatGPT can facilitate the generation of new ideas, refine solutions, and explore new possibilities across a wide range of fields. This approach, combined with conversational interactions, enables collaborative problem-solving and transforms complex information into actionable insights.

This paper explores the fundamental role of CIT in driving innovation, with a specific focus on TRIZ as a leading methodology. It critically examines the strengths TRIZ brings to structured problem-solving while also addressing its challenges in adapting to complex issues. Additionally, the paper introduces a new framework that integrates ChatGPT to guide users through a structured creative process. This process begins with Hazard and Cause of Problem Maps to identify root issues, moves to the Ideal Outcome to set ambitious yet achievable goals, and concludes with Trends of Technical Evolution to align solutions with emerging technological advancements.

Through AI-generated prompts presented as tailored questions, users can interact with ChatGPT in a step-by-step manner. This approach not only simplifies the application of TRIZ techniques but also empowers users of all skill levels to navigate the complexities of innovation and reach well-informed solutions.

This paper also delves into the theoretical foundations of each TRIZ technique within the proposed framework, highlighting their contributions to structured problem-solving. It further examines how AI tools like ChatGPT enhance human intelligence by facilitating interactive and iterative problem exploration, making CIT methodologies more accessible and effective for improving products and processes.

To strengthen the theoretical and empirical grounding of these propositions at the intersection of TRIZ techniques, AI applications, and structured problem-solving methodologies, we draw on studies from academic sources. By advancing the conversation on how technology can democratize innovation and foster creativity across industries, this work significantly contributes to the evolving landscape of innovation practices.

5.2 Literature Review

Innovation is a key force behind progress in various industries, driving advancements in technology, products, and processes through the use of Creative Innovation Techniques (CIT). Among these techniques, TRIZ (Theory of Inventive Problem Solving) stands out for its systematic approach and wide-ranging set of inventive principles (Altshuller, 1999); (Mann, 2002). This literature review explores the existing research on TRIZ, its methodologies, limitations, and the potential enhancement of its application through the integration of AI tools like ChatGPT.

5.2.1 TRIZ Methodology and its Significance

TRIZ is a structured framework developed by Genrich Altshuller for inventive principles and techniques—such as, Hazard and Cause of Problem Maps, Ideal Outcome, and Trends of Technical Evolution that are applied in the solution of complex problems (Altshuller, 1999). Mann (2002) reported that TRIZ provides systematic pathways for the identification, analysis, and resolution of challenges within the fields of both product and process development.

Studies have demonstrated TRIZ's ability to generate innovative solutions by leveraging its structured approach. For instance, Krasnoslobodtsev and Langevin (2006) discusses the practical application of TRIZ across various divisions within the high-tech industry, highlighting its versatility and adaptability in real-world projects. Similarly, Savranksy (2000) underscores the importance of TRIZ in enhancing creative problem-solving capabilities, making it a valuable tool for innovation (Krasnoslobodtsev & Langevin, 2006); (Savranksy, 2000).

5.2.2 Hazard and Cause of Problem Maps

Problem Mapping is a TRIZ technique that helps to methodically identify the root causes of a problem through the mapping of hazards and their contributing factors. This helps to explain and illustrate how elements are interlinked to form a problem, enabling focused problem solutions.

5.2.3 Ideal Outcome

The Ideal Final Result (IFR) or Ideal Final Outcome is one of the basic concepts of TRIZ. It presents an ideal solution in which all the problems have been solved, all benefits have been acquired, and none of the associated costs or harms has been felt. The concept drives the innovation process towards bolder and more optimal solutions (Hipple, 2012).

5.2.4 Trends of Technical Evolution

TRIZ represents patterns among data throughout the whole period of technical systems' existence. They are named trends in technical evolution and help to predict the future condition of technological development. Simultaneously, it leads the innovation process so that the latter goes in the same stream with technological development through nature (Ghane, Ang, Kadir & Ng, 2020).

5.2.5 Limitations of TRIZ

However, though very effective, it had proven to have a number of limitations especially for beginners. Again, in agreement with this is Mikalef and Gupta (2021), who aver that the application of TRIZ is complicated, so its methods are too sophisticated (Mikalef & Gupta, 2021). That's why its deep domain-specific knowledge has caused significant barriers to having effective application. Methods of TRIZ are too complicated, so its application becomes challenging for newbies in adaptive problems of dynamic and many facets.

More specifically, El Ardeliya et al. (2024) research clearly points to the difficulties of translating TRIZ principles into implementable solutions without an extremely deep level of training. The same barriers can be understood as affirming the needs for supportive tools and methodologies that can enhance TRIZ accessibility and the scope of its application (El Ardeliya, Taylor & Wolfson, 2024).

5.2.6 Integration of AI Tools in TRIZ

In fact, a lot can be said about the potential of AI tools in general and NLP model-based ones such as ChatGPT in particular to be a superpower in the TRIZ methodologies. AI can make generating innovative ideas and looking for solutions easier and even better through refinements in solution explorations. Using vast datasets and sophisticated algorithms for pattern recognition, AI tools based on these patterns can help users look into new opportunities across domains (Chakrabarti & Blessing, 2014).

The conversational capabilities of AI models enable interactive and collaborative problem-solving. For instance, interactions designed through AI have the potential to transform complex information into workable solutions, thus contributing to an increased efficacy of the structured problem-solving techniques (Thibault, Kivikangas, Roihankorpi, Pohjola & Aho, 2023).

5.2.7 Empirical Evidence and Theoretical Frameworks

Empirical studies have looked at the incorporation of AI tools into CIT methods and found benefits. For example, AI can be incorporated to enhance creative processes in engineering design or AI-guided prompts could aid users in proceeding through scaffolded creative activities to effectively produce solutions to problem-solving (Zhu, Liapis, Risi, Bidarra & Youngblood, 2018); (Grech, Mehnen & Wodehouse, 2023). The inclusion of AI in TRIZ is theorized to be supported by existing theoretical underpinnings. A framework for the integration of TRIZ principles using AI algorithms is proposed for enhanced identification and resolution of inventive problems. This approach lessens the implementation time of TRIZ techniques and allows complex innovation challenges to be efficiently managed by innovators at any level of experience (Anantrasirichai & Bull, 2022).

5.2.8 Proposed Framework: TRIZ and ChatGPT

Building on existing literature, this article develops a new framework by combining ChatGPT with TRIZ methodologies. The approach will be sequential: from Hazard and Cause of Problem Maps in order to pinpoint the root issues to envision the Ideal Outcome that sets lofty but reachable goals. finally, the Trends of Technical Evolution lead the solution strategy through incoming waves. Each of the steps includes AI-generated stimuli presented as custom-made questions that encourage the user to respond in an order to the ChatGPT. Such an approach makes applying TRIZ techniques accessible and efficient by users at any level of expertise. The applied theory behind every TRIZ technique and its use in the proposed framework is discussed with an emphasis on their application to structured problem-solving.

In conclusion, integrations of AI tools like ChatGPT within TRIZ methodologies would be the venue for greater innovative practices in cross-industrial applications. If the limitations of TRIZ are addressed and the potential of AI tapped into, then, this framework can really take on a more effective and accessible nature toward creative problem-solving.

5.3 Methodology

The proposed methodology provides a structured Creative process on how to exploit the use of AI tools, such as ChatGPT, in synchronization with the 8 Trends of Technical Evolution, for innovative problem-solving. Although application of TRIZ does not guarantee reaching a final feasible solution, the developed methodology is user-friendly in the sense that a person with very little or no knowledge of TRIZ will be able to generate and assess solutions using a structured set of questions. This procedure, takes place in three main steps, each characterized by a definite focus. The sequence of steps and questions is deliberately crafted to guide users through a logical progression, ensuring that the problem is thoroughly understood, broken down into manageable components, and optimized using TRIZ's evolutionary principles. Additionally, it uses a tree diagram structure to enable a systematic exploration of potential solutions.

Step 1: Problem Definition and Hazard Mapping

The first step focuses on understanding the nature of the problem through hazard mapping or identification of the causes of the problem. It is a TRIZ technique that captures the root cause of the problem by mapping the potential hazard and the factors contributing towards it. By starting with a comprehensive exploration of the system and problem's challenges, the methodology ensures that no critical issues are overlooked. The system is the full framework or a set of inter-connected elements such as a product, process, or technology under analysis or study. It involves all the elements which are either causing the problem or contributing to the resolution, and having knowledge about the system is essential to identify what needs to be optimized to get the desired results.

In more concrete terms, this could be something like a manufacturing process, an autonomous vehicle, a software program, or any complex entity made of interacting parts. The word “system” or “problem” in the following question could be changed by the user to avoid any ambiguity.

The process initiates with a detailed description of the current project or problem to ChatGPT, along with the first question "What are the main challenges related to the mentioned problem?" denoted as Q_1. The generated answers are denoted by $A_{1.j}$, where j is the index of generated answers (from 1 to n, n being the number of answers).

The user then goes through these responses and checkmarks one or more of the relevant responses as those that he or she would like to go ahead with. This is again easily graphically presented by a tree diagram: the root of every branch is a question and the branches, the generated responses. Thus, users can take different directions based on the relevancy and potential or otherwise thereof of the responses so far, leading to a dynamic and malleable problem-solving approach.

Step 2: Evaluating Problem Aspects and Ideal Outcomes

After identifying the major issues in Step 1, the next step is to understand which parts of the problem need improvement. This step is grounded in the TRIZ principle of focusing on critical components of a problem that, when optimized, yield the most significant benefits. The questions in this step are designed to refine the problem further by identifying constraints and desired outcomes, which are vital for developing realistic and feasible solutions. The problem is broken down into manageable components and can be approached systematically.

The selected answers from Step 1 are used as the input for the second query, Q_2: "Which aspects of the problem must be improved to solve $A_{1.j}$?" The AI then returns a new set of answers, $A_{2.j}$, and these are refined using the third query, Q_3: "Are there any specific constraints or requirements for each aspect of $A_{2.j}$? " During this step, the focus becomes refined to only include aspects of the problem that are critical while considering constraints or requirements that eliminate possibilities for solutions. It is very important to have this understanding for the development of a realistic and feasible solution. The next question, Q_4: "Based on the generated answers in the last step, provide a simply stated mini-problem that addresses solving constraints of this aspect and mention related desired outcomes based on TRIZ ideal outcome and ideal concepts" takes the information and synthesizes it into actionable mini-problems with clearly defined goals which are based on the concepts of an Ideal Outcome and an Ideal System in TRIZ, which encourage the development of solutions with the greatest possible benefits and, on the other side, with minimal costs and harm. This question involves breaking down the problem not only into well-understood components but also into manageable components, each having an ideal outcome that conforms to TRIZ principles and facilitates the search for solutions that maximize benefits while minimizing costs and harm.

Step 3: Application of TRIZ's Trends of Technical Evolution

The final step subjects the mini-problems that were identified in Step 2 to TRIZ's 8 Trends of Technical Evolution. This is one of the main columns of the TRIZ to look at the patterns in the evolution of technical trends. By leveraging the trends, innovative solutions and forecasts can be derived. The process is done by a series of targeted questions developed with the objective of enhancing the effectiveness and innovativeness potential for the solutions. There are a number of trends which TRIZ identifies in the evolution of the technical trend. Technical Evolution Trends include paths that guide the development of technical trends in the aspect of helping to create innovative and refined solutions. These trends guide the processes through which the technical trends evolve with time, could be used tactically for optimizing problems, and, finally, could guide the innovation process from natural progressive alignment. In another word, the carefully crafted questions in this step are designed to explore how these trends can be applied to the mini-problems identified in Step 2, ensuring that the solutions developed are not only innovative but also aligned with the natural progression of technological trends. Each question corresponds to a specific trend, encouraging users to consider how their solutions can be optimized, made more efficient, and adapted to future challenges. This is how each trend embodies their corresponding questions:

Q_5: "Based on Trend of Increasing Ideality, how can we increase the ideality of the mini-problems to achieve a higher degree of efficiency and effectiveness?". The trend of increasing ideality means that technical trends develop towards providing more and more benefits with fewer losses—for instance, less complexity, cost, or negative side-effects. This trend is important for making more efficient and effective results, i.e., to get the largest relative output from a unit input (Terninko, Zusman & Zlotin, 1996).

Q_6: "Based on Trend of S-Curve Evolution, in what areas can we apply S-Curve technology on the mini-problems to bring about significant advancements or breakthroughs?". S-Curve evolution describes technological systems going through phases of birth, growth, maturity, and decline. Understanding where a technology resides on such a curve can help in making strategic decisions about innovation. Either by extending the curve, through incremental improvements, or by initiating a new curve through breakthrough innovations (Altshuller, 2000).

Q_7: "Based on Trend of Dynamization, how can the coordination of the mini-problems be improved to enhance overall performance and minimize inefficiencies or conflicts?" System coordination based on the 8 trends of technical evolution helps improve general performance while reducing all forms of inefficiencies and conflicts. Quite often, this trend will necessarily result in the better integration and harmonization of solutions, with each component acting in tandem with others (Mann, 2002); (Savranksy, 2000).

Q_8: "Based on Trend of Non-Uniform Development, are there any unmet needs or gaps in the mini-problems that can be addressed through better matching of requirements and resources?" This trend refers to adequate matching of all resources at hand (technology, materials, human resources) with the requirements of the problem. As with a mismatch between resources and requirements, the outcome can be inefficiencies or suboptimal solutions. This trend aims at optimizing resource allocation so that the demand of the problem can be met or exceeded (Altshuller, 1999).

Q_9: "Based on Trend of Automation, what innovative approaches can be implemented to increase automation within the mini-problems, reducing human intervention and improving productivity?" The trend of increasing automation shows that with time, there is a slow reduction in the human intervention; this ensures effectiveness and efficiency, leading to increased productivity. This trend is driven by technological advances in enabling more autonomous operations of systems (Mikalef & Gupta, 2021); (Cascio & Montealegre, 2016).

Q_{10}: "Based on Trend of Segmentation, how can we leverage segmentation and the use of fields to create tailored solutions that address specific needs or challenges in the mini-problems?" Segmentation refers to the division of a system into much smaller parts for easy management but which can also be optimized or tailored per part. The application of fields refers to physical, chemical, or other fields applied to the system to drive it in the desired direction. This trend aids in achieving more accuracy and effective solutions through targeting specified aspects of the problem (Terninko, 1996); (Altshuller, 2002).

Q_{11}: "Based on Trend of Coordination, what strategies can be employed to achieve increased dynamism and controllability within the mini-problems allowing for better adaptability and response to changing conditions?" This is a trend stating that systems evolve to become even more dynamic and controllable, giving them the ability to better adapt to changing conditions and even more precisely controlling their operation. This would particularly be important for environments where conditions are unpredictable or change at a rapid pace (Zwicky, 1969).

Q_{12}: "Based on Trend of Simplification, is there a way to simplify the mini-problems while maintaining or even enhancing their functionality and performance?" By following the trend, systems are making progress toward simplicity and, as a matter of fact, becoming less complicated while maintaining even better functionality. The example includes the possibility of cutting unnecessary components or processes of the system which leads to it being more efficient and reliable (Savransky, 2000).

These questions investigate, in a methodical way, how the mini-problems can be further developed, optimized, and aligned with new technological trends. The answers received from ChatGPT are further discussed, where the user picks the most feasible ones to implement. Including these trends into the methodology both strengthens it and, at the same time, makes sure that its solutions are not just innovative but are efficiently, effectively, and adaptively optimized.

By following this structured sequence of steps and questions, the methodology provides a comprehensive exploration of the problem and its potential solutions. The logical flow from problem definition to solution optimization, supported by the principles of TRIZ and the capabilities of AI, provides a robust framework for innovative problem-solving. This approach is not only systematic but also adaptable, allowing users to tailor their exploration to the specific nuances of the problem at hand. Ultimately, the methodology's strength lies in its ability to combine the best of human creativity with the analytical power of AI, guided by time-tested TRIZ principles.

5.4 Case Study

To demonstrate a practical application of the methodology proposed above, a case of Non-Slippery Shoe Outsole Design and Material Selection is carried out. Non-slippery shoes are important in terms of user safety within different contexts and times specifically in winter, where icy conditions carry much concern about accidents caused by slipping and falling down. In the market, shoes are marketed as non-slippery, but people still face issues with the slipping nature of these shoes. The case study considers a shoe as a system composed of several elements, such as the outsole, midsole, and heel counter. Since the problem of slipperiness is related to the outsole material and design, this part is the focus of the study. The presented case demonstrates how an outsole can be developed to ensure exceptional traction on icy and slippery surfaces while maintaining other essential properties, such as durability, comfort, and usability in everyday life. This case study illustrates how AI tools, such as ChatGPT, in conjunction with TRIZ techniques, can be leveraged to address complex engineering challenges.

Step 1: Problem Definition and Hazard Mapping

The first step involves defining the main challenges associated with Non-Slippery Shoe Outsole Design and Material Selection. The project scope is described in detail to ChatGPT, and the question posed is: "What are the main challenges related to Non-Slippery Shoe Outsole Design and Material Selection?"

ChatGPT generates several challenges, such as:

$A_{1.1}$: Inadequate Traction on Icy Surfaces.

$A_{1.2}$: Durability of Traction Features.

$A_{1.3}$: User Comfort and Flexibility.

For this case study, the challenge of Inadequate Traction on Icy Surfaces ($A_{1.1}$) is selected as the primary focus for further exploration, as it directly impacts the safety and effectiveness of the shoe in winter conditions.

Step 2: Evaluating Problem Aspects and Ideal Outcomes

The next step involves a deeper analysis of the selected challenge through the question, "Which aspects of the problem must be improved to solve Inadequate Traction on Icy Surfaces?"

ChatGPT identifies key areas for improvement:

$A_{2.1}$: Traction Technology Innovation.

$A_{2.2}$: Optimized Tread Patterns and Outsole Design.

$A_{2.3}$: Testing and Performance Standards.

The focus is narrowed down to $A_{2.1}$: Traction Technology Innovation, as it offers the most direct impact on enhancing traction on icy surfaces. Developing or selecting advanced materials that retain flexibility and grip on icy surfaces is crucial. Materials with unique properties, like rubber compounds specifically engineered for cold conditions, can enhance traction.

This leads to the next question, "Are there any specific constraints or requirements for improving Traction Technology Innovation?"

The AI identifies the following constraints:

$A_{3.1}$: Durability and Wear Resistance.

$A_{3.2}$: Adaptability to Diverse Environments.

$A_{3.3}$: Manufacturing Compatibility.

Among these, Durability and Wear Resistance is selected as the key constraint, as the traction technology based on the advanced materials must withstand prolonged use without degrading and be resistant to wear and tear from regular use, including abrasion from rough surfaces and chemical exposure (e.g., salt used on icy roads), without compromising their traction properties.

Finally, the problem is condensed into a mini-problem using Q_4: "Based on the constraints like Durability and Wear Resistance, Adaptability to Diverse Environments, and Manufacturing Compatibility, provide simply stated mini-problems that addresses solving constraints of this aspect and mention related desired outcomes based on TRIZ ideal outcome and ideal concepts"

The mini-problems are defined as:

$A_{4.1}$: "Designing an outsole that offers suitable grip on icy floors."

$A_{4.2}$: " Durable outsole that ensures the shoe's long-term performance."

$A_{4.3}$: "An outsole that is resistant to chemical exposure over time."

The first two mini-problems have been selected for the next step. The questions related to case 1 are represented as $Q_{i,1}$ and the corresponding answers are represented as $A_{i,1,j}$. Similarly, $Q_{i,2}$ and $A_{i,2,j}$ represent the questions and answers related to case 2, respectively. In the next step, only two selected answers will be provided for each question.

Step 3: Application of TRIZ's Trends of Technical Evolution

With the mini-problem defined, the next step is to use TRIZ's 8 Trends of Technical Evolution to improve the solution. The following questions are used to generate potential improvements:

$Q_{5.1}$: " Based on Trend of Increasing Ideality, how can we increase the ideality to achieve a higher degree of efficiency and effectiveness in designing an outsole that offers suitable grip on icy floors? "

$A_{5.1.1}$: Integration of Adaptive Microstructures: Utilize adaptive microstructures within the outsole material that can dynamically alter their surface texture in response to temperature and surface conditions. These microstructures can become more pronounced in cold, icy environments, enhancing grip by increasing surface contact and friction. The adaptability ensures that the outsole provides optimal traction on icy floors without compromising flexibility and comfort under different conditions.

$A_{5.1.2}$: Development of Composite Materials with Embedded Nanoparticles: Incorporate nanoparticles such as silica or carbon nanotubes into the outsole material to increase its grip and durability. These nanoparticles can enhance the material's ability to maintain a consistent grip on icy surfaces by creating a rougher texture at the microscopic level, which increases friction. Additionally, this composite material would resist wear and tear, ensuring long-term performance and maintaining its gripping properties over time.

$Q_{5.2}$: " Based on Trend of Increasing Ideality, how can we increase the ideality to achieve a higher degree of efficiency and effectiveness in a durable outsole that ensures the shoe's long-term performance? "

$A_{5.2.1}$: Incorporation of Self-Healing Polymers: Integrate self-healing polymers into the outsole material, allowing the outsole to repair minor wear and tear autonomously. This technology would extend the lifespan of the outsole by maintaining its structural integrity and performance over time, reducing the need for frequent replacements and ensuring consistent durability.

$A_{5.2.2}$: Use of Advanced Wear-Resistant Composites: Develop an outsole using advanced wear-resistant composites, such as hybrid rubber materials reinforced with ceramic particles or graphene. These materials would significantly enhance the outsole's resistance to abrasion and deformation, ensuring that the shoe remains durable and maintains its performance even under prolonged and harsh usage conditions.

Q$_{6.1}$: "Based on Trend of S-Curve Evolution, in what areas can we apply S-Curve technology on designing an outsole that offers suitable grip on icy floors, to bring about significant advancements or breakthroughs?"

A$_{6.1.1}$: Emerging Materials (Early Stage S-Curve): Invest in the development of novel composite materials that are in the early stages of their technological evolution, such as nano-engineered rubber or biomimetic surfaces. These materials could offer groundbreaking improvements in grip by mimicking natural structures like gecko feet, which provide exceptional traction on slippery surfaces.

A$_{6.1.2}$: Optimization and Integration (Late Stage S-Curve): Optimize and integrate existing advanced technologies, such as micro-textured surface patterns and adaptive rubber compounds that have matured on the S-Curve. By refining these technologies and combining them in innovative ways, you can achieve a significant enhancement in grip performance on icy floors without requiring entirely new material developments.

Q$_{6.2}$: "Based on Trend of S-Curve Evolution, in what areas can we apply S-Curve technology on a durable outsole that ensures the shoe's long-term performance, to bring about significant advancements or breakthroughs?"

A$_{6.2.1}$: Mature Technologies (Mid-Stage S-Curve): Utilize advanced rubber compounds that have matured in their technology curve, such as high-performance vulcanized rubbers with enhanced wear resistance. These materials, already proven in terms of durability, can be further optimized for longevity and resilience, ensuring the outsole remains effective over extended use without compromising flexibility or comfort.

A$_{6.2.2}$: Optimization and Integration (Late Stage S-Curve): Focus on the integration of advanced manufacturing techniques like high-precision 3D printing and automated layering processes. These techniques, which are in the late stages of their S-curve, can be used to create multi-layered outsoles that combine different material properties—such as hard-wearing surfaces with shock-absorbing layers—ensuring long-term performance while minimizing material degradation over time.

$Q_{7.1}$: “Based on Trend of Dynamization, how can the coordination of designing an outsole that offers suitable grip on icy floors, be improved to enhance overall performance and minimize inefficiencies or conflicts?”

$A_{7.1.1}$: Dynamic Traction Adjustment: Implement adaptive traction elements within the outsole, such as dynamic micro-spikes or retractable grips that adjust their height and configuration based on real-time surface conditions. This feature can be controlled by sensors embedded in the outsole, which detect icy conditions and automatically extend or retract the traction elements to optimize grip, ensuring maximum effectiveness across varying icy surfaces.

$A_{7.1.2}$: Responsive Material Integration: Utilize temperature-sensitive materials that adjust their properties based on environmental conditions. For instance, incorporating thermoplastic elastomers (TPEs) that become softer and more flexible in cold temperatures can enhance grip on icy surfaces. This dynamization approach ensures that the outsole remains adaptable to different temperature ranges, improving overall performance and reducing the risk of slipping.

$Q_{7.2}$: “Based on Trend of Dynamization, how can the coordination of a durable outsole that ensures the shoe's long-term performance, be improved to enhance overall performance and minimize inefficiencies or conflicts?”

$A_{7.2.1}$: Multi-Layered Material Systems: Develop a multi-layered outsole system incorporating composite materials with varying properties. For instance, use a high-abrasion-resistant outer layer to withstand rough surfaces and a shock-absorbing inner layer for enhanced comfort and impact resistance. These layers can be dynamically bonded to allow for modular replacements as the outsole wears down, ensuring long-term durability and minimizing performance degradation over time.

$A_{7.2.2}$: Self-Healing Polymers: Integrate self-healing polymers in the outsole construction. These advanced materials can repair minor cuts and abrasions autonomously, significantly extending the lifespan of the outsole. By incorporating self-repairing features that activate when the material is damaged, the outsole maintains its durability and functionality over prolonged use, addressing wear and tear while optimizing overall performance.

$Q_{8.1}$: "Based on Trend of Non-Uniform Development, are there any unmet needs or gaps in designing an outsole that offers suitable grip on icy floors, that can be addressed through better matching of requirements and resources?"

$A_{8.1.1}$: Localized Grip Enhancements: Address the unmet needs by developing segmented outsole designs that use specialized compounds tailored to specific surface conditions. For instance, create different grip-enhancing materials or tread patterns for varying degrees of ice severity or surface texture. By customizing the outsole for different ice conditions—such as incorporating soft, flexible grips for mild ice and hard, sharp spikes for extreme ice—the outsole can provide optimal traction where needed. This approach ensures that each segment of the outsole performs effectively in its intended condition, enhancing overall grip and safety.

$A_{8.1.2}$: Dynamic Adaptation Technologies: Implement real-time adaptive technologies to address gaps in current designs. This includes integrating sensors and actuators within the outsole that can adjust the grip dynamically based on detected surface conditions. For example, sensors could measure ice thickness or slipperiness and adjust the traction elements (e.g., micro-spikes or tread patterns) accordingly. This ensures that the outsole continually matches the requirements of varying icy surfaces, optimizing performance and reducing the limitations of static designs.

$Q_{8.2}$: "Based on Trend of Non-Uniform Development, are there any unmet needs or gaps in a durable outsole that ensures the shoe's long-term performance, that can be addressed through better matching of requirements and resources?"

$A_{8.2.1}$: Material Durability Optimization: Address the unmet needs by developing advanced composite materials that combine high-wear resistance with flexibility and impact resistance. For example, integrating reinforced polymers with nano-coatings can enhance durability while maintaining comfort. Utilize advanced computational modeling to simulate long-term wear and tailor material properties to match the specific stress conditions the outsole will encounter. This ensures that the outsole maintains its performance over time, even under varied and harsh conditions.

$A_{8.2.2}$: Resource and Technology Integration: Enhance durability by aligning resources more effectively across material science and manufacturing processes. Invest in new manufacturing technologies such as precision extrusion or advanced molding techniques to produce outsoles with consistent quality and performance. Additionally, leverage cross-disciplinary innovations, such as incorporating aerospace-grade materials or automotive technology to improve the outsole's resistance to environmental factors and mechanical wear. By integrating cutting-edge technologies from other fields, you can address the performance gaps and enhance the long-term durability of the outsole.

$Q_{9.1}$: "Based on Trend of Automation, what innovative approaches can be implemented to increase automation, reducing human intervention and improving productivity with in designing an outsole that offers suitable grip on icy floors?"

$A_{9.1.1}$: Automated Material Testing and Optimization: Implement robotic systems for automated material testing and analysis. These systems can quickly and precisely evaluate properties such as grip, flexibility, and wear resistance under various conditions. By using AI algorithms to analyze test results, you can rapidly optimize material formulations and tread patterns for enhanced performance on icy surfaces. This approach not only accelerates the development process but also improves consistency and accuracy in the material selection and design optimization phases.

$A_{9.1.2}$: Advanced Automated Design and Manufacturing: Utilize 3D printing and robotic manufacturing techniques to automate the production of outsoles with intricate tread patterns and multi-material components. Advanced automated design software can generate and refine outsole designs based on real-time performance data and environmental conditions. This integration allows for rapid prototyping and customization of outsoles to meet specific grip requirements for icy floors. Additionally, smart manufacturing systems can adapt in real-time to production needs, minimizing human intervention and enhancing overall productivity and efficiency in the manufacturing process.

$Q_{9.2}$: "Based on Trend of Automation, what innovative approaches can be implemented to increase automation, reducing human intervention and improving productivity with in a durable outsole that ensures the shoe's long-term performance?"

$A_{9.2.1}$: Automated Material Development and Testing: Deploy robotic systems equipped with advanced sensors and analytical tools to automate the development and testing of durable outsole materials. These systems can perform high-throughput testing for durability, wear resistance, and longevity under various conditions. Integrate AI-driven analytics to evaluate material performance and identify optimal formulations for long-term durability. By reducing manual intervention in the testing process, this approach speeds up development and ensures consistent quality and performance of the outsoles.

$A_{9.2.2}$: Smart Manufacturing and Real-Time Quality Control: Implement smart manufacturing technologies, such as automated molding and robotic assembly systems, to streamline the production of durable outsoles. Utilize machine learning algorithms to monitor and control production parameters in real time, ensuring that each outsole meets durability standards. Additionally, integrate real-time quality control systems with automated feedback loops to detect and correct deviations from desired performance criteria during production. This approach enhances productivity by reducing defects and ensuring that the final product consistently meets long-term performance requirements.

$Q_{10.1}$: "Based on Trend of Segmentation, how can we leverage segmentation and the use of fields to create tailored solutions that address specific needs or challenges in designing an outsole that offers suitable grip on icy floors?"

$A_{10.1.1}$: Segmented Outsole Patterns and Material Zones: Design an outsole with segmented tread patterns and differentiated material zones tailored to specific grip requirements for icy floors. For instance, integrate micro-spike segments in high-friction areas for superior grip on ice, while using flexible, cushioned materials in areas that require enhanced comfort and shock absorption. This segmentation allows the outsole to provide optimal traction where needed, while also maintaining comfort and flexibility in other regions. 3D modeling and simulation tools can be employed to optimize the layout and functionality of these segments for maximum effectiveness.

$A_{10.1.2}$: Modular Outsole Components: Develop a modular outsole system where components can be customized based on environmental conditions and user needs. For example, create interchangeable modules or pads that can be swapped out depending on the level of grip required for icy surfaces. This modular approach enables users to adapt their footwear to varying conditions, such as different ice textures or slopes, by selecting the most appropriate module for each situation. Advanced manufacturing techniques, such as 3D printing, can facilitate the rapid production and customization of these modular components, allowing for tailored solutions that address specific grip challenges.

$Q_{10.2}$: "Based on Trend of Segmentation, how can we leverage segmentation and the use of fields to create tailored solutions that address specific needs or challenges in a durable outsole that ensures the shoe's long-term performance?"

$A_{10.2.1}$: Segmented Material Compositions: Implement a multi-layered outsole design where different segments are made from composite materials optimized for specific durability challenges. For instance, use abrasion-resistant compounds in high-wear areas like the heel and toe, and flexible, impact-absorbing materials in regions prone to high stress or frequent flexion. This approach ensures that each part of the outsole addresses particular wear patterns and performance requirements, extending the overall lifespan of the shoe. Finite element analysis (FEA) can be used to model and predict wear patterns, ensuring that each material segment performs optimally under various conditions.

$A_{10.2.2}$: Field-Specific Durability Enhancements: Design the outsole with field-specific durability features by integrating targeted reinforcements based on the expected conditions. For example, add reinforced edge guards in areas prone to scuffing and chemical-resistant coatings in regions exposed to harsh chemicals. By segmenting the outsole into distinct functional fields and applying appropriate treatments or materials to each field, the design can address specific long-term performance challenges. Automated quality control systems can be employed to ensure consistency in the application of these features, enhancing overall durability and performance.

$Q_{11.1}$: "Based on Trend of Coordination, what strategies can be employed to achieve increased dynamism and controllability allowing for better adaptability and response to changing conditions within designing an outsole that offers suitable grip on icy floors?"

$A_{11.1.1}$: Dynamic Traction Adjustment System: Integrate a dynamic traction adjustment system into the outsole design that employs adaptive tread patterns. This system could use micro-mechanical actuators or smart materials that respond to varying surface conditions. For example, micro-spikes or dynamic tread elements could extend or retract based on the detected surface type, providing enhanced grip on ice or wet surfaces as needed. The system can be controlled via sensors that detect changes in surface conditions, automatically adjusting the outsole's traction properties to maintain optimal performance.

$A_{11.1.2}$: Real-Time Feedback Loop Integration: Implement a real-time feedback loop that uses embedded sensors to monitor and respond to environmental changes. These sensors could track factors like temperature, surface texture, and pressure distribution. The feedback collected would be used to adjust the outsole's properties dynamically, such as activating temperature-sensitive compounds that alter their stiffness and flexibility in response to temperature changes. This approach enhances the outsole's ability to adapt to varying conditions, improving grip and stability in real-time. The integration of such a system could involve sophisticated machine learning algorithms to predict and respond to different conditions effectively.

$Q_{11.2}$: "Based on Trend of Coordination, what strategies can be employed to achieve increased dynamism and controllability allowing for better adaptability and response to changing conditions within a durable outsole that ensures the shoe's long-term performance?"

$A_{11.2.1}$: Modular Outsole Design with Adaptive Components: Develop a modular outsole system that incorporates adaptive components designed for specific performance needs. This system can feature interchangeable modules or segments with varying properties, such as different rubber compounds or tread patterns, which can be easily swapped based on performance requirements. For example, modules could include specialized segments for enhanced traction, cushioning, or wear resistance. The modular approach allows for customization based on the environment and user requirements, ensuring durability and performance across different conditions. This design also facilitates easier maintenance and replacement of worn parts, extending the outsole's overall lifespan.

$A_{11.2.2}$: Integrated Sensor and Actuation System: Incorporate an integrated sensor and actuation system within the outsole that provides real-time adaptability. Sensors embedded in the outsole can monitor environmental variables such as temperature, surface texture, and impact forces. This data can be used to adjust the outsole's properties dynamically through actuators or smart materials that alter their stiffness or flexibility in response to detected conditions. For instance, a material that stiffens in high-impact scenarios or softens for enhanced comfort in low-impact conditions. The system could be controlled by an adaptive algorithm that processes sensor inputs and adjusts the outsole's performance characteristics accordingly, improving the shoe's response to changing conditions and enhancing its long-term durability.

$Q_{12.1}$: "Based on Trend of Simplification, is there a way to simplify designing an outsole that offers suitable grip on icy floors and maintaining or even enhancing their functionality and performance?"

$A_{12.1.1}$: Unified Multi-Function Material: Develop a single, multi-function material that combines the properties needed for grip on icy floors with durability and comfort. This material should integrate advanced composites or polymers that inherently offer traction, flexibility, and resilience. For instance, using a blend of thermoplastic elastomers (TPEs) with embedded micro-textures can provide effective grip on ice while being resistant to wear and tear. Simplifying the material selection to a single, high-performance compound reduces complexity in design and manufacturing, while maintaining or even enhancing overall functionality and performance.

$A_{12.1.2}$: Streamlined Tread Pattern Design: Optimize the outsole design by using a simplified, but adaptive tread pattern that can handle various surface conditions, including icy floors. Implement a modular tread design where key elements of the pattern (like traction lugs or grooves) are designed to function effectively across different conditions. This approach minimizes the need for multiple tread designs and material combinations, while ensuring consistent performance. For example, a tread pattern with self-cleaning features that prevents snow and ice accumulation can maintain grip without adding complexity to the design. This streamlined approach ensures ease of production and maintenance while enhancing the outsole's effectiveness and longevity.

$Q_{12.2}$: "Based on Trend of Simplification, is there a way to simplify designing a durable outsole that ensures the shoe's long-term performance and maintaining or even enhancing their functionality and performance?"

$A_{12.2.1}$: Modular Design Integration: Employ a modular outsole design that allows for easy replacement or upgrades of key components, such as traction pads or cushioning layers, without needing a complete redesign of the shoe. This approach simplifies manufacturing and maintenance by focusing on interchangeable parts that can be optimized individually. For example, modular inserts made from high-durability rubber or advanced composites can be swapped out based on wear patterns or performance needs, extending the outsole's lifespan while maintaining high performance.

$A_{12.2.2}$: Advanced Composite Materials: Utilize advanced composite materials that integrate multiple functionalities into a single layer. For instance, develop a composite outsole material that combines high-durability polymers with embedded reinforced fibers or nano-coatings to enhance wear resistance and impact absorption. Simplifying the material composition to a single, multi-functional compound reduces the number of layers and components needed, making the design both easier to manufacture and more durable. This material should ideally include self-healing properties to automatically address minor abrasions, further extending the outsole's service life and maintaining performance.

Step 4: Final Innovative Solution

1. Designing an Outsole that Offers Suitable Grip on Icy Floors:

To achieve exceptional grip on icy surfaces, the innovative solution involves integrating smart materials and dynamic traction systems. Specifically, develop an outsole using thermo-responsive polymers combined with adaptive micro-spike technology.

Thermo-Responsive Polymers: Utilize polymers that adjust their hardness and flexibility based on temperature changes. These materials become softer and more flexible in cold conditions, enhancing grip on icy surfaces. At warmer temperatures, they revert to a firmer state, maintaining durability and stability on regular surfaces.

Adaptive Micro-Spike Technology: Incorporate micro-spikes or retractable traction elements that deploy automatically based on the detected surface conditions. Sensors in the outsole can detect ice and engage spikes when necessary, providing additional grip when needed and retracting when on regular surfaces to avoid excess wear.

This approach ensures optimal performance across various conditions by dynamically adjusting to environmental changes, improving overall safety and effectiveness on icy floors.

2. Durable Outsole that Ensures the Shoe's Long-Term Performance:

For a durable outsole that guarantees long-term performance, the solution involves modular design integration combined with advanced composite materials.

Modular Design Integration: Design the outsole with replaceable components such as high-durability traction pads and cushioning layers. This modular system allows users to replace worn parts without discarding the entire outsole, extending the overall lifespan of the shoe. Modular inserts can be made from high-performance thermoplastic elastomers (TPE) that offer excellent wear resistance and comfort.

Advanced Composite Materials: Develop a single, advanced composite material that combines high-durability polymers with embedded nano-coatings. This composite should integrate properties such as wear resistance, impact absorption, and self-healing capabilities. Nano-coatings can provide additional protection against chemical exposure and abrasion, while the material's inherent properties enhance durability and performance over time.

By simplifying the design to use multi-functional materials and modular components, this approach maintains high performance and durability while making manufacturing and maintenance more efficient.

To address both mini-problems effectively, the innovative approaches outlined above can be combined into a comprehensive outsole design. By integrating these technologies, the final solution offers both exceptional grip on icy surfaces and enhanced durability, ensuring that the outsole performs well in diverse environments while extending the lifespan of the shoe.

5.5 Discission

The case study of the Non-Slippery Shoe Outsole Design and Material Selection indicates that complex engineering problems can be effectively solved by applying the proposed methodology. In such case, this method offers a guided, structured, practical, and innovative answer to users working on complex engineering challenges, converging principles both from TRIZ and AI-based insights. The resulting non-slippery shoe design highlights the methodology's potential to drive innovation, leading to safe, and user-friendly solutions.

The proposed solution leverages cutting-edge materials and technologies to address the critical issue of inadequate traction on icy surfaces. By integrating a versatile adaptive material, and a dynamic traction system, the outsole design achieves superior performance in various conditions while maintaining durability and comfort. The use of automated manufacturing and simplified modular design enhances production efficiency and reduces complexity, ensuring a practical and effective footwear solution. This innovative approach not only resolves the primary challenge of traction but also aligns with TRIZ principles to optimize functionality, adaptability, and user safety on slippery surfaces.

Such an approach not only tackles immediate challenges of real-time data processing but also opens up new possibilities for enhancing the overall performance and reliability. The flexibility and adaptability of the methodology make it a strong instrument for grappling with a great number of problems from different industries.

5.6 Conclusion

The proposed methodology will provide a step-by-step approach for integrating AI tools with TRIZ techniques and try to overcome some of the current drawbacks of TRIZ to make it more user-friendly at all levels. By focusing on the 8 Trends of Technical Evolution, this methodology helps overcome psychological inertia, thereby guiding users through a structured problem-solving process that leads to more innovative and effective solutions. The case study on Non-Slippery Shoe Outsole Design and Material Selection demonstrates the practical application and impact potential of this approach. Results indicate a significant potential to increase efficiency, adaptability, and innovativeness of technical systems through AI in combination with TRIZ. As AI evolves further and is integrated with methodologies such as TRIZ, it could be playing a critical role in pushing innovations in many industries and providing new opportunities to democratize creative problems and foster technological advancements. A focus on the interface of CIT methodologies with AI applications will probably continue to come by new research further in the course of advancement of the discourse on democratizing innovation and fostering creativity.

CHAPTER 6

ENHANCING C-K DESIGN THEORY: A NOVEL FRAMEWORK INTEGRATING ARTIFICIAL INTELLIGENCE AND TRIZ FOR IMPROVED CONCEPT GENERATION AND USER KNOWLEDGE ENRICHMENT

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Résumé

L'intégration des méthodologies TRIZ et C-K, ainsi que d'outils d'IA comme ChatGPT, offre un cadre dynamique pour améliorer l'efficacité et la créativité en conception. Cette approche innovante s'attaque aux limites des méthodes de conception traditionnelles en exploitant des heuristiques de conception formalisées, en guidant la formulation des problèmes et en favorisant de nouvelles connexions sémantiques au sein de l'espace de conception. En intégrant les connaissances issues de l'IA aux processus de collecte de connaissances et d'idéation, nous pouvons relever systématiquement les défis de conception critiques tout en garantissant l'adéquation des solutions innovantes aux exigences et contraintes spécifiques. La synergie collaborative entre les espaces de connaissances enrichis par l'IA et les espaces de conception conceptuellement enrichis facilite un processus de conception plus éclairé et créatif, conduisant au développement de solutions percutantes dans divers domaines.

Abstract

The integration of TRIZ and C-K methodologies, alongside AI tools like ChatGPT, presents a dynamic framework for enhancing design efficiency and creativity. This innovative approach addresses limitations in traditional design methods by leveraging formalized design heuristics, guiding problem formulation, and fostering new semantic connections within the design space.

By incorporating AI-driven insights into the knowledge gathering and ideation processes, we can systematically address critical design challenges while ensuring that innovative solutions align with specific requirements and constraints. The collaborative synergy between AI-enhanced knowledge spaces and conceptually enriched design spaces facilitates a more informed and creative design process, leading to the development of impactful solutions across various domains.

6.1 Introduction

From a theoretical standpoint, C-K stands as a cutting-edge theory in the field of innovative design. Nevertheless, as a practical method, it necessitates further advancements to achieve widespread application. Notably, there is a deficiency in support at the reasoning level, and methods for fostering creativity are notably absent within the C-K framework. On the other hand, TRIZ, as a creative problem-solving method, offers a distinctive framework that addresses a portion of the identified requirements (Boujut & Lincas, 2009). As a result, the proposed integration of C-K theory and TRIZ in the context of innovative design processes introduces a novel framework that addresses inherent limitations in both theories.

In the conventional C-K model, where problem formulation is not explicitly emphasized, TRIZ, as a comparative framework, places significant importance on this fundamental step. Consequently, integrating initial concepts from TRIZ into C-K not only addresses the weakness of limited knowledge but also brings the advantage of structured problem formulation to the C-K process. This synergistic relationship between C-K and TRIZ aligns their respective concept and solution spaces (Hatchuel & Weil, 2009).

While C-K traditionally relies on expert knowledge limited to organizational or field-specific expertise, the proposed integration with ChatGPT enhances the human cognitive process. By incorporating more relevant knowledge into the K-space, the quality of information within the C-K framework is significantly improved, influencing the overall outcomes of C-K operations.

Acknowledging the historical human-centered nature of both C-K and TRIZ, the proposed framework introduces an innovative approach by incorporating AI capabilities to automate specific components, while still maintaining a critical level of human involvement. This automation is particularly relevant to the C-K process, which lacks explicit guidance for the progression from a given problem to a solution, emphasizing the need for AI support in enhancing the design thinking process and empowering K-space with critical information linked to the problem.

Drawing parallels to TRIZ, the proposed framework integrates the problem formulation process into C-K, providing a method to clarify constraints and contradictions, and guiding participants in generating more relevant concepts. Additionally, it addresses another limitation of C-K (the absence of defined ways to act on information) by offering a process to analyze a wealth of related knowledge, enhancing information quality, and establishing a path for deriving concepts (K→C).

Both C-K and TRIZ are recognized for their inventive design theories, engaging creative thinking in non-routine and ill-defined activities (Vorms, 2013). The cross-fertilization between C-K and TRIZ, emphasized by Dubois et al., underscores TRIZ's ability to act on information through its resolution tools (Dubois, De Guio & Chibane, 2019). This highlights the synergistic potential of combining these two innovative design theories. The proposed framework contributes holistically to both C→K and K→C operations, providing a comprehensive solution to enhance the effectiveness and efficiency of the design process. In essence, the proposed framework seeks to bridge the gap between true facts, true assumptions, and undecidable propositions in the knowledge and concept spaces, mirroring the interdependence modelled by C-K.

In brief, C-K theory renowned for its innovative design approach grounded in users' cognitive processes, faces challenges associated with limited user knowledge in specific domains and the quality of initial concepts. This brief overview exposes these weaknesses, particularly in the resulting outcome quality. To address these limitations, a novel framework is proposed.

This framework augments C-Space with high-quality initial concepts and enhances K-Space with a wealth of knowledge obtained by querying predefined questions through ChatGPT, an AI tool, strategically formulated based on TRIZ tool specifications. This innovative integration aims to overcome the identified shortcomings and elevate the effectiveness of the C-K design theory.

6.2 Literature review

6.2.1 Creativity Vs. Innovation

Creativity often involves the generation of novel and valuable ideas, which unfolds through a systematic process wherein an individual utilizes their capacity to produce innovative concepts. Innovation, on the other hand, encompasses the transition of these ideas into novel products or services. Essentially, innovation can be defined as the realization of creative outcomes, involving the development of new products, processes, or services. In essence, creativity serves as the foundational phase in the comprehensive innovation process, acting as the inception point from which the entire process evolves. Expanding on this relationship, creativity embodies the imaginative spark that ignites the innovation journey. It is the inception of unconventional thoughts and concepts that, when nurtured, have the potential to pave the way for ground breaking developments (Alves, Marques, Saur & Marques, 2007); (Chulvi, Mulet, Chakrabarti, López-Mesa & González-Cruz, 2012). This initial phase sets the stage for innovation by serving as the wellspring from which novel solutions can be drawn. Once creative ideas are harnessed and refined, they undergo a transformative process that culminates in the manifestation of innovative products, processes, or services. Therefore, while creativity sparks the genesis of inventive thought, innovation represents the tangible realization and application of these creative concepts, ultimately driving progress and advancement.

6.2.2 TRIZ

TRIZ (Theory of Inventive Problem Solving) is a methodological approach that integrates systematic problem-solving techniques with analysis and forecasting methods gleaned from the study of invention patterns in worldwide patent data. Offering 40 principles and 76 standards, TRIZ facilitates problem encapsulation, allowing for the matching of solutions to address specific issues. Problem formulation stands as a cornerstone within the TRIZ framework (Royzen, 2014).

The systematic methodology of TRIZ serves as a guiding framework for individuals engaged in problem-solving endeavors, steering them away from arbitrary explorations within the solution space. TRIZ not only prescribes a deliberate exploration within a confined space to unearth innovative solutions but also directs problem solvers toward strategies that have proven effective in analogous situations, whether within the same domain or entirely disparate application realms (Altshuller 1996).

As outlined by (Rantanen & Domb, 2002); (Banciu, Draghici & Grozav, 2010), the fundamental principles of TRIZ center on the recurrence of problems and solutions across various domains, the repetition of patterns in technical evolution, and the utilization of innovations employing scientific effects beyond their original fields of development. These principles can be grouped into three main categories: tools designed for problem modeling, such as Substance-Field Analysis; tools aimed at overcoming mental resistance during problem formulation and interpretation tasks, like Ideal Final Result, Multi-screens, or the Nine-box approach; and tools intended for addressing general problems, including Scientific Effects, Principle Separation, and the Contradiction Matrix (Regazzoni, Pezzotta, Persico, Cavalieri & Rizzi, 2013). TRIZ, thus, provides a structured and proven approach, incorporating a range of tools tailored for problem analysis, overcoming psychological barriers, and formulating innovative solutions with a solid foundation in past successes (Motyl & Filippi, 2014).

6.2.3 C-K

The C-K (Concept-Knowledge) design theory, introduced by Hatchuel and Weil, integrates various design traditions, including systematic design, axiomatic design, and creativity theories. It offers a comprehensive approach to design reasoning, presenting a unified framework that depicts design as the interaction between two interrelated spaces: the realm of concepts (C) and the domain of knowledge (K). In this theoretical framework, the concept space represents the realm of the unknown, where ideas reside solely in potentiality. Design processes aim to navigate from undecidable propositions to established truths by jointly expanding both the C and K spaces. This theory diverges from conventional design approaches by characterizing design reasoning as a progression of expansion processes, guiding the generation of novel concepts (Hatchuel & Weil, 2003).

A critical aspect of C-K theory lies in its description of the reasoning process of designers as they create new objects, be products, services, or processes. This theoretical framework not only provides explanatory power but also offers generative mechanisms to overcome cognitive obstacles, enhancing innovative capabilities.

Contrary to the perception that the Concept space is unstructured, it is highly organized, representing ideas in a concept tree. The Knowledge space complements the Concept space, housing the information necessary to imagine or design new concepts, highlighting the interplay between the known and the unknown.

The genesis of C-K theory was motivated by the perceived limitations of existing design theories. Addressing these limitations, C-K theory introduces a domain-independent approach, allowing action on unknown objects and redefining known objects during the process (Hatchuel & Weil, 2009).

At the core of C-K theory lies the meticulous delineation of a design scenario, commencing with the articulation of a brief as a conceptual entity, thereby establishing a formal demarcation between the realms of concept and knowledge. This foundational phase is paramount for navigating the complex terrain of design endeavors.

C-K Design Theory extends its applications to the field of AI, offering principles that can be potentially applied to the design and development of AI systems. The iterative expansion of C and K spaces aligns with the generative process in AI system design, where new concepts (C-space) are created and existing knowledge (K-space) is applied.

Furthermore, in machine learning, the principles of C-K theory can be translated into the design of algorithms and models, with the concept space representing possible models and the knowledge space encompassing existing knowledge in the domain. Similarly, in data science, C-K theory provides a foundation for designing data analysis strategies, with the concept space representing potential strategies and the knowledge space encapsulating existing data analysis knowledge.

In summary, C-K theory stands as a domain-independent formalization of design, explaining invention, creation, and discovery within the same framework as design processes. Its applications extend across various fields, and the potential integration with AI, machine learning, and data science opens new avenues for innovation and design exploration.

6.2.4 AI

Artificial Intelligence (AI) has become a transformative force in the realm of design, revolutionizing how we approach information integration, data analysis, and decision-making processes (Verganti et al., 2020). As a collaborative tool, AI empowers human creativity, serving as an ally in automating aspects of problem-solving and thereby fostering the generation of innovative and efficient solutions (West & Allen, 2018), (Anantrasirichai & Bull, 2022). Nevertheless, the integration of AI into design necessitates a nuanced consideration of ethical implications and responsible application practices (Singh & Duo, 2023).

Innovation management also stands to benefit significantly from the integration of AI technologies (Gama & Magistretti, 2023). Across various sectors, AI is reshaping innovation capabilities by redefining information integration, data analysis, and decision-making paradigms (West & Allen, 2018).

AI's potential extends to enhancing both the Concept and Knowledge spaces within the C-K theory framework (Hatchuel & Weil, 2009). By aiding in problem identification and formulation while facilitating pattern recognition for solutions, AI contributes to managing and unveiling knowledge elements essential for exploration. However, the integration of AI into C-K theory presents challenges related to the quality of initial concepts and the diverse expertise levels among users.

Similarly, AI's integration into the TRIZ problem-solving process promises increased innovation and efficiency. Through automation, AI streamlines aspects of problem-solving, thereby enhancing TRIZ's effectiveness and adoption rates. Nonetheless, this integration introduces complexities regarding TRIZ principles and formalization, necessitating careful navigation (Ni, Samet & Cavallucci, 2021).

6.2.5 Integration of TRIZ and C-K Design Theory

During the concept design phase, design solutions are formulated to fulfill the entirety of design prerequisites. The objective of this stage is to produce a plethora of ideas without engaging in any form of evaluation. Various methods to enhance creativity, such as brainstorming, TRIZ, or alternative idea-generation approaches, may be employed to aid in the generation of innovative concepts. The primary goal remains to foster a diverse array of ideas at this juncture, promoting an open and uninhibited exploration of potential design solutions.

TRIZ and C-K are both recognized as theories aimed at facilitating innovation. While C-K initially served as a descriptive theory of innovation, it has evolved over time into methods with a more operational focus. In recent years, researchers have delved into the distinctions and potential synergies between TRIZ and C-K (Senghor, Ndiaye & Gaye, 2023).

Dubois et al. (2019) conducted a study examining the disparities and complementarities between C-K and TRIZ. They offer a theoretical exploration of these distinct approaches and propose an innovative interpretation of TRIZ within the framework of C-K theory. Viewing C-K as a design theory and TRIZ as a theory of inventive problem-solving, they explore whether these theories diverge, conflict, or complement each other (Dubois et al., 2019).

Another research endeavor aimed to integrate the two methodologies, offering a methodological framework for their more efficient utilization. This effort resulted in a unique perspective on TRIZ within the context of C-K theory, suggesting ways in which the two methods can be effectively combined (Boujut & Lincas, 2009).

Motyl and Filippi (2014) have demonstrated the amalgamation of diverse tools for enhancing creativity, drawing from both the C-K theory and TRIZ, within the context of medical device design procedures. Their findings suggest a plausible synergy between TRIZ and C-K theory. Specifically, C-K theory emerges as a valuable approach for organizing design reasoning, particularly during the conceptual phases of product innovation and development. Furthermore, it proves adept at delving into market information, presenting a multifaceted utility. On the other hand, TRIZ exhibits its strengths in systematically formulating and refining design problems (Motyl & Filippi, 2014).

The scrutiny of the case study underscores the potential for a more methodical exploration of the design space, particularly during the conceptual development phase, while also accounting for knowledge requirements. The judicious application of both C-K theory and TRIZ accentuates their efficacy as tools for enhancing creativity. This not only structures the design space but also facilitates the exploration and interpretation of market information, along with the adept management of technology forecasting. This integration thus unfolds as a robust strategy for optimizing the creative potential and strategic maneuvering in the intricate landscape of medical device design (Motyl & Filippi, 2014).

The integration of TRIZ and C-K methodologies offers a promising avenue for enhancing design efficiency, as proposed by Boujut and Linces (2009). While C-K prioritizes design reasoning and mapping the structure between knowledge and concept spaces, TRIZ introduces valuable tools for fostering creativity and problem-solving (Boujut & Lincas, 2009). By merging these methodologies, we aim to capitalize on the strengths of each approach to overcome their respective limitations.

C-K theory emphasizes the importance of starting with a conjecture aligned with market requirements, termed a ‘semantic disjunction,’ and then developing the knowledge side through existing or newly constructed knowledge spaces (K-K operators). However, C-K lacks explicit tools to support the creative process. This is where TRIZ complements C-K by offering formalized design heuristics, particularly through its contradiction matrix, which serves as a robust heuristic within the knowledge space (K-Space). TRIZ tools guide designers in progressively formulating problems in more abstract terms, fostering new semantic connections and presenting innovative propositions within the concept space (Boujut & Lincas, 2009).

Moreover, TRIZ's contradiction mechanism plays a crucial role in stimulating creativity within the concept space. While standard solutions retrieved from the TRIZ principles database may not directly align with the specific design problem's grammar, they act as cognitive triggers, sparking semantic disjunctions and facilitating the generation of novel concepts (Boujut & Lincas, 2009). This transition from standard solutions to innovative concepts underscores the transformative potential of integrating TRIZ principles into the C-K theoretical framework.

In essence, by incorporating TRIZ into the C-K methodology, we aim to enhance design reasoning and problem-solving capabilities. TRIZ's structured approach to problem formulation and its array of formalized design heuristics complement C-K's emphasis on design reasoning, enabling designers to navigate the design space more effectively and generate innovative solutions that address complex design challenges (Boujut & Lincas, 2009).

6.2.6 Application of AI (ChatGPT) in C-K Design Theory

ChatGPT, developed by OpenAI, stands as a remarkable artificial intelligence technology known as Conditional Generative Pre-trained Transformer. Leveraging supervised machine learning and reinforcement learning techniques, ChatGPT empowers computers to autonomously generate natural language conversations. Utilizing the transformer architecture and trained on vast conversation datasets from diverse sources, ChatGPT embodies a sophisticated language generation system (Bahrini et al., 2023).

In a study involving ten qualitative researchers, ChatGPT emerged as a valuable collaborator for thematic analysis. It significantly enhanced coding efficiency, facilitated initial data exploration, provided detailed quantitative insights, and assisted comprehension, particularly for non-native speakers and non-experts (Royzen, 2014).

Moreover, the integration of AI, including systems like ChatGPT, into educational settings has garnered considerable attention. These AI systems offer personalized responses promptly, catering to individual student needs. By delivering immediate feedback and simplifying complex concepts, AI technologies enrich the learning experience, fostering a deeper understanding among students (Chiu, 2021).

In the C-K design theory, AI can help in identifying and formulating problems through generic frames enabling the use of patterns of solutions. The initial phase of the methodology commences with the establishment of the Knowledge space (K space) by systematically identifying available knowledge elements at the given moment. AI can potentially increase the quality of information and knowledge in the K-space in the C-K design theory. It can also help in managing the knowledge available at the beginning of exploration and reveal knowledge elements that might be hidden (Dubois, Lutz, Rousselot & Caillaud, 2005).

This marks a critical juncture where the application of Artificial Intelligence (AI) significantly contributes by acquiring extensive, pertinent, and systematically classified data. The utilization of AI in this context directly enhances the accessibility and richness of knowledge, enabling a more comprehensive understanding of the existing informational landscape. This, in turn, lays the foundation for a robust K space that serves as a reservoir of relevant insights and information.

Moreover, the Concept space (C space) undergoes initiation through the outcomes generated by the AI-based TRIZ framework. The integration of AI into the TRIZ methodology not only expedites the ideation process but also introduces a level of sophistication in the conceptualization phase. The AI-driven TRIZ framework becomes instrumental in suggesting innovative concepts that align with the identified problem space. This synergistic approach not only leverages the power of AI for efficient knowledge gathering but also integrates it seamlessly into the creative ideation process. As a result, the interplay between the AI-enhanced K space and the conceptually enriched C space establishes a dynamic and harmonized framework, fostering a more informed and creative design process.

6.3 Methodology

In this section, we delve into the implementation of artificial intelligence (AI) for the generation of initial concepts. This involves posing a predefined set of questions to an AI tool, such as ChatGPT, with the outcomes of each step serving as inputs for subsequent stages. By formulating specific questions, we open the door to a broad spectrum of users, allowing even those without specialized knowledge of TRIZ tools to leverage the proposed model. This article employs four renowned TRIZ tools, spanning from problem formulation to concept generation; nevertheless, the author suggests additional sets of TRIZ tools in separate publications.

As elucidated earlier, the AI tool responds to each question based on an extensive knowledge repository available on the internet, ensuring the production of high-quality concepts.

However, it is imperative to emphasize that the feasibility of each concept necessitates validation by users and experts. In many instances, the application of an otherwise excellent concept may be constrained by existing limitations, such as available infrastructures or market requirements.

In the final stage, the selected initial concepts undergo application within the C-K theory, where they are further expanded, refined, and adjusted in alignment with precise requirements and infrastructural considerations. This iterative process ensures seamless integration of AI-generated concepts into the broader framework of the C-K theory, optimizing their alignment with the specific needs and contextual intricacies of the design problem.

6.3.7 Hierarchical procedure based on function analysis and standard solution tools

This branch of the TRIZ problem-solving framework contains four sections named Hazards or cause of the problem map, ideal outcome, Su-field analysis and standard solutions.

In the initial stages of the TRIZ methodology, a fundamental prerequisite is to deeply comprehend and define the scope of the problem under scrutiny. This entails delineating the problem's boundaries, identifying its key constituents, and pinpointing the inherent contradictions that impede optimal resolutions. By articulating the problem with precision, TRIZ practitioners can channel their efforts towards the most critical facets, streamlining the problem-solving process for enhanced efficiency and effectiveness. This pivotal step aligns seamlessly with the TRIZ principle of 'problem formulation,' underscoring the significance of expressing the problem in a comprehensive and unequivocal manner. The establishment of a well-defined problem serves as the cornerstone for subsequent TRIZ stages, including the identification of inventive principles and the generation of innovative solutions. As emphasized by Altshuller, the progenitor of TRIZ, a clearly defined problem is indispensable for unearthing inventive solutions and surmounting the barriers that confine conventional problem-solving methodologies (Altshuller, 1996).

Moving forward, the procedural sequence involves presenting ChatGPT with a comprehensive problem description, accompanied by the inquiry, 'What are the main challenges related to the mentioned problem?'. This structured approach generates multiple answers at each step, creating a hierarchically organized framework where the selection of one answer dictates the subsequent question. Termed as Xij, this hierarchical methodology signifies the i-th step and the j-th generated answer. For instance, X12 corresponds to the second generated answer in response to the first question.

Consider the example of Xij where i=1 and j=2, representing the second answer in the initial step. Subsequent steps can be navigated based on this specific answer, exploring potential solutions. However, the methodology provides flexibility, allowing users to opt for a different answer, such as X11, in subsequent iterations, facilitating the exploration of alternative feasible solutions.

To illustrate further, envision Xij as a solution space in a mathematical model, with the user seeking to maximize a specific objective function within this space. Each iteration through the procedure, with varying Xij values, corresponds to the exploration of distinct regions in the solution space. This iterative nature empowers users to traverse through various combinations of generated answers, refining their approach with each cycle.

To maintain simplicity and manageability, leveraging ChatGPT capabilities is recommended to restrict the number of generated answers. This limitation ensures a focused exploration of the solution space. Essentially, the methodology offers a dynamic and iterative problem-solving process, enabling users to systematically navigate the hierarchy of generated answers in pursuit of the most viable and innovative solutions.

The subsequent questions in the TRIZ process delve into further analysis, addressing aspects that require improvement to solve specific Xij and identifying any constraints or requirements for each aspect. This comprehensive approach scrutinizes the challenges of the problem, discerning aspects that demand resolution, and considering constraints and requirements.

The procedure also involves two key inquiries 'What facets of the issue need enhancement to resolve Xij?' and 'Are there any particular limitations or prerequisites for each facet?' These questions facilitate a thorough examination of the problem and its influencing factors by identifying the primary hurdles, pinpointing the elements of the problem that require resolution, and acknowledging the constraints and requirements of the problem

In the subsequent stage of the TRIZ problem-solving process, the spotlight turns to the identification of succinct mini-problems, guided by the command, 'Based on the previous answers, provide a simply stated mini-problem that addresses solving constraints of this aspect and mention related desired outcomes based on TRIZ ideal outcome and ideal system concepts.' These mini-problems serve to accentuate specific contradictions within the broader problem context. TRIZ advocates for clear and concise articulation of these contradictions, involving the definition of conflicting elements within the system and envisioning the ideal situation in the absence of these contradictions. TRIZ introduces the concept of an 'Ideal Final Result' (IFR), serving as a guiding beacon for problem resolution, urging innovators to envision an ideal system where conflicts are eradicated or coexist harmoniously. Aligning with TRIZ principles, the consideration of ideal outcomes and ideal system concepts fosters a systematic approach to innovation, transcending incremental improvements. These foundational steps form the bedrock of the framework and are reiterated for the remaining roots.

Su-field analysis, also known as TRIZ function analysis, is a technique within TRIZ that focuses on understanding and optimizing the interactions between system elements. It involves breaking down a system into its essential components and examining the relationships between them, specifically identifying the substance-field interactions. By analyzing these interactions, innovators can gain insights into the core functions and conflicts within a system, facilitating the identification of more targeted and effective solutions.

The analysis operates through three distinctive modes, each offering unique insights into the system's structure and behavior:

Adding a Substance or Field:

In this mode, the focus is on the augmentation of elements within the system. By introducing new substances or fields, analysts seek to understand how these additions can positively impact the system's performance. 'Analyse the mini-problem (Xij) with the substance-field model and provide solutions to solve the problem by adding any substance or field.' involves enhancing existing functionalities, fortifying components, or introducing novel elements to address specific challenges. The goal is to explore opportunities for improvement and innovation by strategically incorporating new variables into the system.

Removing a Substance or Field:

The removal mode directs attention towards the elimination of specific substances or fields within the system and is questioned as 'Analyze the mini-problem (Xij) with the substance-field model and provide solutions to solve the problem by removing any substance or field.'. By dissecting the system and identifying components that may not be essential or could be hindering optimal performance, analysts aim to streamline and simplify the system. This process can lead to increased efficiency, reduced complexity, and a more focused design. Removing unnecessary elements or addressing detrimental interactions can pave the way for streamlined processes and improved overall system functionality.

Changing a Substance or Field:

This mode involves a dynamic exploration of how alterations to existing substances or fields can impact the system. By introducing modifications to the properties or characteristics of certain elements, analysts aim to understand the potential ripple effects throughout the system. This can include changes in material properties, physical attributes, or functional parameters. The objective of the question 'Analyze the problem (Xij) with the substance-field model and provide solutions to solve the problem by changing any substance or field.' is to identify creative solutions by manipulating key elements, fostering adaptability, and addressing challenges through strategic alterations.

The Su-Field analysis, with its three modes, serves as a versatile tool for problem-solving and innovation across various domains. Its application extends to engineering, design, and process optimization, offering a structured approach to dissecting and improving complex systems. By systematically applying these modes, practitioners can uncover latent opportunities, identify inefficiencies, and devise inventive solutions that contribute to the enhancement of system performance. Furthermore, Su-Field analysis aligns seamlessly with the broader TRIZ framework, enriching the problem-solving repertoire with a nuanced understanding of substance-field interactions and their transformative potential within intricate systems.

Additionally, the application of standard solutions is a key aspect of the TRIZ framework. The concept of standard solutions in TRIZ refers to a set of proven, generalized principles or approaches to overcoming common engineering challenges. There are 76 standard solutions that have been derived from the analysis of inventive solutions across diverse technical domains. These standard solutions provide a repository of knowledge, offering a structured set of strategies for resolving recurring problems and contradictions in different systems. The solution cased on this tool is extracted by 'Reinforced the generated answer Su-Field answer (Xij) through TRIZ 76 standard solution tool.'

By combining Su-field analysis and standard solutions, TRIZ practitioners can systematically analyze the functional aspects of a system and leverage a comprehensive set of proven strategies to enhance the quality and effectiveness of their solutions. This approach aligns with the TRIZ principle of applying patterns of success to guide inventive problem-solving.

6.3.8 Improved C-K theory

The initial phase of the process unfolds with the generation of concepts facilitated by the innovative framework empowered by AI. Once these concepts materialize, their feasibility undergoes rigorous scrutiny by both experts and users. Through a seamless transition, the selected concepts then traverse the C→C operation, propelling the generation of additional concepts within the C-Space. It is crucial to note that this iterative procedure operates concurrently through both C→K and K→C operations, showcasing the multifaceted role of AI in enhancing the C-K framework.

Users are presented with a dual approach within this augmented C-K landscape. On one hand, they retain the option to rely on their pre-existing knowledge, adhering to the traditional structure of C-K theory. On the other hand, the infusion of AI tools provides users with the unprecedented ability to leverage advanced functionalities evaluating, comparing, strengthening, or even generating entirely new concepts. This expanded cognitive toolkit, empowered by AI, furnishes users with a spectrum of strategic choices, enriching the decision-making process and unlocking innovative possibilities within the design space.

In essence, the infusion of AI into the fabric of C-K theory not only narrows the gap between K-Space and C-Space as shown in Figure 4.1 but also introduces a transformative dynamic, empowering user to navigate seamlessly between the traditional and AI-enhanced dimensions of the C-K framework. This synthesis of human expertise and AI capabilities positions C-K theory at the forefront of innovative design methodologies, offering a holistic and adaptive approach to problem-solving and concept generation.

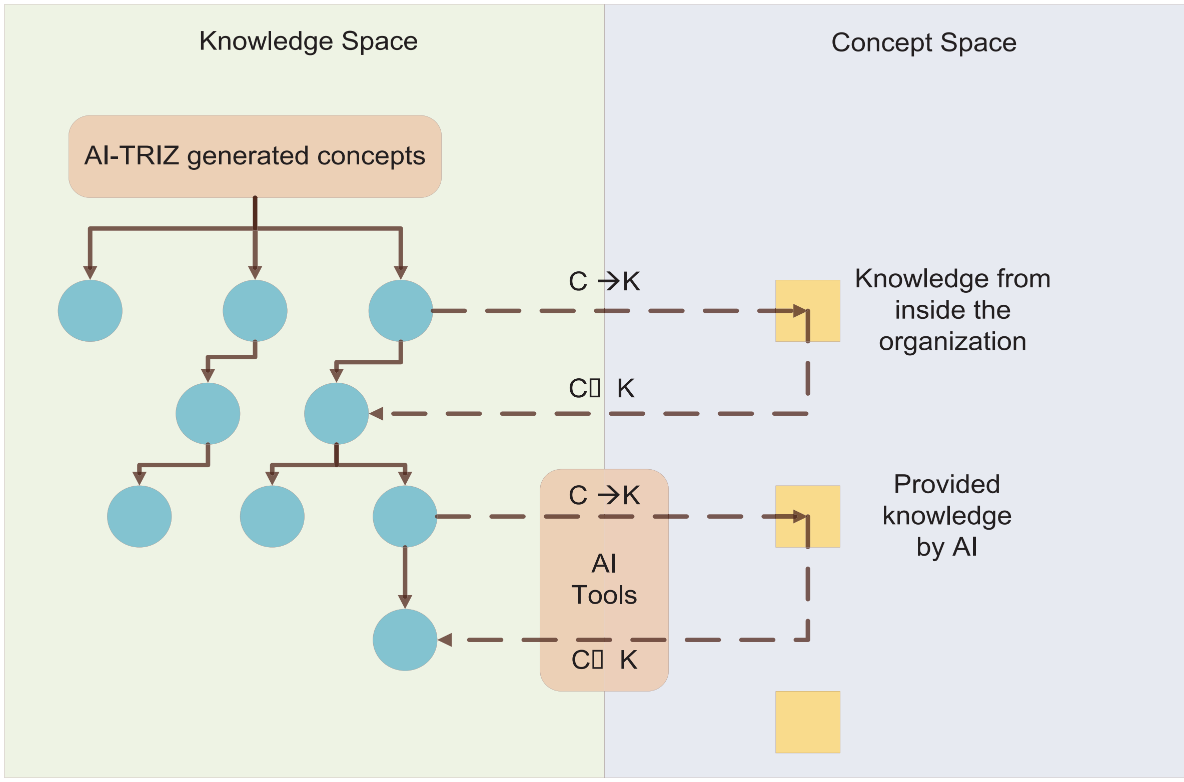

Figure 6.1 The role of AI in enhancing C-K framework

6.4 Case study

The issue of contaminated toilet seats, particularly in public areas, poses significant health risks due to the potential transmission of various contaminants such as bacteria, viruses, and skin cells. Public toilets serve a large number of people daily, increasing the likelihood of cross-contamination and the spread of infectious diseases. Traditional toilet seats, which require users to make direct contact with the surface, exacerbate this problem. Despite efforts to maintain cleanliness through regular cleaning protocols, manual sanitation methods may not always be sufficient to eliminate all pathogens, leaving users vulnerable to potential infections.

One major threat associated with contaminated toilet seats is the transmission of infectious diseases. Bacteria such as E. coli, Salmonella, and Staphylococcus aureus can thrive on toilet surfaces and cause gastrointestinal illnesses, urinary tract infections, and skin infections upon contact with the skin. Additionally, viruses like norovirus, hepatitis A, and influenza can survive on surfaces for extended periods, posing a risk of transmission to subsequent users. These pathogens can be easily transferred from contaminated toilet seats to users' hands and other body parts, leading to the spread of infections within the community.

Furthermore, the presence of contaminants on toilet seats can contribute to the emergence of antibiotic-resistant strains of bacteria. Overuse or misuse of antibiotics can promote the development of resistant bacteria, which can persist on surfaces and pose a serious public health threat. Antibiotic-resistant infections are challenging to treat and may result in prolonged illness, increased healthcare costs, and higher mortality rates. Therefore, reducing the transmission of bacteria through contaminated toilet seats is crucial in mitigating the spread of antibiotic resistance and preserving the effectiveness of antimicrobial treatments.

Another concern is the potential psychological impact of using unhygienic toilet facilities, particularly in public settings. Fear of exposure to contaminants on toilet seats may lead to anxiety and discomfort among users, affecting their overall well-being and mental health. Moreover, the perception of poor sanitation practices in public restrooms can damage the reputation of establishments and deter visitors, impacting business operations and public trust. Therefore, addressing the issue of contaminated toilet seats is not only essential for physical health but also for promoting a sense of safety and hygiene in public spaces.

To address the challenges associated with contaminated toilet seats, three main areas of focus have been identified as Effective Sanitation Technology, Integration into Existing Infrastructure, and Maintenance and Sustainability although, each face related constraints and requirements.

Increased Sanitation Efficiency Without Compromising User Experience: Develop an automated sanitation toilet seat system that efficiently eliminates contaminants while providing a seamless and comfortable user experience. Implement advanced sanitation technologies, such as UV-C light disinfection or chemical-free cleaning solutions, to ensure thorough sanitation without causing discomfort or inconvenience to users.

Seamless Integration with Existing Infrastructure and Operations: Integrate the automated sanitation toilet seat system seamlessly into existing restroom infrastructure and operational workflows. Design the system to retrofit easily onto standard toilet models, requiring minimal modifications to plumbing or electrical systems. Ensure compatibility with existing restroom maintenance procedures to streamline implementation and reduce disruption to facilities.

Sustainable and Cost-Effective Maintenance Practices: Establish sustainable and cost-effective maintenance practices for the automated sanitation toilet seat system to ensure long-term functionality and reliability. Employ smart touchless sensors to command the cleaning procedure. Utilize eco-friendly sanitation methods and materials to minimize environmental impact and reduce operational costs over time.

A Mini-Problem Statement has been defined, in alignment with TRIZ ideal outcome and ideal system concepts, to guide the problem-solving process: Developing an Automated Sanitation Toilet Seat Solution that Effectively Eliminates Contaminants while Seamlessly Integrating with Existing Infrastructure and Operations, and Maintaining User Comfort and Convenience.

Analyzing the mini-problem using the TRIZ substance-field model involves identifying the substances (elements or components) and fields (interactions or forces) involved in the problem and proposing solutions to address the constraints. Some of these solutions as initial concepts for C-K procedure are represented in the Table 6.1.

These initial concepts are applied to the C-K process. During the C-K process some of these concepts have been abandoned and some expanded to be matched with the mini-problem and evaluated by the experts to be according to accessible technology, market requirements, and final product desired price interval.

Table 6.1 ChatGPT generated concepts based on substance-field model

Su-fi Mode	Generated Concept
Adding substance or field	Integration of UV-C Light Disinfection Technology
	Utilization of Self-Cleaning Nanotechnology Coatings
	Implementation of Sensor-Activated Cleaning Systems
	Development of Biodegradable Sanitation Solutions
Removing substance or field	Remove the Need for Chemical Disinfectants
	Eliminate Manual Controls with Fully Automated Operation
	Integrate Energy-Efficient Sanitation Technologies
	Streamline Material Selection for User Interface Components
Changing substance or field	Change the Sanitation Mechanism Substance to Photocatalytic Materials
	Replace Traditional User Interface Components with Holographic Interfaces
	Change the Structural Material to Antimicrobial Polymer Blends
	Replace Electrical Power with Piezoelectric Energy Harvesting
	Change Mechanical Forces with Pneumatic Actuators

Integration of UV-C Light Disinfection Technology:

Strengths: Ultraviolet (UV) light is used to kill microorganisms on the toilet seat. Automated systems use UV-C light, which has a shorter wavelength and higher energy, to effectively destroy bacteria and viruses without the need for chemicals, providing thorough sanitation. The integration into the seat ensures ease of use and minimal disruption to the user experience.

Weak Points: UV-C light may have limited penetration capabilities, requiring multiple exposure points or longer exposure times for effective sanitation. Additionally, UV-C light can cause eye and skin damage if not properly contained.

Solution: Positioning UV lights within the toilet seat to effectively cover the entire seating area presents a complex challenge. While UV-C light is known for its effectiveness in eliminating bacteria and viruses on surfaces, achieving comprehensive coverage requires direct exposure to the light for a specific duration. However, certain areas of the toilet seat, such as hard-to-reach crevices or hidden spots, may not receive sufficient UV exposure. To address this issue, an innovative solution involves integrating UV-C light emitters directly into the toilet seat while covering it with a soft layer. Rather than employing multiple exposure points to cover the entire seat, this approach concentrates UV radiation within a confined space. The toilet seat is designed to rotate, allowing the soft cover to pass under the concentrated UV light area, ensuring thorough sanitization. By confining the UV light to a closed area within the seat, this solution enhances user safety and minimizes the risk of eye and skin damage. Additionally, the rotating mechanism ensures that all parts of the toilet seat receive adequate UV exposure, effectively eliminating harmful pathogens.

Implementation of Sensor-Activated Cleaning Systems:

Strengths: Sensors detect user presence and activate cleaning mechanisms, ensuring timely sanitation without user intervention. This solution enhances user convenience and reduces reliance on manual cleaning procedures.

Weak Points: Sensor malfunction or false activation may lead to unnecessary cleaning cycles, potentially causing inconvenience or wasting resources. Additionally, the complexity of sensor systems may increase production and maintenance costs.

Solution: Replace manual controls with fully automated operation, allowing users to activate cleaning mechanisms automatically before each use. Touchless sensors eliminate physical touchpoints, thereby minimizing the risk of surface contamination and enhancing the user experience. The cleaning process duration and procedure are precisely regulated via a circuit board, ensuring optimal efficiency and effectiveness. These sensors offer an economical solution and prevent cross-contamination by eliminating the need for multiple users to touch the same surface.

Remove the Need for Chemical Disinfectants:

Strength: Reduces the risk of chemical exposure and minimizes maintenance requirements associated with refilling or replacing disinfectant solutions.

Weakness: May require alternative sanitation methods with equal effectiveness, such as UV-C light or ozone disinfection, which could involve higher initial costs or energy consumption.

Solution: Toilet seats can accumulate dirt from various sources, including urine drops, dust, and other contaminants, necessitating thorough cleaning before UV sanitation can occur. Automated toilet seat systems have been developed to address this issue, incorporating self-cleaning mechanisms that operate after each use. These mechanisms typically utilize water jets and a plastic blade to effectively cleanse the toilet seat surface. In these systems, high-pressure water is dispensed through an electric valve to thoroughly wash the seat surface. Following the water wash, a specially designed blade is deployed to remove any excess water and residual contaminants from the surface, ensuring optimal cleanliness. This automated process not only enhances hygiene but also simplifies maintenance, providing users with a convenient and sanitary restroom experience.

Integrate Energy-Efficient Sanitation Technologies:

Strength: Minimizes energy consumption and operating costs by utilizing efficient sanitation methods such as LED-based UV-C light or low-power sensors.

Weakness: Initial investment in energy-efficient technologies may be higher, and there may be limitations in sanitation effectiveness compared to more energy-intensive methods.

Solution: The system boasts electronic and electric components with exceptionally low power consumption rates. This feature not only offers energy efficiency but also facilitates the integration of rechargeable batteries. This enables the device to function effectively in areas with restricted access to power outlets or where wiring may not be feasible. Despite the potential for higher initial investment in energy-efficient technologies, the utilization of rechargeable batteries presents a sustainable solution for powering the device, addressing concerns related to sanitation effectiveness and energy consumption.

Streamline Material Selection for User Interface Components:

Strength: Simplifies design and reduces manufacturing costs by standardizing materials for user interface components.

Weakness: Limited flexibility in material selection may compromise aesthetics or durability in certain applications.

Solution: Silicone, Thermoplastic elastomers (TPE), Polyurethane (PU), Ethylene-vinyl acetate (EVA) foam, Polyethylene (PE), and Polypropylene (PP) are some materials that can be used to produce a cover for toilet seats that are durable, anti-static, anti-bacterial, elastic and strong enough to be rotated by an electromotor in an oval shape for sanitation procedure by a fixed UV light after each user leave toilet. However, Polypropylene (PP) could be the best choice among the mentioned materials by considering the mentioned characteristics.

Polypropylene (PP) is a thermoplastic polymer known for its durability and resistance to chemicals, moisture, and impact. It can be manufactured in various forms, including injection molding, which makes it feasible for mass production. PP also possesses anti-static and anti-bacterial properties, which are desirable for toilet seat covers. Additionally, PP is relatively cost-effective and widely available in the market.

While materials like silicone, thermoplastic elastomers (TPE), and polyurethane (PU) may offer some of the required characteristics, they might be more expensive and less readily available compared to PP. Ethylene-vinyl acetate (EVA) foam, on the other hand, may not be durable enough to withstand the mechanical requirements of being rotated by an electromotor in an oval shape.

Hence, considering all aspects, Polypropylene (PP) is the best choice for a toilet seat cover that meets the mentioned characteristics, along with cost-effectiveness, manufacturing feasibility, and availability.

Figure 6.2 and Figure 64.3 depict the initial design of an automated sanitation toilet seat, showcasing both front and top views along with its various constituent parts. The primary objective of this design iteration is to achieve a smaller and more compact form factor while ensuring compatibility with existing toilet seat designs and maintaining user comfort. To enhance overall sanitation efficacy, the design integrates UV-C light with other cleaning methods. As illustrated, the self-cleaning mechanism utilizes water jets in conjunction with UV-C light for comprehensive drying and sanitation procedures.

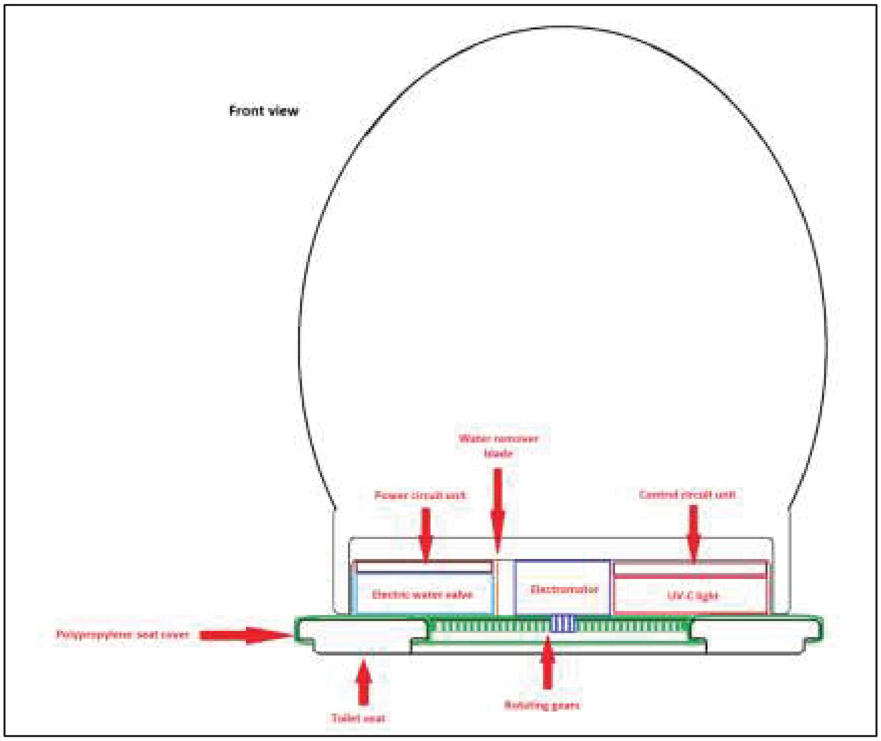

Figure 6.2 Front view of the designed seat

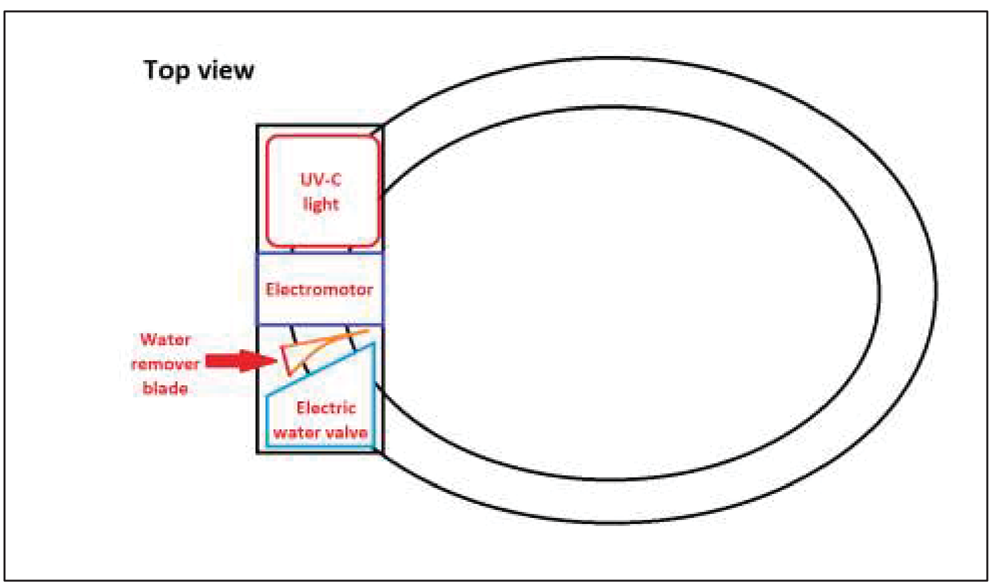

Figure 6.3 Top view of the designed seat

Instead of disposable seat covers, the design incorporates a rotating liner that undergoes washing and sanitation procedures after each use. This rotating liner not only eliminates the need for disposable cover rolls but also enables focused UV-C exposure in specific areas. The UV-C light is strategically positioned within a covered area at the back of the seat to prevent reflections and potential user exposure. Moreover, maintaining an optimal distance between the liner and UV-C source ensures maximum intensity.

Additionally, a water remover blade is integrated to collect any residual water and channel it towards the toilet bowl. User interaction with the system is facilitated through a touchless button, enhancing ease of use and user-friendliness. This innovative design requires minimal maintenance and eliminates the need for disposable seat cover rolls, making it a sustainable and eco-friendly solution. By eschewing chemical materials and generating zero waste during operation, it aligns with sustainability goals and promotes environmental stewardship.

6.5 Conclusion

In conclusion, the integration of TRIZ and C-K methodologies, alongside AI tools like ChatGPT offers a promising pathway to enhance design efficiency and creativity. A novel framework augments the C-Space with high-quality initial concepts and enriches the K-Space with extensive knowledge obtained through AI tools, strategically formulated based on TRIZ specifications. This innovative integration aims to overcome the limitations of traditional approaches and elevate the effectiveness of the C-K design theory.

By incorporating TRIZ into the C-K methodology, we aim to enhance design reasoning and problem-solving capabilities. TRIZ's formalized design heuristics, particularly through its contradiction matrix, serve as robust tools within the knowledge space (K-Space), guiding designers in formulating problems in more abstract terms and fostering new semantic connections within the concept space (C-Space).

Furthermore, the utilization of AI, such as ChatGPT, significantly contributes to knowledge gathering and ideation processes. ChatGPT aids in identifying critical issues and guiding the formulation of initial concepts through Substance-Field analysis. This collaborative approach ensures that innovative solutions are generated while addressing specific requirements and constraints.

Our innovation, focused on developing a compact automated sanitation system, exemplifies the synergistic relationship between AI-enhanced K-Space and conceptually enriched C-Space. Insights obtained from ChatGPT continue to enrich the knowledge space, particularly in crucial areas such as material selection, thereby facilitating a more informed and creative design process.

In essence, the integration of TRIZ, C-K methodologies, and AI tools presents a dynamic and harmonized framework for design exploration and innovation. By leveraging the strengths of each approach and addressing their respective limitations, we can navigate the intricate landscape of design with greater efficiency and creativity, ultimately leading to the development of impactful solutions in diverse domains.

RECOMMENDATIONS

The findings of this research show that combining artificial intelligence with established creativity and innovation methods such as TRIZ and C–K theory has strong potential. The proposed frameworks demonstrate that AI can help reduce knowledge barriers and provide clearer guidance for both experienced users and beginners during the problem-solving process. At the same time, this research also highlights several areas that deserve further study before these frameworks can be fully applied in practice.

One important next step is to test these methodologies in a wider range of real-world settings. In this research, the frameworks were applied mainly in engineering and product design cases. Although the results were encouraging, their broader value can only be confirmed by applying them in other fields such as healthcare, energy systems, sustainability, and manufacturing. Since each of these areas has its own specific challenges, testing the framework in different contexts would help evaluate its flexibility and practical reliability.

Another useful direction for future work is to compare results produced with AI-supported frameworks against those developed without AI assistance. Such comparisons would make it possible to better measure the real contribution of AI in terms of creativity, solution quality, feasibility, cost-effectiveness, and speed of implementation. This would provide clearer evidence of where AI creates the greatest added value in innovation processes.

Future studies should also pay more attention to how users interact with and accept these AI-supported systems in professional environments. Even if a framework is technically strong, its success depends on whether users find it understandable, trustworthy, and easy to use.

By exploring these directions, future research can strengthen both the theoretical foundation and the practical impact of AI-assisted creativity frameworks. The long-term goal is to justify the proposed framework's reliability, accessibility, and ease of use, and expand it to cover other TRIZ tools. The suggested framework would improve the effectiveness of innovation activities while creating a stronger partnership between human creativity and machine intelligence.

CONCLUSION

This thesis explored how artificial intelligence can support the practical application of TRIZ and C–K theory. Across the four studies, a consistent observation emerged: although TRIZ and C–K theory provide well-established frameworks for structured creativity and problem-solving, their use in practice is often constrained by their complexity, reliance on expert knowledge, and a lack of clear procedural guidance. The aim of this research was therefore to examine how AI can function as a supportive interface, helping users navigate, interpret, and apply these methods in an easier and structured way.

The first study focused on a common difficulty associated with TRIZ, not being sure about the start point and appropriate tools to be used within the method. By incorporating a step-by-step guidance and AI-driven tools (ChatGPT) application, the study proposed a framework that leads users through the TRIZ process. The results suggest that such guidance can help users follow the logic of TRIZ more easily, particularly those with limited prior experience, without altering the underlying principles of the method.

The second study examined the application of the suggested framework in an engineering safety context, with a focus on issues related to driver visibility and distraction. This case demonstrated how structured AI assistance could clarify problem definitions, link them to potential solution directions, and support evaluation using explicit criteria. The results show that AI can assist practitioners in applying TRIZ more systematically in complex situations.

The third study shifted attention to the use of the “8 Trends of Technical Evolution.” In this case, ChatGPT was used to assist users in identifying and applying evolutionary patterns in design process. The findings indicate that AI-supported questioning can encourage users to consider alternative directions and broaden their exploration, making the trends more approachable across different technical contexts.

The fourth study explored the interconnection among AI, TRIZ and C–K. In this framework, AI enriches the knowledge space by helping users access relevant information and structures concept development. While TRIZ provides systematic problem-solving techniques, and C–K theory offers a comprehensive approach based on interconnection between concepts and knowledge spaces, AI acts as a facilitating element to connect these approaches.

Taken together, the four studies suggest that AI could improve useability and facilitate the application of TRIZ and C–K theory by offering structured guidance, access to relevant knowledge, and support throughout the reasoning process. Rather than replacing human judgment or expertise, AI helps users work through steps that are often difficult to manage, especially for those with limited methodological background.

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