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Denis Cavallucci
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Towards AI-Aided Invention and Innovation

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Denis Cavallucci · Pavel Livotov ·
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Editors

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Preface

As we stand on the brink of new horizons of innovation and discovery, the 23rd edition of the TRIZ Future Conference (TFC 2023) continued to foster critical discussions on the pressing issues that steer our scientific pursuits and societal evolution. Engaging with a rich tapestry of ideas and breakthroughs, we explored the themes that are shaping our contemporary dialogues and paving the way for our future.

For this edition of the TRIZ Future Conferences the program committee decided to highlight a number of topical themes that dominate current scientific knowledge production and have an impact on society. We received exactly 80 abstracts and selected 60 of them for full paper submission. These papers underwent a triple open review and we added a fourth review in conflicting situations. Each article was verified to have implemented required changes and finally 43 articles were accepted for publication in this volume.

At the heart of this edition is the confluence of the Theory of Inventive Problem Solving (TRIZ) and Artificial Intelligence (AI). As an increasingly significant thread in our scientific discourse, it prompts us to examine the synergies between Artificial Intelligence (AI) techniques and TRIZ methods. The goal is not only to automate invention and innovation tasks but also to augment the human intellect in complex problem-solving processes. This theme is supported by a rich array of 11 papers that shed light on the broad spectrum of supervised and unsupervised AI techniques, Large Language Models, and recently released OpenAI tools. Reflecting the nature of this exploration, some authors comment on this trend and discuss their vision of the evolving landscape. The consensus seems to be that the impact of AI on TRIZ is inevitable and profound - the evolution of TRIZ and AI are intertwined, influencing each other as they progress.

Sustainable development follows closely behind with 10 thought-provoking articles. This recurring theme underlines its continuing importance for our community. Combining TRIZ and sustainable development holds the potential to inspire environmentally friendly innovation and help us move towards a more sustainable future. The persistence of this theme in our discourse reaffirms our collective commitment to reducing environmental impact, designing products, and developing processes that are in harmony with our planet.

The next category, “General Vision of TRIZ”, represents a long-standing tradition of the TRIZ Future Conferences. Here, contributors share their unique perspectives on how to improve TRIZ by revisiting its basic principles or by introducing new approaches that could advance the theory and its applications.

The fourth theme observes the broader societal impact of TRIZ in less conventional fields such as marketing, strategy, social sciences, and writing. This influx may mark a milestone of maturity for the TRIZ community, shifting the lens from seeing TRIZ as merely a toolset to appreciating it as a paradigm that can shape our worldview and influence diverse fields.

The last but equally important category encompasses case studies. Although fewer this year, these real-world applications of TRIZ continue to provide valuable insights into its tangible benefits in industry and research. These case studies underscore the ongoing relevance of TRIZ and its potential to inspire and catalyze breakthroughs.

These five main conference themes encapsulate the broad spectrum of our community's intellectual engagement over the years and reflect the two pivotal forces reshaping our world - digitalization and preservation. As we look to the future, the question before us is whether human intellect and machine capabilities can merge to build a sustainable world. Our hope, and the objective of these scientific engagements, is to foster progress towards this vision by enabling scientists and engineers to leverage the power of AI to bridge the gap between complex problems and their solutions. This proceedings book concludes with an outlook chapter that describes the evolution of TRIZ and forecasts its possible development scenarios in the age of AI.

The implications of Artificial Intelligence on TRIZ are profound and multifaceted, and the scholarly work presented in this volume suggests that we are only scratching the surface of understanding the full potential of this intersection. The trend of merging TRIZ and AI not only forecasts a revolution in problem-solving methodology but also promises an exciting journey towards new frontiers of scientific exploration.

Firstly, the prospect of AI automating some elements of TRIZ implies a seismic shift in the way we approach problem-solving and innovation. AI algorithms can process vast amounts of data at unprecedented speeds, identifying patterns and generating insights that might elude human observers. When applied to the TRIZ methodology, this computational prowess could transform the concept of inventive problem-solving by enabling the automated generation of solutions. Such a development would not only accelerate the innovation process but also democratize access to inventive thinking by making it available to a wider audience.

Secondly, the potential role of AI in enhancing TRIZ reflects another layer of this fascinating dynamic. AI is capable not only of automating tasks but also of augmenting human abilities, offering tools to amplify our creativity, and deepen our problem-solving capacity. Machine learning algorithms, for instance, could be trained on a wealth of past inventive solutions, then used to suggest novel approaches to new challenges based on patterns identified in the data. This means we could move beyond simply automating TRIZ to actively enhancing it through AI, evolving it into a more powerful and versatile framework for innovation.

Yet, the integration of AI and TRIZ is not without its challenges. One potential area of concern is in the interpretability and transparency of AI processes. Known as the "black box" problem, this issue refers to the fact that AI algorithms, particularly complex ones like deep learning models, often produce output without a clear explanation of how they arrived at those results. Integrating such algorithms into TRIZ may compromise one of the key strengths of TRIZ - its transparency and the ability of practitioners to understand and learn from the process. Addressing this issue is likely to be a major area of focus in the ongoing development of TRIZ and AI fusion.

It's also important to remember that the purpose of TRIZ is to guide human creativity, not replace it. While AI can perform impressive feats of pattern recognition and prediction, it lacks the capacity for true understanding and the spark of inspiration that

often lies at the heart of inventive solutions. Therefore, the future of TRIZ and AI should not be seen as replacing the human element, but rather as enhancing it.

In conclusion, the fusion of TRIZ and AI holds great promise for the future. It's a progressive field, ripe with opportunities and challenges that researchers and practitioners are only beginning to explore. As we continue to delve into this complex and fascinating intersection, we invite and encourage an ongoing dialogue within our community, to share insights and experiences, and to collectively shape the path that TRIZ and AI will follow in the years to come. This collaboration of minds, just like the merging of TRIZ and AI, promises to lead us towards exciting, uncharted territories of discovery and innovation.

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AI and TRIZ



Mapping the Evolutionary Journey of TRIZ and Pioneering Its Next S-Curve in the Age of AI-Aided Invention

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Abstract. The Theory of Inventive Problem Solving (TRIZ) has revolutionized the space of innovation and problem-solving since its inception in the mid-20th century. This paper traces the evolutionary journey of TRIZ, exploring its development across different periods marked by S-Curves - a fundamental concept in TRIZ that represents the lifecycle of a system. It also examines the origin and evolution of TRIZ, from its basic principles' development to its global spread, computerization, and current integration into broader innovation management practices. This historical analysis underscores the flexibility and durability of TRIZ, demonstrating its capacity to navigate and shape various technological and methodological transformations throughout the years. As we chart this progression, we identify pivotal moments of growth, maturity, and transition, offering insights into the maturation and future trends of TRIZ. In the quest to predict the next S-Curve for TRIZ, we anticipate a potential shift towards AI-driven innovation, increased emphasis on sustainability, and further cross-disciplinary approaches. This paper invites a nuanced understanding of TRIZ's past, present, and emerging directions, contributing to a more anticipatory framework for problem-solving and innovation in the 21st century.

Keywords: TRIZ · Theory of Inventive Problem Solving · S-Curve · System Evolution · Future of TRIZ · AI and TRIZ · Cross-Disciplinary TRIZ · Innovation Engineering

1 Introduction

TRIZ, also known as the “Theory of Inventive Problem Solving”, was born out of the Soviet Union during the mid-twentieth century [1]. The acronym “TRIZ” is derived from its Russian name, “Teoriya (Theory) Resheniya (Solving or Resolution) Izobreatatelskikh (Inventive or Creative) Zadatch (Problems)” [2].

The development of TRIZ began in 1946 with the work of a young engineer named Genrich Altshuller and a team around him [3, 4]. He and his team started a systematic review and analysis of over 200,000 patents to identify what makes an invention

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innovative. Altshuller and his co-workers sought to identify and codify the principles of creativity that lead to technological innovation, with the aim to make the process of invention predictable, controllable, and teachable [5].

Altshuller's initial research resulted in the establishment of several principles and concepts that are still central to TRIZ. These include the Laws of Technical Systems Evolution, the concept of Ideality, and the identification of Contradictions as key drivers for innovative solutions [6]. TRIZ was not immediately recognized or accepted; it even faced suppression in the early years of its development. Altshuller was arrested in 1950 and spent several years in prison due to the political climate of the time. It was only after his release that he was able to continue his work on TRIZ [7].

Throughout the 1960s and 70s, Altshuller and his co-workers refined the methodology and organized training sessions. He established a public institute for TRIZ (like the Baku TRIZ School in Azerbaijan, an important center for TRIZ development). Together with other enthusiasts, they continued to improve the TRIZ methodology. Its practical success in a variety of applications, such as industrial design problems, complex engineering challenges, and technological innovation projects, gradually led to its growing recognition [8]. The original work on TRIZ was conducted in Russian and was not widely translated into other languages until much later. This made it difficult for non-Russian speakers to learn about or apply the methodology.

Prior to the collapse of the Soviet Union in 1991, there was limited dissemination of TRIZ outside of the country. After that moment, knowledge of TRIZ started to spread worldwide. After TRIZ started to spread outside of Russia, its adoption was still gradual. TRIZ is a radical departure from traditional problem-solving approaches, and like many innovative ideas, it was not immediately accepted. Businesses had to recognize its value, learn the method, train employees, and integrate it into their problem-solving processes. It began to be implemented in organizations in the United States, Europe, and Asia, often as part of quality improvement initiatives [2]. The Association of German Engineers (VDI) has developed the TRIZ guideline VDI4521, which describes the contents of the TRIZ methodology and facilitates access to more than 25 TRIZ methods and tools [9].

TRIZ has continued to evolve and be adapted to a wide variety of applications, not just in engineering and product development, but also in areas such as business process improvement and strategic planning. New tools and techniques have been added to the TRIZ toolkit, and it has been integrated with other innovation and quality management methodologies. As of today, TRIZ is recognized globally and used by many multinational corporations to enhance their problem-solving and innovation processes. There are numerous TRIZ societies (e.g., International TRIZ Association (MATRIZ) that promotes TRIZ among practitioners and establishes and maintains TRIZ certification standards; The European TRIZ Association (ETRIA) that serves as an international platform for TRIZ research, applications, and communications; TRIZ Association of Asia that promotes the understanding and use of TRIZ throughout Asia, etc.), research groups (e.g., INSA Strasbourg, Politecnico di Milano, Offenburg University of Applied Sciences, The Laboratory for Quality Innovation at the University of Bergamo, The Laboratory of Intellectual Information Technologies TRIZ-Chance FEFU, TRIZ group at National Tsing Hua University, Centre for Systematic Innovation at IIT Madras, Systematic Innovation Lab at the University of Twente, Technical University of Cluj-Napoca,

etc.), and training organizations (e.g., The Altshuller Institute for TRIZ Studies based in the United States to promote innovation and creativity using the TRIZ methodology, TRIZ Consulting Group, Institute of Systematic Innovation, Oxford Creativity, etc.) around the world, and the methodology continues to evolve through the work of these communities.

While the aforementioned research groups, associations, and training organizations represent some of the key contributors to the field, the global TRIZ landscape is vast and diverse, encompassing countless researchers, institutions, and practitioners. It's important to recognize that what is mentioned in this paper represents just a snapshot of the innovative work being done in TRIZ worldwide, and there are many other equally valuable contributors who continue to advance this field.

2 A Perspective of TRIZ Evolution Through S-Curves

In the journey of technological evolution and problem-solving methodologies, understanding the progression of TRIZ since its inception provides a fascinating perspective. One way to view this evolution is through the lens of S-curves, a tool often used in TRIZ itself to depict technological lifecycles. In this section, we map the major developmental milestones of TRIZ onto S-curves. This will not only highlight its growth and maturation over time but also provide insights into its potential future trajectory. This approach resonates with the spirit of TRIZ, which is rooted in understanding patterns of problem-solving and innovation; and applying these patterns to navigate technological evolution.

TRIZ has undergone a significant evolution since it was first developed in the 1940s by Genrich Altshuller and his co-workers. When mapping the evolution of TRIZ, it can be broadly divided into several distinct stages. Please note that the following is a qualitative perspective, rather than a quantitative one, based on historical context and the subjective nature of mapping theoretical concepts:

First S-Curve: Development of the Basic Principles (1946–1960s): This period marks the birth of TRIZ. Altshuller and his colleagues started working on the theory in 1946. The initial research was focused on understanding the patterns in patents and coming up with principles that could guide innovative problem-solving.

Second S-Curve: Formalization and Expansion of TRIZ (1960s–1980s): During this time, TRIZ matured and expanded with the addition of several tools and methods, such as the contradiction matrix, inventive principles, the laws of system evolution, algorithm of inventive problem solving (ARIZ), substance-field analysis, ideal final result (IFR), separation principles, resources analysis, trends of engineering system evolution (TESE). TRIZ became more structured and was taught in the Soviet Union.

Third S-Curve: Global Spread and Computerization of TRIZ (1980s–2000s): With the fall of the Soviet Union, TRIZ spread globally. Many Western companies started adopting TRIZ methodologies. This period also saw the computerization of TRIZ with the development of several software tools that facilitated the application of TRIZ (e.g., TechOptimizer, TRISolve, Ideation TRIZ, Goldfire, TRIZsoft, Simplified TRIZ,

SITools, TRIZExplorer, TRIZ GB, and many others). The development of some of these software tools continued in the next two decades.

Fourth S-Curve: Integration of TRIZ into Broader Innovation Management Practices (2000s-present): TRIZ has increasingly been integrated into broader innovation management and strategic planning practices. It is also the period with new tools being adopted in the TRIZ framework, such as function analysis, problem formulation and problem model, main parameters of value, system operator, etc. It is also being adapted to specific industries and applications. For example, multinational corporations like Samsung, Ford, and Procter & Gamble began applying TRIZ methodologies to innovate and solve problems in their operations. Translation and publication of TRIZ books and academic articles in multiple languages had happened. This played a crucial role in disseminating TRIZ globally. Universities around the world started offering courses in TRIZ, and it began to be integrated into engineering and design curricula. The organization of international TRIZ conferences and the formation of professional associations facilitated the exchange of ideas and advanced TRIZ development. New methods and algorithms have been also proposed to the so-called Modern-TRIZ. Examples are anticipatory failure determination (AFD), directed evolution (DE), algorithm of inventing and decision-making (AIDA), chain system diagram technique (CSDT), technology evolution theory (TET), trimming, function-oriented search (FOS), problem-flow technology (PFT), etc. It was also the era of occurring new tools for problem-solving inspired from TRIZ, such as advanced systematic inventive thinking (ASIT), unified structured inventive thinking (USIT), systematic approach to value enhancement (SAVE), etc., as well as researches on the theory of technical system evolution. New variants and offshoots of TRIZ have emerged, such as BioTRIZ, EcoTRIZ, TRIZ for services, TRIZ for software engineering, Business TRIZ, TRIZ for education, Cognitive TRIZ, systematic innovation in IT (SIIT), etc. It was also the time for Digital-TRIZ, when extensive databases were created containing thousands of patents and inventive principles categorized by the type of problem they solve. In this category we can include software that search in databases of patents driven by TRIZ rules, as well as the first attempts to combine natural language processing (NLP) techniques and data mining with TRIZ for more systematic investigation of databases with collective knowledge.

Each of these S-curves represents a significant evolution of TRIZ as a system - from a rudimentary approach to understanding invention, to a formalized methodology, to a globally recognized set of tools for innovation, and finally to an integrated part of broader innovation practices.

3 Empirical Analysis of TRIZ Evolution from Scientific Databases and Search Trends

In an effort to quantitatively gauge the evolution, growth, and current trends in the field of TRIZ, this section utilizes an empirical approach. By leveraging information from various scientific databases, Google Scholar, and Google Trends, we aim to map the trajectory of TRIZ from its inception to the present day. These resources offer a rich wellspring of data, shedding light on the diffusion of TRIZ methodology, the academic

and industrial interest over time, the geographic distribution of TRIZ research and application, and the emerging themes in recent years. This empirical analysis will augment our understanding of TRIZ's evolution, complementing the theoretical framework and anecdotal evidence that has been discussed so far.

According to Google Scholar, a search about TRIZ (theory of inventive problem solving) since 1950 till 2023 indicates 15,800 results, distributed along the years as follows: 10 results for 1950–1960, 14 results for 1961–1970, 29 results for the interval 1971–1980, 33 results for the decade 1981–1990, 305 results for 1991–2000, 3,930 results for the period 2001–2010, 11,600 for the interval 2011–2020, and 3,900 for a very short interval between 2021 and mid of 2023. The data sourced from Google Scholar provides a fascinating quantitative look into the evolution and spread of TRIZ since the 1950s. It clearly illustrates the exponential growth of TRIZ-related publications over time. The initial period from 1950s to 1980s shows limited academic output on TRIZ, reflective of its relatively secluded development within the Soviet Union. The minimal increase during this period also suggests the marginal visibility and recognition of TRIZ in the global scientific community. The noticeable uptick in results from the 1990s represents the international exposure and diffusion of TRIZ following the dissolution of the Soviet Union. The significant leap in publications in the 2000s corresponds with the period when TRIZ began to be more widely accepted in both academia and industry, especially in the West. The highest number of results is observed for the period 2011–2020, which can be interpreted as a reflection of TRIZ's mature phase. This is the period when TRIZ had not only been recognized but was being actively applied and explored in diverse fields, leading to substantial research output. The data for 2021 till mid-2023 suggests a steady continuity of interest in TRIZ, with the potential of even surpassing the previous decade if the current trend continues. This is also supported by the results extracted from Google Trends, too. In Fig. 1 we have represented the interest about TRIZ, created with a machine learning application based on data downloaded from Google Trends. Results show a declining interest about TRIZ from 2004 till 2015, with a slight increasing in interest from July 2015 till today. The trend is best described by a second order polynomial, which lead to the minimal mean squared error for the dataset.

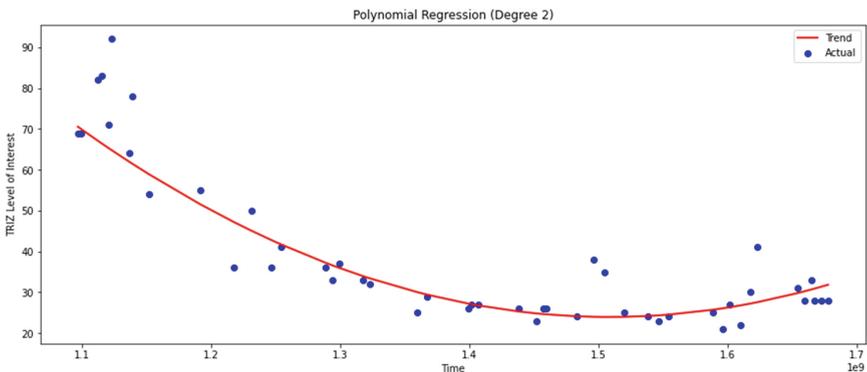


Fig. 1. Level of interest worldwide about TRIZ on web between 2004 and mid of 2023.

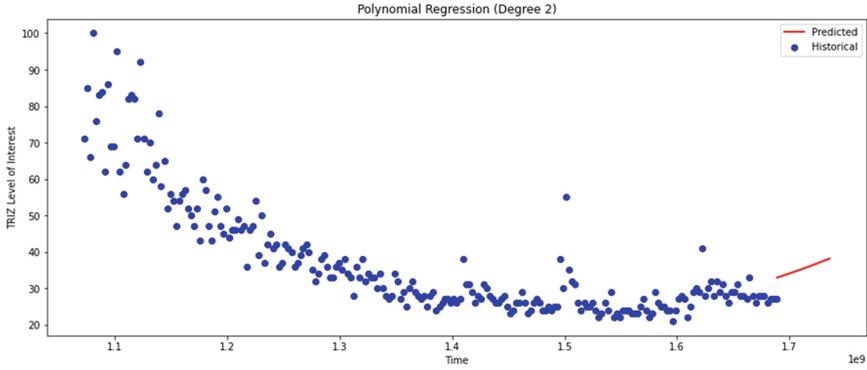


Fig. 2. Predicted trends worldwide about the interest on TRIZ on web until the end of 2024.

Drawing on historical data and leveraging machine learning algorithms, we project a rising interest in TRIZ by the end of 2024, as depicted in Fig. 2. For a more extended forecast, prediction becomes inherently challenging due to the imminent paradigm shift we are currently witnessing in the evolution of TRIZ. The advent of the artificial intelligence (AI) era marks a significant turning point for TRIZ from a scientific standpoint. We will delve deeper into these transformative aspects in the subsequent sections of this paper.

The data obtained from the Web of Science offers a comprehensive picture of the academic attention and research output related to TRIZ since 1975. In the Web of Science, from 1975 till 2023 there are 2,207 papers that include TRIZ in their topics. The absence of any results from 1975–1994 corresponds to TRIZ’s early stages when it was primarily confined to the Soviet Union, with limited recognition and application outside this context.

The first emergence of TRIZ in the Web of Science database in 1995, albeit with a sparse 3 papers, signifies its initial exposure to the broader global academic community. The slight fluctuation in the numbers in the latter part of the 1990s suggests an incremental recognition and adoption of TRIZ, with no results in 1996, with 3 results in 1997, with 7 results in 1998, with 7 results in 1999, and 9 results in 2000. The start of the 21st century saw a more significant surge in TRIZ-related papers, with 502 papers recorded from 2001 to 2010. This dramatic increase can be attributed to the global spread and acceptance of TRIZ methodologies within academic and industry spheres. From 2011 to 2020, the TRIZ-related contributions almost tripled, with a total of 1,299 papers. This period marks the full-fledged integration and application of TRIZ in various domains, underlining its established role in the field of inventive problem-solving.

The number of papers between 2021 and mid-2023, a total of 240, indicates a sustained and active interest in TRIZ. Given this rate, the output for the decade could potentially surpass the previous one. Notably, a considerable 597 titles have been published in the last 5 years, further emphasizing the ongoing relevance and vitality of TRIZ in contemporary research.

From the total of TRIZ papers visible in Web of Science, 1,381 are published at conferences, 811 are articles in journals, 29 are review articles, 19 are book chapters,

and the remaining are letters, etc. The majority of papers are in the field of mechanical, industrial, and manufacturing engineering (1,070), 458 in electrical, telecommunication and automation engineering, 742 in computer science. Figure 3 shows a network visualization of the core topics of these papers about TRIZ.

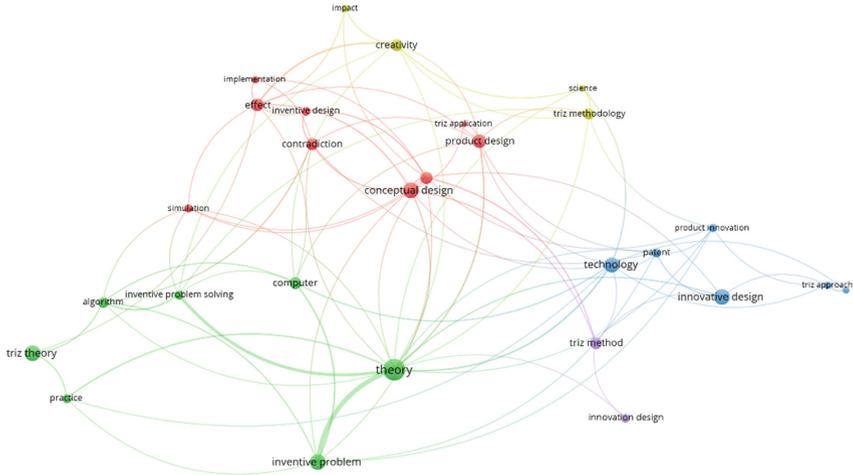


Fig. 3. Network visualization of TRIZ issues in the papers from Web of Science.

As Fig. 3 shows, the highest density of researches are around innovative design, conceptual design, TRIZ theory, with five clusters of topics (see the various colors in Fig. 3). Similar results are returned also from the SCOPUS database. In this case, we count 3,231 results, with 2,050 in engineering field, 1,174 in computer science, 496 in business and management, 440 in decision sciences, 339 in mathematics, and the remaining in other areas. Here, we reckon 1,673 conference papers, 1,291 articles, and 112 book chapters, among others.

4 The Emergence of a New S-Curve of TRIZ

This section unfolds the exploration of the evolution of TRIZ. Here, we investigate an essential element that signifies this progression: the emergence of a new S-curve in TRIZ, which we'll refer to as the NeoTRIZ or TRIZ-X S-curve.

The S-curve model, inherent to the TRIZ philosophy, shows that as we advance into the NeoTRIZ or TRIZ-X era, we witness the emergence of a new S-curve, characterized by novel methodologies, innovative strategies, and the incorporation of cutting-edge technologies such as artificial intelligence and machine learning. This new S-curve signifies a phase of rejuvenation and reinvigoration in the realm of TRIZ, leading to breakthrough developments and transformative potential in problem-solving and innovation.

To make foresights on the evolution of TRIZ, several angles and approaches are further considered. We start with the PAIPS framework (Problem-Agitate-Intrigue-Positive

Future-Solution) [10]. This implies addressing a problem, to agitate it, to intrigue, after that to paint a positive future and lastly to deliver a solution. To decode the TRIZ evolution, we will operate with options applied in the PAIPS framework. Thus, for addressing the problem we consider:

- Option 1: The application of TRIZ, the theory of inventive problem-solving, is currently limited by the human capacity for creativity and pattern recognition.
- Option 2: The traditional application of TRIZ can be a time-consuming process, and it can be difficult to adapt to rapidly changing technological contexts.
- Option 3: TRIZ's effectiveness is constrained by the ability to interpret vast amounts of past and present data to predict the future trajectory of innovation.

Now, we agitate the problem. This leads to the following options:

- Option 1: The limitations of human capacity can lead to missed opportunities for innovative solutions, slowing down technological progress.
- Option 2: The lengthy process of applying TRIZ can leave organizations lagging behind in the fast-paced technological landscape, impeding their competitive advantage.
- Option 3: The inability to harness the vast array of data for effective TRIZ application stifles innovation and prevents organizations from realizing their full innovative potential.

In the next step, we provoke. This generates the following options:

- Option 1: What if AI could augment the TRIZ process, enhancing our creative problem-solving capabilities and leading to breakthrough innovations?
- Option 2: Imagine the potential of integrating AI into TRIZ, significantly speeding up the inventive process and helping organizations stay ahead of the technological curve.
- Option 3: Consider a world where AI assists in analyzing and interpreting data to forecast TRIZ's S-curve, providing unique insights into the future of innovation.

Now we can project a positive future about TRIZ in the era of AI:

- Option 1: In this new reality, the fusion of AI and TRIZ leads to radical innovations, accelerating technological progress and creating a world of endless possibilities.
- Option 2: With AI integrated into TRIZ, organizations can innovate at breakneck speed, maintaining a competitive edge in the constantly evolving technological landscape.
- Option 3: With AI's assistance, TRIZ becomes a powerful predictive tool, enabling organizations to foresee the trajectory of innovation and strategically position themselves for the future.

In this desirable landscape, we can now formulate the solution. It has to be seen in terms of options, too.

- Option 1: The solution lies in the convergence of AI and TRIZ, utilizing AI's computational power to enhance our creative problem-solving abilities and redefine the S-curve of TRIZ.

- Option 2: The path forward is the integration of AI into the TRIZ process, automating and accelerating the inventive process while adapting to the rapid pace of technological change.
- Option 3: The key to unlocking this potential is by harnessing AI to analyze and interpret data for TRIZ application, transforming TRIZ into a powerful tool for predicting the future of innovation.

Now, we can visualize a possible S-curve of TRIZ over the next 20 years. Below are the reasons why a 20-year time frame has been chosen:

- Long-term Forecasting: In technological trend analysis and forecasting, a 20-year period is often used to account for significant developments and changes that can occur. This timeframe is typically long enough to observe the full development, maturity, and potential decline of a technological innovation.
- Technological Generations: It's generally estimated that a new generation of technology emerges approximately every 20 years. For instance, the transition from mainframe computers to personal computers, and then to mobile devices, each took about 20 years. Thus, a 20-year timeframe might be seen as a reasonable estimate for the lifespan of a technology like AI-integrated TRIZ.
- Historical Trends: Previous implementations of TRIZ followed a similar lifespan, therefore 20-year prediction is also considered in this case, too.
- Practicality: A 20-year time span allows for a granular breakdown of various stages, and yet it is not so long that it becomes difficult to imagine or forecast.

The S-curve in this context describes the life cycle of the integration of AI into TRIZ methodology and how its influence and effectiveness change over time. The parameter of value in this case is the effectiveness of adopting AI-TRIZ methodology. The Y-axis of the S-curve represents the effectiveness of adoption, while the X-axis represents the time period from 2023 to 2043.

In addition, the life cycle is divided into 5-year segments. The reasons why a 5-year span is used for each phase are shown below:

- Predictability: A 5-year timeframe is a common period for technology forecasting, as it's often seen as a balance between near-term predictability and long-term uncertainty. Beyond 5 years, the uncertainty increases significantly due to the exponential nature of technological advancement.
- Technology Adoption Lifecycle: The lifecycle of technology adoption usually involves a period of slow initial growth as early adopters start using the technology, followed by rapid growth as the technology becomes mainstream, and finally, maturity and potential decline. A 5-year period for each phase of this cycle might be seen as reasonable, given historical trends.
- Business Planning: In business and strategic planning, a 5-year plan is a common timeframe. This influenced the choice of a 5-year timeframe for each phase.
- Consistency and Simplicity: Using a consistent timeframe for each phase simplifies the model and makes it easier to understand and communicate.

It's crucial to remember that the duration of each phase in a technology lifecycle can vary significantly in reality. While here we have used 5-year periods for the model, this

doesn't mean each phase will definitely last exactly 5 years. The model should be seen as a framework for understanding how technology might evolve, rather than a precise prediction of the future. With these in mind we have the following S-curve:

1. **Initial Growth Stage (2023–2028):** The transition into this stage is triggered by the integration of AI into TRIZ (Solution 2). This causes a rapid increase in the effectiveness of TRIZ and a subsequent increase in its adoption. AI augments human creativity and automates part of the problem-solving process, leading to more efficient and innovative solutions. We see a rapid influx of organizations adopting this AI-powered TRIZ model, fueling its initial growth.
2. **Expansion Stage (2029–2033):** The transition into this stage is driven by the enhanced computational power of AI, which elevates creative problem-solving abilities to a higher level (Solution 1) and normalizes the use of AI in analyzing and interpreting data for TRIZ application (Solution 3). This leads to a massive expansion of TRIZ's influence.
3. **Maturity Stage (2034–2038):** The transition into this stage is marked by the maturation of the AI-TRIZ model. The model's continued evolution slows the pace of growth, as most organizations are already using AI-TRIZ, and further advancements in AI technology are incremental.
4. **Decline/Innovation Stage (2039–2043):** The transition into this stage is signaled by the saturation of the current AI-TRIZ model. The effectiveness and influence of the model might start to decline, but this stage might also give rise to new technological advancements that bring about a new innovation in TRIZ, thus potentially starting a new S-curve.

Now, we analyze the evolution using a different method, the scenario management methodology. This is necessary to refine and consolidate our findings from the initial S-curve model. Rather than viewing the S-curve and scenario development processes as independent or linear, we embraced an iterative cycle that allows continuous improvement of our predictions.

After creating an initial S-curve based on our current understanding and assumptions, we will generate multiple scenarios to explore various possible futures. Each scenario, built on a unique set of assumptions, offered a different perspective on potential outcomes. We then incorporate the insights gathered from these diverse scenarios to enhance our initial S-curve, offering a more nuanced, comprehensive, and robust forecast. This circular, rather than linear, process enables us to continually adapt and refine our predictions as new information becomes available. Here are four major uncertainties and influence factors for the evolution of TRIZ:

- The development of AI technologies: Will AI rapidly mature or will it evolve at a slower pace?
- The integration of AI with TRIZ: Will it be seamless and widely accepted or will it face significant challenges and resistance?
- Changes in the global business environment: Will it be stable, or will there be major disruptions?
- Adoption rate of TRIZ methodology: Will it be widely adopted or remain niche?

Each of these factors could have two potential outcomes: high or low. By combining these, we can create sixteen possible scenarios. We will focus on six scenarios:

Scenario A: *Seamless Integration & Rapid Adoption (High AI development, Seamless AI & TRIZ integration, Stable business environment, High TRIZ adoption):* This is the most favorable scenario where AI develops rapidly and integrates seamlessly with TRIZ in a stable business environment, leading to widespread adoption of the TRIZ methodology. The probability of this scenario occurring is moderately high, given the advancements in AI and the increasing interest in TRIZ. From the set of all six scenarios, we give the highest chance.

Scenario B: *Resistance & Slow Adoption (High AI development, Challenging AI & TRIZ integration, Stable business environment, Low TRIZ adoption):* Despite rapid AI development and a stable business environment, integration challenges lead to a slower adoption of TRIZ. This scenario could also happen, especially if integration challenges are underestimated or if there's pushback from stakeholders. We give about 60% chance to this scenario in comparison to Scenario A.

Scenario C: *Disruptive Innovation (High AI development, Seamless AI & TRIZ integration, Disruptive business environment, High TRIZ adoption):* Rapid AI development and seamless integration with TRIZ lead to significant disruption in the business environment, but TRIZ methodology is still widely adopted. This scenario is less likely as it would require significant disruptions in the business environment coinciding with seamless integration and high adoption. We give about 30% chance to this scenario in comparison with Scenario A.

Scenario D: *Disruptive Challenge (High AI development, Challenging AI & TRIZ integration, Disruptive business environment, Low TRIZ adoption):* Rapid AI development combined with a disruptive business environment and integration challenges result in low TRIZ adoption. This is a fairly plausible scenario, given the inherent uncertainty of AI development and the potential for global business disruptions. Estimated probability is 60% relative to Scenario A.

Scenario E: *Slow Progress & Stable Adoption (Low AI development, Seamless AI & TRIZ integration, Stable business environment, High TRIZ adoption):* AI development is slower but still integrates seamlessly with TRIZ in a stable business environment, leading to high TRIZ adoption. This scenario is quite likely if AI development is slower than expected but TRIZ adoption continues to increase steadily. Estimated probability is 30% relative to Scenario A.

Scenario F: *Slow Progress & Resistance (Low AI development, Challenging AI & TRIZ integration, Stable business environment, Low TRIZ adoption):* Slow AI development and integration challenges result in low adoption of TRIZ despite a stable business environment. This scenario is less likely due to the growing interest in both AI and TRIZ, but it could occur if integration challenges are significant and not overcome. Estimated probability is 15% in comparison to Scenario A.

When determining the relative probabilities of the six scenarios, we employed a method based on sensitivity analysis. In this approach, all six scenarios collectively represent 100% of possible outcomes. Through careful examination of the interrelationships

between the four influencing factors and their corresponding scenarios, we were able to derive the relative probabilities. This ensures a comprehensive and balanced assessment of all potential outcomes, providing us with a nuanced understanding of their relative likelihood. Results of the analysis are shown in Table 1. In this table, 9, 3, 1, and 0 represent strong, medium, weak, and no relationships respectively between each scenario and influencing factor.

Table 1. Sensitivity analysis to define relative probability of each scenario.

Factors	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F
Rapid AI Development	9	9	3	9	1	1
Seamless AI & TRIZ Integration	9	1	3	3	3	1
Stable Business Environment	9	9	1	3	3	1
High TRIZ Adoption	8	1	3	3	3	1
Sum	35	20	10	18	10	4
	Reference	60%	30%	60%	30%	15%

Considering that Scenario A has the highest chances to happen, we can visualize the S-curve of NeoTRIZ (or TRIZ-X) for the next 20 years:

Initial Growth Stage (2023–2028): Rapid growth due to quick integration and high adoption rates. Companies make significant strides in utilizing AI with TRIZ, leading to innovative solutions.

Expansion Stage (2029–2033): Widespread adoption of the AI-TRIZ model across industries leads to peak innovation. This results in an explosion of new ideas and problem-solving methods.

Maturity Stage (2034–2038): The growth rate slows down as the AI-TRIZ model becomes standard. New inventions are fewer but more significant.

Decline/Innovation Stage (2039–2043): The curve flattens and begins to decline as the model reaches saturation. However, a new breakthrough in technology could rejuvenate the model, starting a new S-curve.

Now we will analyze the S-curve of NeoTRIZ in relation to the ideality concept promoted by TRIZ itself. As we know, ideality is a concept from TRIZ that refers to the ideal state of a system where all the desired functions are delivered without any costs or undesired effects. In the context of TRIZ evolution, the “useful function” is the delivery of new and innovative problem-solving techniques (the TRIZ novelties), and the “costs” involve the effort and resources required to integrate AI into the TRIZ system. The results are:

2023–2028: Beginning (Inception/Introduction Stage): During these initial 5 years, we will be at the beginning of the S-curve where ideality is relatively low. The focus will be on research, integration, and early adoption of AI within TRIZ. Costs will be high due to the need for extensive research and development, as well as training and awareness campaigns. The benefits in terms of new TRIZ novelties will be limited but will begin to emerge towards the end of this period.

2029–2033: Growth (Expansion Stage): In this next 5-year period, we enter the growth phase of the S-curve. Here, ideality starts to increase as the cost of integrating AI into TRIZ begins to decrease due to improved understanding and efficiencies, and wider adoption starts to take place. Meanwhile, the delivery of innovative problem-solving techniques starts to increase, providing more functional benefits.

2034–2038: Maturity (Established Stage): During this period, the ideality of TRIZ will reach its peak. The cost of integrating AI into TRIZ will have significantly decreased due to widespread adoption and continued efficiency improvements, while the functional benefits in terms of innovative problem-solving techniques will be at their maximum.

2039–2043: Decline (Exhaustion Stage) & Innovation/Disruption (Rejuvenation Stage): In the final period, we may start to see the ideality ratio decline as costs start to increase again due to the need for more advanced technologies and the saturation of the current TRIZ model. However, this could also be the period when a disruptive innovation or significant improvement in the TRIZ model emerges, triggering the start of a new S-curve and a new cycle of increasing ideality.

Each of the three S-curves offers unique insights into the lifecycle of the AI-TRIZ model and can be used to explore different facets of the model's development and potential future evolution.

S-curve 1: It articulates the impact of integrating AI into TRIZ, mapping out how the enhanced problem-solving capabilities lead to increased effectiveness and adoption of the TRIZ model. It paints how different solutions will influence each stage and provides a future trajectory for the model, considering both the potential saturation and the possibility of a new technological breakthrough.

S-curve 2: It focuses more on the tangible outcomes of each stage, such as the innovation explosion during the Expansion stage or the fewer but more significant inventions during the Maturity stage. It provides a more outcome-oriented perspective, which can be useful for understanding the potential real-world implications of each stage.

S-curve 3: It offers an in-depth look at the lifecycle of the model through the lens of ideality. It emphasizes the cost-benefit trade-off in each stage, presenting a clear picture of how costs, efficiencies, and benefits evolve over time. It also hints at a possible rejuvenation stage, tying the lifecycle back to the concept of cyclical S-curves.

The three S-curves, while described differently, lead to a similar conclusion: The aggregation of the three perspectives into a single one shows as follows:

Initial Growth Stage (2023–2028): The integration of AI into TRIZ kickstarts this stage, leading to a steep rise in the effectiveness and adoption of TRIZ. AI not only augments human creativity but also automates part of the problem-solving process, resulting in more innovative and efficient solutions. This stage sees a surge of organizations adopting this AI-powered TRIZ model, fueling its initial growth. However, ideality

is relatively low at this stage as high costs associated with research, development, and training campaigns outweigh the limited functional benefits of new TRIZ innovations that start emerging towards the end of this stage.

Expansion Stage (2029–2033): The expansion stage is driven by the amplified computational power of AI, enhancing creative problem-solving abilities and the normalization of AI use in TRIZ application data analysis and interpretation. This period witnesses a massive spread of TRIZ's influence, leading to peak innovation and an explosion of new ideas and problem-solving methods. Ideality begins to increase as the cost of integrating AI into TRIZ decreases due to enhanced understanding and efficiencies, and wider adoption begins to occur.

Maturity Stage (2034–2038): As the AI-TRIZ model matures, the growth pace starts to decelerate, as most organizations are already leveraging AI-TRIZ for their problem-solving processes, and further advancements in AI technology are incremental. Despite the slowed growth, this stage sees peak ideality as costs significantly decrease due to widespread adoption and continued efficiency improvements, while innovative problem-solving techniques are at their zenith.

Decline/Innovation Stage (2039–2043): The S-curve begins to flatten and decline as the model reaches saturation. The effectiveness and influence of the current AI-TRIZ model might start to wane. Simultaneously, costs may begin to rise again due to the need for more advanced technologies and the saturation of the current TRIZ model. However, this stage is also ripe for the emergence of disruptive innovation or a significant improvement in the TRIZ model, potentially initiating a new S-curve and a fresh cycle of increasing ideality.

The S-curve of NeoTRIZ as shown in the previous paragraphs of this section is framed by a still narrow perspective of evolution. TRIZ represents a form of embedding the collective intelligence of humankind. TRIZ must encapsulate the distilled wisdom from a large number of human innovations, ideally from all innovations. TRIZ must allow users to take advantage of all previous innovative solutions that may have been used in different contexts or fields and apply them to their own unique challenges. TRIZ must continually represent the latest advancements in human innovation and knowledge. TRIZ must help in disseminating the collective intelligence of humankind in a manner that isn't limited to experts in a particular field. TRIZ must promote a knowledge ecosystem where each problem solved immediately can contribute to the broader pool of knowledge and innovation.

Thus, considering this perspective of TRIZ's mission and ambition, NeoTRIZ or TRIZ-X (The Expanded Methodology for Innovation and Problem-Solving), must go beyond the Digital and AI-driven TRIZ, it must integrate sustainability and circular economy principles, as well as more cross-disciplinarity. This could involve developing new principles or tools for inventing sustainable solutions or for transitioning linear systems to circular ones, as well as ideas from fields like biology, sociology, or psychology, or applying TRIZ in fields where it hasn't been used extensively before. These are just a few potential directions for the next S-curve of TRIZ, and they might overlap or happen simultaneously. The actual direction will depend on various factors, including advancements in technology, changes in society, and the work of researchers and practitioners in the TRIZ community.

5 Some Insights into the AI-Driven TRIZ

As a systematic methodology for fostering creativity and solving complex problems, TRIZ has achieved global recognition, even if it is less comfortable in application for the wider public. But, as in martial arts, not everyone is capable of becoming a master without effort. The advent of artificial intelligence can revolutionize TRIZ, propelling it to new heights of effectiveness.

AI's capacity for analyzing large data sets and spotting patterns eludes human perception, making it a potent tool for breaking psychological inertia, the human tendency to cling to known concepts. By pushing the boundaries of conventional thinking, AI exposes new insights and ideas, enhancing TRIZ's creative ideation and spawning innovative solutions.

Further, AI comes into play in identifying and resolving contradictions within complex systems. Specifically, reinforcement learning algorithms have proven adept at navigating intricate decision spaces to discern optimal paths to contradiction resolution. This accelerates TRIZ's problem-solving process, as AI models can automate contradiction analysis, propose optimal solutions, and thus expedite the resolution of contradictions.

The union of AI and TRIZ is particularly harmonious in the context of system evolution laws. By analyzing historical data, machine learning algorithms can discern trends and patterns, yielding predictive insights. This predictive capability enables AI models to forecast technological developments, a feature that bolsters strategic planning in TRIZ and could be invaluable for foreseeing future challenges and opportunities.

AI algorithms also optimize the creative use of resources, assigning tasks based on resource availability and capability, thereby maximizing overall system performance. Furthermore, AI's ability to simulate various scenarios and model their outcomes helps visualize and evaluate potential solutions, steering towards the Ideal Final Result (IFR).

The role of AI in problem formulation, system analysis, and knowledge-based innovation is equally noteworthy. By swiftly processing extensive data sets to extract pertinent information, AI enhances many aspects of these processes. Furthermore, machine learning algorithms can draw on past cases and examples from TRIZ's comprehensive knowledge base, making these resources more accessible and valuable for new problem-solving instances.

AI also excels in automating the creation and analysis of substance-field models, thereby identifying opportunities for innovation. In the initial stages of TRIZ, AI can automate problem definition and contradiction identification, effectively leveraging its data-processing capabilities.

By proposing creative solutions that may elude human thinking, AI enhances TRIZ's creativity aspect. It also refines decision-making processes by suggesting the most fitting TRIZ principles or inventive patterns based on the problem context. Moreover, machine learning algorithms can learn from past innovation projects, continuously refining TRIZ methodology and boosting its efficiency and effectiveness.

AI also personalizes TRIZ learning to individual skills, knowledge, and past experiences. Through natural language processing (NLP), it facilitates global collaboration by translating and adapting solutions from different languages and cultures, enriching the pool of inventive ideas.

In addition, AI can refine and strengthen the Algorithm for Inventive Problem Solving (ARIZ) by learning from its past successful applications. It can also continually expand and update TRIZ knowledge bases, such as databases of inventive principles or effects, making TRIZ a more dynamic and adaptable methodology.

AI's ability to recognize patterns in successful TRIZ applications across various fields could pave the way for TRIZ's adaptation to new domains or disciplines. This could further enhance TRIZ's applicability and impact.

Machine learning algorithms can update TRIZ principles and tools by identifying patterns in historical invention data. Neural networks can aid the TRIZ process by generating novel combinations of solutions. Simultaneously, NLP can enrich TRIZ's knowledge base by extracting valuable information from various documents.

Evolutionary algorithms could enhance the law of system completeness, while fuzzy logic could extend TRIZ tools to better accommodate ambiguity. Swarm intelligence could facilitate collaborative problem-solving in complex TRIZ scenarios.

AI also plays a crucial role in addressing the so-called "black boxes" in TRIZ, where established inventive principles may not provide clear solutions. AI can suggest new potential principles for problem-solving by scanning large textual data. Its proficiency in pattern recognition and simulation can uncover non-obvious ways to resolve contradictions. Moreover, by facilitating a crowdsourcing approach to problem-solving, AI can contribute to an evolving, comprehensive contradiction matrix.

Current AI models have shown an impressive ability to generate creative content, like writing poetry or composing music. Similarly, they can be used to expand the creative aspects of TRIZ. An AI model trained on the history of invention could potentially generate inventive principles or problem-solving methods that have not yet been conceived by humans. This could open up completely new perspectives and solutions, extending the boundaries of TRIZ beyond what was previously imaginable.

Inspired by biological evolution, AI-based evolutionary algorithms can optimize solutions over time through the process of iterative selection, crossover, and mutation. This parallels TRIZ's Law of System Evolution, which theorizes the natural progression of systems over time. AI can provide a more mathematical and precise approach to this evolution, allowing for the prediction and creation of future, advanced solutions that evolve from current ones.

Just as AI benefits from TRIZ's systematic problem-solving framework, TRIZ can also leverage the adaptability and learning capabilities of AI. Hybrid methodologies could be developed, combining TRIZ's strength in tackling complex problems and AI's abilities to handle ambiguity, uncertainty, and incomplete information. This could enable the development of adaptive, self-learning problem-solving methodologies, transforming the way we approach innovation and design.

AI's capacity for real-time data processing and pattern recognition could allow for continuous tracking and monitoring of global innovation trends. This could enable TRIZ practitioners to stay updated on cutting-edge inventions and ideas, accelerating their own problem-solving processes.

In today's world, many complex problems involve ethical considerations. By integrating ethics-based algorithms with TRIZ, AI could help resolve moral contradictions, providing a fresh and innovative approach to complex ethical problems.

AI's versatility can extend TRIZ's applicability beyond engineering and technology. For example, AI can help adapt TRIZ principles to fields like social sciences, business strategy, or environmental science, widening the spectrum of TRIZ's impact.

Emotional AI, also known as affective computing, is AI that can understand, interpret, and simulate human emotions. When combined with TRIZ, emotional AI could add an emotional dimension to problem-solving, allowing for the design of products and systems that not only solve technical contradictions but also resonate with human emotions and needs. This could lead to more holistic, human-centered innovations.

Even as AI becomes more capable of problem-solving, the role of TRIZ researchers and inventors remains crucial. These individuals have the creative thinking ability, domain-specific knowledge, and the instinctual insight that AI currently lacks. AI can certainly augment and automate part of the problem-solving process, but it's unlikely to completely replace human creativity and ingenuity. TRIZ researchers will still be needed to pose the right questions, interpret AI-generated solutions, apply contextual understanding, and implement solutions. They would also be in charge of continuously improving and adapting AI models for problem-solving.

As in any other area where AI is going to be applied, explainable AI (XAI) is an important issue. XAI seeks to make AI's decision-making process more understandable to humans and this aspect is crucial when AI is used in problem-solving, as understanding how an AI system reached a particular solution can help validate the solution and provide valuable insights into the problem-solving process. Explainable AI can also help build trust in AI systems and make it easier for users to interact with these systems effectively. However, with the human expert in the loop, any solution proposed by the AI system can be critically analyzed and corrected if this is necessary.

With AI's integration into TRIZ, the methodology itself is likely to evolve. Researchers and inventors would not only use AI as a tool but also work on refining and innovating the AI-TRIZ methodology itself. They would still play a significant role in explaining changes and innovations, designing new problem-solving processes, and bringing in the human factor that AI cannot replicate.

6 Emerging Technologies and Their Potential Impact on Future TRIZ Problem-Solving Capabilities

Future TRIZ promoters and researchers must challenge the existing norms and boundaries. AI and machine learning can augment TRIZ's problem-solving capabilities by providing data-driven insights, assisting in ideation, and supporting decision-making. Quantum Computing (QC) [11], when will reach a maturity beyond laboratory, could enable more sophisticated analysis, simulation, and optimization techniques within TRIZ, leading to improved problem-solving outcomes. Blockchain [12] could contribute to the transparency and traceability of TRIZ problem-solving processes. Blockchain can contribute to TRIZ by improving IP protection, enabling secure knowledge sharing, and fostering trusted collaborations among TRIZ practitioners.

Internet of Things (IoT) [13] could enhance the data collection capabilities for TRIZ problem-solving. By connecting devices and systems, TRIZ practitioners could gain access to real-time and diverse data, leading to more robust and effective

problem-solving. Big Data Analytics (BDA) [14] could support TRIZ by providing insights from massive amounts of data, thereby informing more effective and informed problem-solving. Integrating IoT and big data analytics with TRIZ methodologies can enhance the understanding of system behavior, enable predictive analysis, and support evidence-based decision-making.

Virtual Reality (VR) [15] and Hyper-Reality Environments (HRE) [16] could enhance the visualization capabilities in the TRIZ problem-solving process. It could help in modeling and simulating problems, thereby leading to a better understanding and more innovative solutions. VR can enhance TRIZ by providing interactive problem-solving environments, facilitating knowledge sharing, and enabling virtual prototyping of new concepts.

Edge Computing (EC) [17] could support real-time TRIZ problem-solving by processing data closer to the source. By mimicking the human brain's neural structure, Neuromorphic Computing (NC) [18] could enhance the capabilities of AI and machine learning within TRIZ, leading to more intelligent and intuitive problem-solving tools and techniques. If future research will lead to sophisticated Brain-Computer Interfaces (BCI) [19] that can enable direct and efficient communication between human minds and computers, this could allow for unprecedented efficiency in problem-solving using TRIZ. The ability to convert thoughts directly into computational models could radically speed up and enhance the TRIZ process. If the distant future will provide the capacity for becoming a reality the neural uploads, this technology could revolutionize how we approach problem-solving. Entire teams could collaboratively 'think' in a shared digital space, harnessing the power of combined intellectual capacities to solve complex problems using TRIZ.

If the speculative concept of Quantum Brain Dynamics (QBD) [19] becomes in the distant future a reality, quantum processes will be involved in human cognition. It could lead to a new level of problem-solving capacity, potentially transforming TRIZ methods into even more powerful tools. If in the distant future we will develop the ability to manipulate neural connections at a nanoscale level, by means of Neuroscience and Nano-Robotics [20], this could potentially allow us to enhance our cognitive abilities, including our problem-solving capabilities. This could lead to significant advancements in the application of TRIZ. Artificial General Intelligence (AGI) [21] is still speculative, but if realized, it could fully automate the TRIZ problem-solving process, making it incredibly fast and efficient.

7 Conclusions

Our investigation provides a comprehensive analysis of the evolution of TRIZ, the Theory of Inventive Problem Solving, from its inception in mid-twentieth century Soviet Union to its current global recognition. Our study highlighted four key phases of TRIZ evolution: initial development, formalization and expansion, global dissemination, and integration into broader innovation management practices.

It was observed that the proliferation of digital tools, and fusion techniques such as natural language processing and data mining with TRIZ, indicate a promising frontier for the methodology. Our study, based on data from scientific databases, Google Scholar,

and Google Trends, revealed a remarkable growth in TRIZ-related academic interest and output since the 1950s. Despite an observed decline in interest from 2004 to 2015, a resurgent interest trend is predicted by the end of 2024.

A significant turning point identified in our study was the advent of the artificial intelligence era, signaling new challenges and opportunities for TRIZ's future evolution. The integration of AI and other cutting-edge technologies with TRIZ has initiated the emergence of a new S-curve, NeoTRIZ or TRIZ-X, projected to bring about significant breakthroughs in problem-solving and innovation over the next two decades. The expected trajectory of this curve, however, is subjected to several uncertainties including the pace of AI development, integration challenges between AI and TRIZ, changes in the global business environment, and the adoption rate of TRIZ methodology.

The concept of ideality was also studied, revealing an expected evolution in tandem with the stages of the S-curve. To achieve maximum ideality and transformative potential, we propose that NeoTRIZ or TRIZ-X incorporate sustainable and circular economy principles, encourage cross-disciplinary approaches, and find application in various fields. This holistic approach should ensure the methodology can evolve alongside technological advancements and societal changes.

Although the incorporation of AI and other emerging technologies into TRIZ suggests immense potential for enhancing its problem-solving and innovation capabilities, this research was not without its limitations. The inherent challenge of predicting trends amidst an imminent paradigm shift posed a difficulty. Furthermore, we acknowledge the role of speculative future technologies, like Brain-Computer Interfaces (BCI), Quantum Brain Dynamics (QBD), and Artificial General Intelligence (AGI) in potentially revolutionizing TRIZ, albeit these remain largely theoretical at this stage. Future research should aim to address these challenges, focusing on how TRIZ could effectively capitalize on these emerging technologies.

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Question Answering with Transformers and Few-Shot Learning to Find Inventive Solutions for IDM-TRIZ Problems and Contradictions in Patents

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Abstract. In this paper, a question-answering (QA) system based on BERT Transformer models is introduced to identify innovative solutions to problems and contradictions from patents. As a first step, a classification system based on Sentence-Transformer Fine-Tuning (SetFit) is developed to classify patents sentence-wise into IDM-TRIZ entities and to add the identified problems and contradictions to a search index. The second step is the creation of an end-to-end QA system. It is shown that a RoBERTa model trained with the SQuAD 2.0 dataset is better suited for the extraction of problem solutions than a BERT model fine-tuned with the same data set. Comparing different patent sections and search strategies, it turns out that more solutions can be extracted from the “State-of-the-Art” than from the “Claims” and “Abstract” sections. The presented QA system achieves an F1 score of 0.82, outperforming a state-of-the-art QA approach for IDM-TRIZ solution extraction.

Keywords: BERT · Bi-Encoder · Classification · Dense Retrieval · Dual-Encoder · Few-Shot Learning · Fine-Tuning · IDM-TRIZ · Information Retrieval · Question-Answering · Retriever-Reader Architecture · RoBERTa · SBERT · Sentence-Transformer · SetFit · SQuAD · Transformer

1 Introduction

Over the past decades companies look for approaches helping to get more innovative and to shorten innovation cycle times in order to improve their business results. These approaches include TRIZ-based systematic inventive design processes such as the Inventive Design Methodology (IDM-TRIZ).

A core finding of TRIZ, the theory of inventive problem solving, is that highly innovative solutions are often created by overcoming contradictions between system parameters. Another one is that many (if not most) innovations are based on the application of already existing solutions to new problem domains [1]. Thus, engineers working on new technical solutions need not only deep knowledge about their domain but also,

if they want to be innovative, a broad knowledge of other domains. Patents are a powerful knowledge base for technical solutions from all domains as every patent offers at least one innovative technical solution, depending on the complexity of the invention most likely even more than one [1]. However, due to the huge number of patents, their length, and their complicated writing style conventional search for valuable technical knowledge is very time-consuming and error-prone, even if performed by experts and supported by lexical keyword search as offered today by most patent search engines. The first potential problem of lexical patent search is that of vocabulary mismatch: only if the query's keywords are (at least partly) present in the patent text, the patent will be found. This obstacle is particularly relevant for cross-domain search, where different terms, synonyms or even a completely diverging jargon is common. Second, depending on the number of keywords in the query and their logical linking, search engines will return either a lot of irrelevant patents or only very few and miss important ones.

The IDM-TRIZ approach builds on TRIZ concepts and specifies the entities “problem”, “contradiction”, “parameter” and “solution” using formalized ontologies. In addition, it provides a set of syntactic and semantic rules that can be used in computer-linguistic methods to automatically identify these entities as text passages in patents when searching for new solutions to design problems or contradictions.

On the other hand, in computational linguistics and information retrieval (IR) new Artificial Intelligence (AI) methods of natural language processing (NLP) have attracted a great deal of attention in recent years. The Bidirectional Encoder Representations from Transformers (BERT) method [27] developed by Google is a pre-trained language model that, in contrast to previous models, enables a better context-based understanding of texts and can be used for classification tasks and question-answering (QA), among other downstream tasks. This language model and its derivatives could thus be well suited for identifying IDM entities in patents. The aim of QA applications is to automatically extract answers from documents for naturally formulated questions. An approach from the IDM ecosystem has already successfully shown that QA can help to link problems and solutions within a patent. However, there is still a lack of systems that offer end users the option of extracting appropriate solutions for a specific problem or contradiction by simply formulating a question.

The aim of this paper is therefore the prototypical development of an IR system able to automatically identify solutions to problems and contradictions from a document corpus of patents in English language by means of QA. The system will be designed to understand natural language using pre-trained BERT models or its derivatives, and extract corresponding information from a corpus of patents. In addition to identifying solutions for problems and contradictions, the system should be able to point to the source of the information and make it available to its users. The QA system will then be used to examine which patent sections are best suited for identifying relevant solutions and whether a search strategy using a problem/contradiction index leads to better results than identifying relevant passages simply by their semantic similarity to the query.

2 State-of-the-Art and Related Work

2.1 Patents

The special structure of patent documents makes them an ideal field for the application of text embeddings in transformer architecture such as BERT. This applies from both a technical and an economic perspective. There are over 20 million patents worldwide, each with an average of around 10,000 words. This text corpus is not only extensive, but is also characterized by unusual words, syntax, or neologisms that easily lead to the problem of vocabulary mismatch. From an economic point of view, patents are worth hundreds of billions of US dollars every year, so even small efficiency gains can have large financial benefits [4].

Despite of regional differences in the regulations for patent applications, patents have predominantly similar content structures across countries. Textually, patents mostly comprise the sections “Abstract”, “Description” and “Claims”. The “Description” usually consists of sub-sections like “Background (of the Invention)”, “Summary (of the Invention)”, “Brief Description of the Drawings” and “Detailed Description” [2]. Although it is known that problems are often listed in the “Background” section describing the state-of-the-art [3], it has not been sufficiently investigated to what extent the use of question-answering for the identification of problem solutions differs in quality depending on the section and which search strategies are most suitable for this task.

2.2 Inventive Design Method Based on TRIZ (IDM-TRIZ)

TRIZ is a heuristic assuming that invention takes place by overcoming technical conflicts which manifest as contradictions of parameters [1]. The type of contradictions can be abstracted and then mapped to a subset of 40 innovative principles using the TRIZ contradictions table in order to look for promising solutions from other domains, possibly adaptable for one’s own problem [10].

Based on the TRIZ principles, the Inventive Design Method (IDM-TRIZ) was developed. Its intention is a more formalized framework for inventive problem solving. TRIZ concepts are defined through ontologies, opening the door for automated analysis methods [1].

Figure 1 shows the IDM-TRIZ sub-ontologies for problems and contradictions in UML/SysML. Problems are situations that hinder the achievement of a goal or progress. (Partial) solutions, on the other hand, describe a verified result [1]. A problem can be solved by a partial solution; at the same time a partial solution can also lead to new problems. Problems can cause or include other problems. In IDM-TRIZ, problems are associated with evaluation parameters, while partial solutions are associated with action parameters. The aim of the IDM-TRIZ is to systematically arrive at concrete solutions for one’s own situation from problems or contradictions of a similar kind by transferring the solutions from other domains or alternatively serving as inspiration for the development of new innovative solutions.

Important aspects of the semantic IDM-TRIZ analysis are (1) the identification of the entities “problem”, “parameter”, “contradiction” and “solution” in texts, (2) quantifying the semantic text similarity (STS) between them and (3) linking them to each other to

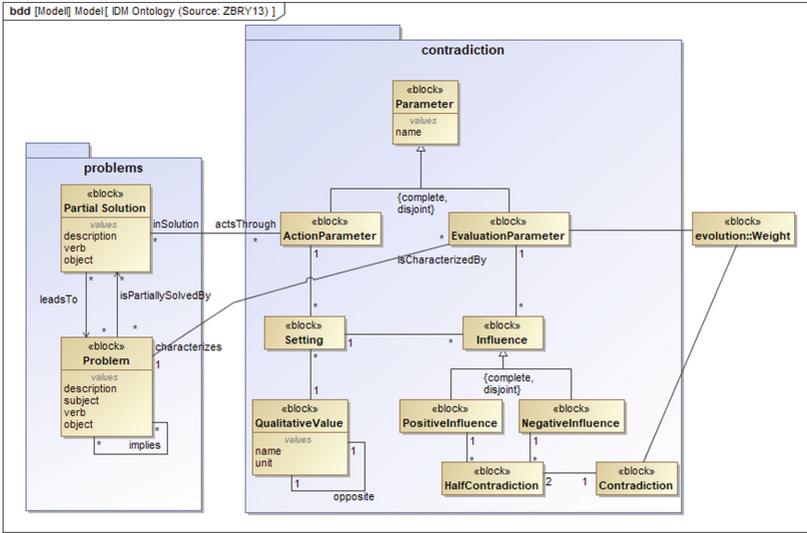


Fig. 1. IDM-TRIZ ontology for problems and contradictions [7].

find concrete solutions for problems. The latter is important, because patents typically contain multiple sentences verbalizing problems or solutions which are not necessarily related to each other. It is thus important to detect relationships between problems and partial solutions to understand which solution is the answer to which problem.

The IDM-TRIZ literature mainly relies on rule-based NLP (syntactics of sentences and signaling markers) to retrieve IDM-TRIZ entities and to link them to each other [11, 12]. However, Heller and Warschat show that BERT outperforms static word embeddings such as Word2vec and GloVe in the sentence-wise classification of problems and solutions [13]. “IDM-Matching” is a recent approach that determines links between solutions and problems within a single patent using a pre-trained XLNet QA model. A previously identified problem is reformulated as solution-search question to find the associated partial solutions in the text passages surrounding the initial problem [14].

For the recognition of similar problems in patents, problem sentences can be transformed into word embeddings using the shallow neural network Word2vec, which are then compared using their cosine similarity [8]. An alternative approach uses Long Short-Term Memory neural networks (LSTMN) to detect similar problems [15]. LSTMN are known to offer good accuracy, but are computationally expensive due to their structure [16]. The software application “PatentSolver” [9] offers the solutions from [8, 15], and [14] as separate steps, but does not integrate them into an end-to-end QA system.

2.3 Information Retrieval and Question-Answering Approaches

Information retrieval (IR) can be defined as “finding material (usually documents) of an unstructured nature (usually text) that satisfies an information need from within large collections (usually stored on computers)” [6]. There are various strategies for identifying relevant documents. Traditionally, lexical approaches have been used for IR, such as

Boolean retrieval using keywords and logical operators to check whether a document meets given conditions, or statistical relevance ranking like TF-IDF and BM25 [17]. However, these systems suffer from the lexical gap already mentioned in Sect. 1 [18] and cannot model lexical-semantic relations between query and document (document and query are treated as bag-of-words). Recently, dense retrieval (DR) methods have shown promising results, outperforming lexical approaches [19–21]. Contrary to lexical systems, they can discover semantic matches between a query and a document, thereby overcoming the lexical gap. DR methods learn query and document representations in a comparatively low-dimensional shared vector space with typically 100 to 1,000 dimensions (this is “low-dimensional” when compared with traditional bag-of-words sparse vectors). DR relies on largescale pre-training [27] and fine-tuning on IR datasets of considerable size [28, 29].

For digital processing, representations of documents or the information contained therein are often included in a document index in order to speed up the retrieval process and avoid carrying out complex operations on all full texts of the document collection with every search query. The type of index differs depending on the retrieval method used and can be sparse vectors, for example, frequencies of terms within the documents (for TF-IDF and BM25) or dense vector representations [6]. In vector-based models, documents and queries are translated into vector representations so that mathematical distance and similarity measures can be calculated to assess relevance [30]. At inference, a query representation is compared to each document vector. Among other possible metrics, the similarity can be calculated using the cosine similarity, with the maximum similarity being 1 if both vectors are the same [32, 42].

The problem with the original BERT model and other transformers specifically for IR is that they are Cross-Encoders (CE), i.e., they directly concatenate query and document as input to compute a relevance score. This enables direct, token-wise query-document interactions, but on the other hand this approach is computationally expensive and does not allow to pre-compute representations for a document index. To avoid this limitation, Dual-Encoders (DE, aka. Bi-Encoders or Sentence-Transformers) were developed, which independently convert text passages to be compared into a vector representation [31]. For IR, this allows to vectorize and index the corpus in advance, independently from a specific query. Compared to CE, DE are much faster, but on the other hand less effective than CE, since only the latter can consider attention-based relevance signals between the search and candidate texts on each transformer-encoder layer. The use of DE thus represents a compromise that inevitably sacrifices effectiveness in favor of gains in efficiency [43]. DE can be further divided into Siamese Dual-Encoders (SDE) and Asymmetric Dual-Encoder (ADE). While the parameters for encoding query and corpus are identical in SDE, few or no parameters are shared between the encoders in ADE. Using a QA example, Dong et al. show that SDE achieve better results than ADE [44].

To achieve state-of-the-art IR or QA results, nowadays often a two-stage architecture is used as shown in Fig. 2. First, an efficient and recall-optimized retrieval method (either lexical retrieval or dense retrieval using DE) retrieves an initial set of documents resp. text passages. Subsequently, a neural re-ranker optimizes the rank of the top retrieved documents. In QA the re-ranker (aka. as “reader” in this case) additionally delivers an

answer span (i.e., one or multiple words) within the document/passage. Like in DR, neural re-ranker/reader models benefit from pre-training and fine-tuning on large datasets. CE are the currently predominant architecture for re-rankers/readers [22].

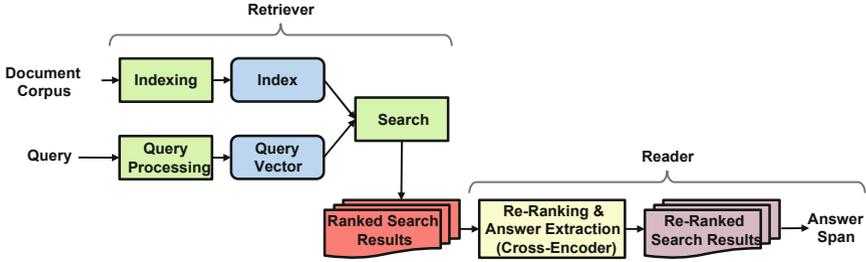


Fig. 2. Retriever-Reader Architecture for Question-Answering. Based on [5, p. 270/279].

2.4 Fine-Tuning Using Few-Shot Learning

Fine-tuning is an approach for improving the results of a pre-trained language model on a downstream task using an additional task-specific dataset. In contrast to other techniques like tuning the prompts for querying the model (prompt-tuning), fine-tuning adapts the model weights (parameters) of the pre-trained language model. Supervised learning of neural models requires comprehensive training data, but this data is often difficult to obtain or difficult to annotate. Specifically in the patent domain there is a lack of such data. Few-shot learning is a promising method for fine-tuning language models with a smaller amount of training data. The applicability of this methodology is also proven to solve text classification problems [23, 24].

Few-shot classification is typically based on similarity functions trained with pairs of objects that are known to belong either to the same class or different classes. Sentence-Transformer Fine-Tuning (SetFit) is one of the promising few-shot approaches for text classification that builds on these foundations and achieves considerable hit rates with just a few training data [37]. For binary classification with SetFit, sentence-pairs are created automatically from annotated sample data and given a new label, resulting in a group of three elements. For two sentences with a positive label, the resulting sentence-pair also receives a positive label, otherwise a negative label. For binary classification, according to the rules of combinatorics, n choose 2 sentence-pairs can be created as training data from n annotated sentences [46].

The SetFit approach comprises three steps: First, a pre-trained Sentence-Transformer model is fine-tuned with the created sentence-pairs in a contrastive Siamese manner. Second, the resulting fine-tuned Sentence-Transformer model is used to calculate sentence embeddings. Third, these embeddings are used to train a logistic regression classification head for the sentence-pairs. For the classification of an unknown sentence, the fine-tuned Sentence-Transformer model is used to calculate an embedding representation and to make a prediction with the logit model [37].

3 Question-Answering System Concept and Realization

This chapter describes the conceptual design and the realization of the QA system.

3.1 QA System Concept

The concept of the QA system comprises three major steps as described in the following sub-sections.

Sentence-Classifiers for IDM-TRIZ Entities. The first step is the creation of three sentence-classifiers for IDM-TRIZ entities according to Fig. 3.

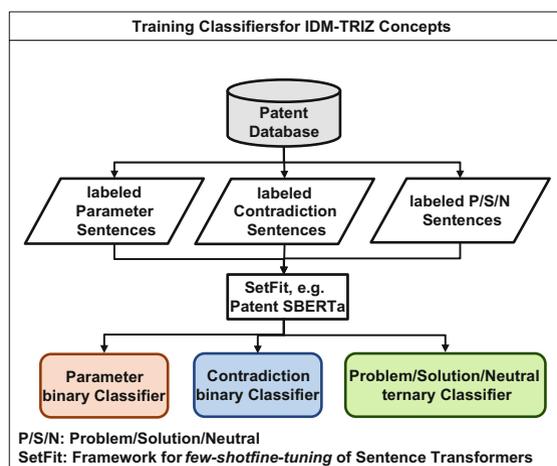


Fig. 3. Training Classifiers for IDM-TRIZ Entities.

There will be two binary classifiers (parameter/no_parameter) resp. (contradiction/no_contradiction) and one ternary classifier (problem/solution/neutral). The sentence-classifiers will be fine-tuned and evaluated using the SetFit framework for few-shot classification [25]. SetFit is a Python library that can be used in cloud-based development environments like Google Colab [26]. Colab allows the easy execution of Python code as Jupyter Notebooks on GPUs with high computing capacities, thus the environment is particularly suitable for training neural language models.

Index Creation. The second step is the index creation and storage of the patent corpus for QA according to Fig. 4. The indexing process starts with the patent content being loaded section-wise from the source data (Patent Database). Each patent section is saved separately in the document store to allow for differentiation and later filtering. In order not to exceed the maximum Sentence-Transformer token count of typically 512 tokens, documents must be split into multiple contexts beforehand, if the number of words in a section exceeds 500. When splitting, it must be ensured that sentences are always completely present in one context and that splits overlap with at least 10 words so that

no important information from adjacent sentences is lost. Furthermore, the system must calculate embeddings for the text passages using a Sentence-Transformer model. They are saved in the document storage for the case that a direct search on patent contexts (called “Deep Retrieval”) is desired. Additionally, the indexer splits every patent section into individual sentences and examines these with the classifiers. Sentences predicted as “problem” or “contradiction” are added separately to the document storage together with their calculated Sentence-Transformer embedding. Due to the use of DE and a passage index the QA system’s architecture is well prepared for extensive corpora, which are typical for the patent domain.

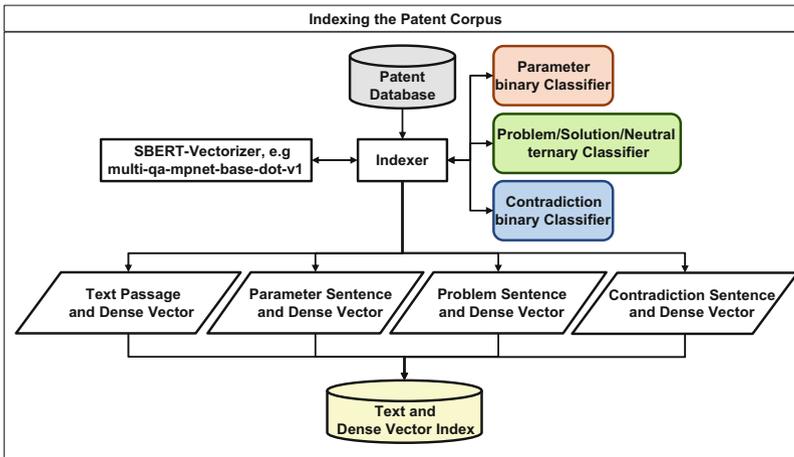


Fig. 4. Indexing the Patent Corpus.

Question-Answering for Inventive Solutions. The retrieval component of the QA system, as shown conceptually in Fig. 5, is used to identify relevant candidates from the document storage for a given question. During the indexing process, problems and contradictions are, in addition to patent passages, already included as documents in the database together with their embeddings. All these embeddings are calculated with the same Sentence-Transformer model, e.g., `multi-qa-mpnet-base-dot-v1` [38]. Therefore, it is possible via API to carry out either a similarity search on all indexed patent passages (“Deep Retrieval”), or to limit the similarity search to the indexed problem and contradiction sentences. For both cases the same language model is used to select relevant candidates based on cosine similarity.

3.2 Corpus and Training Data

The patent corpus used for this paper is provided by a research team of the Institut national des sciences appliquées de Strasbourg (INSA). It contains a total of 3,200 English-language patents from the database of the United States Patent and Trademark

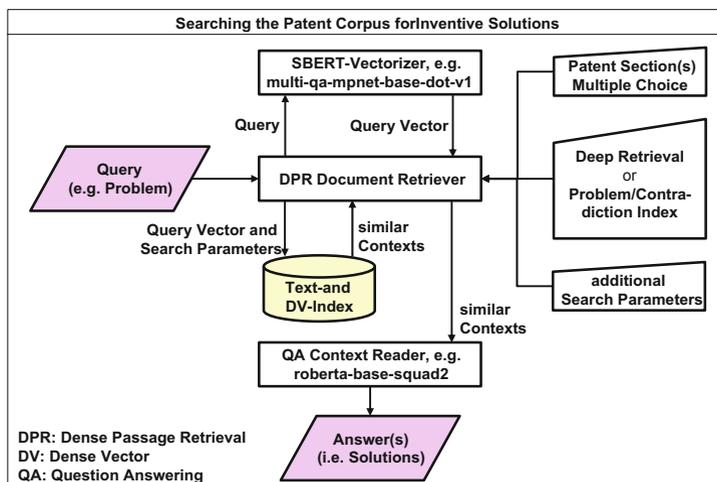


Fig. 5. Searching the Patent Corpus for Inventive Solutions

Office (USPTO). Half of these patents (1,600) already contain expert-annotated IDM contradictions, each consisting of two sentences [45]. Data sets were compiled from this corpus for the training and evaluation of the classifiers. This is a relatively small corpus, however, as already mentioned in Sect. 3.1, the architecture of the QA system is suitable for much bigger corpora.

Data for Contradiction Classification. The raw data set has already been examined and annotated by several domain experts for contradictions consisting of two sentences, one describing an improving and the other a deteriorating parameter [45]. However, since the concept of a contradiction can also be described in a single sentence, sentences with syntactic and semantic indications of a contradiction were randomly selected from the raw data. The returned sentences were checked in a manual evaluation process and finally annotated. The checked labeled datasets were mixed with random contradictory sentences from the raw dataset as well as with manually checked sentences that cannot be assigned to this concept. The final data set consists of 470 sentences in total, which are annotated as ‘contradiction’ (1) or ‘no contradiction’ (0).

Data for Problem and Solution Classification. For the ternary classifier, which assigns patent sentences to one of the three classes ‘problem’, ‘solution’, or ‘neutral’, a data set with a total of 183 annotated sentences was compiled. To accelerate the identification of problem and solution sentences, potential candidates were pre-qualified using a syntactic classifier [9] using random sentences from the raw data set. These were then checked manually and mixed with other random and manually labeled sentences.

Data for Parameter Classification. Since the raw dataset already contains labeled parameter sentences within the annotated contradictions, the compilation of the dataset for the binary ‘parameter’ classifier started with the selection of a random subset of the already labeled sentences. Further candidates were identified using a syntactical parameter extractor from the source code of the “PatentSolver” [9] application, then

checked for correctness, labeled, and appended to the dataset. Other random sentences from the raw data were checked and annotated as ‘parameter’ (1) or ‘no parameter’ (0). Eventually, 328 patent sentences are evenly distributed between the two classes.

Data Preparation. The datasets were imported using the Pandas Python library, which transforms labels into numeric values and finally into a `Dataset` class. The order was randomized based on a defined seed to ensure random ordering while maintaining reproducibility. All three datasets were split into training and test data in randomized order.

3.3 QA System Realization

Classifier Fine-Tuning. The fine-tuning of the classification models was carried out with the SetFit framework based on different initial models in order to compare the performance and to select the best possible model. The fine-tuning was done in three epochs with a batch size of 32 resp. 64. Cosine similarity was chosen as loss function, since it has proven to be suitable for sentence classification [37]. Six base models were fine-tuned. Three of them (*all-mpnet-base-v1*, *all-distilroberta-v1*, *all-MiniLM-L6-v2*) are provided by the Sentence-Transformers framework and represent the state-of-the-art of general-purpose models with different size and encoding speed (*all-mpnet-base-v1*: 2,800 sentences per sec on a V100 GPU, *all-distilroberta-v1*: 4,000, *all-MiniLM-L6-v2*: 14,200). Model *all-mpnet-base-v1* was chosen over *all-mpnet-base-v2*, because it showed better results in all three classification tasks, probably due to its longer sequence length of 512 vs. 384 [38]. Three other “external” models were chosen, that are specifically adapted via initial training or fine-tuning to patents resp. scientific texts (*allenai/scibert_scivocab_uncased* [39], *AI-Growth-Lab/PatentSBERTa* [40], *anferico/bert-for-patents* [41]).

Microservice for Classification. A common microservice was implemented for the three classifiers with the Python-based web framework Flask [33]. To ensure portability, the application was orchestrated into a Docker container. To classify sentences, the web service provides three endpoints (`/contradiction`, `/parameter`, `/nps`) and expects POST requests with a JSON object as payload, which contains a list of sentences to classify. The return values of the binary classifiers are coded as 1 and 0. For the ternary “problem classifier” the three return values are 0 for neutral, 1 for problems, and 2 for solutions.

Index, Storage, and Retrieval. Due to its characteristics, the database and search system Weaviate [34] was chosen for index creation, storage, and retrieval. It combines the storage of JSON objects with associated vector representations. Weaviate supports approximate nearest neighbor search (ANN) using a Hierarchical Navigable Small World (HNSW) index in order to approximately detect nearest neighbors with high performance [35]. In addition, Weaviate natively offers semantic search queries, QA extraction, and classification. Calls to the system can be made both as REST or GraphQL requests. To store documents, the `WeaviateDocumentStore` class from the Haystack framework is used, which establishes a connection to the Weaviate database. Together with the textual content and the associated embedding, meta information can be stored, allowing

to limit search queries to a subset of the texts stored by meta data filtering [36]. Due to this feature, it was decided to include both, the contents of the patents, plus the problems and contradictions detected by the classifiers, in the same document storage. To distinguish the document types, the meta information values “patent” for patent content, resp. “problem” or “contradiction” are stored in a metadata field. All embeddings for the retriever (i.e., index and query) are calculated using the Sentence-Transformer model *multi-qa-mpnet-base-dot-v1* [38].

Microservice for Question-Answering. The API for the QA system was implemented as microservice using the Framework FastAPI [47] and orchestrated as Docker container. The main endpoints are `/query` for searching the problem/contradiction index and `/deep_query` for searching in all text passages.

Front-End. The front-end of the web application was implemented using the Streamlit framework and orchestrated as Docker container. A screenshot is shown in Fig. 6.

It has an input field for the query and a side menu to define query and filter choices. Filtering includes the option to limit the search to selected sections of the patent. The choices “Abstract”, “State-of-the-Art”, “Claims” and “Description” are available. Multiple patent sections can be selected at the same time or the search can be extended to all sections by leaving the filter blank. The “KNN for Retrieval” option can be used to vary the number of similar documents (problems, contradictions, or passages) from the index to be considered. To search within a specific patent from the index, it is possible to enter the desired patent ID. The maximum number of answers to be displayed and a threshold value for the estimated relevance of the results can also be set using sliders.

Instead of searching the index specifically for problems or contradictions already detected by the classifiers and stored separately in the database, the front-end also allows to search for relevant patent documents via similarity between query and the passages created from the full texts. This can be accomplished selecting the “Deep Retrieval” checkbox.

4 Evaluation

4.1 Evaluation of the IDM-TRIZ Classifiers

Contradiction Classifier. When training on a total of 128 sample sentences, combined to a data set of 7,936 sentence-pairs for 3 epochs and batch size 64, the test data of 342 sentences shows that the classifier based on `scibert_scivocab_uncased` reaches the best F1 value of 0.909. A detailed comparison is shown in Table 1. The value range for accuracy, precision, recall and F1 is from 0 to 1 with 1 being the best possible value in each case. All results are rounded to three digits. The best performing model for each (unrounded) metric is marked in **bold** letters, the second-best model is shown underlined. As precision and recall are conflicting values for IR systems, the F1 score, calculated as the symmetric harmonic mean of precision and recall, is taken as the dominant metric to rank the models.

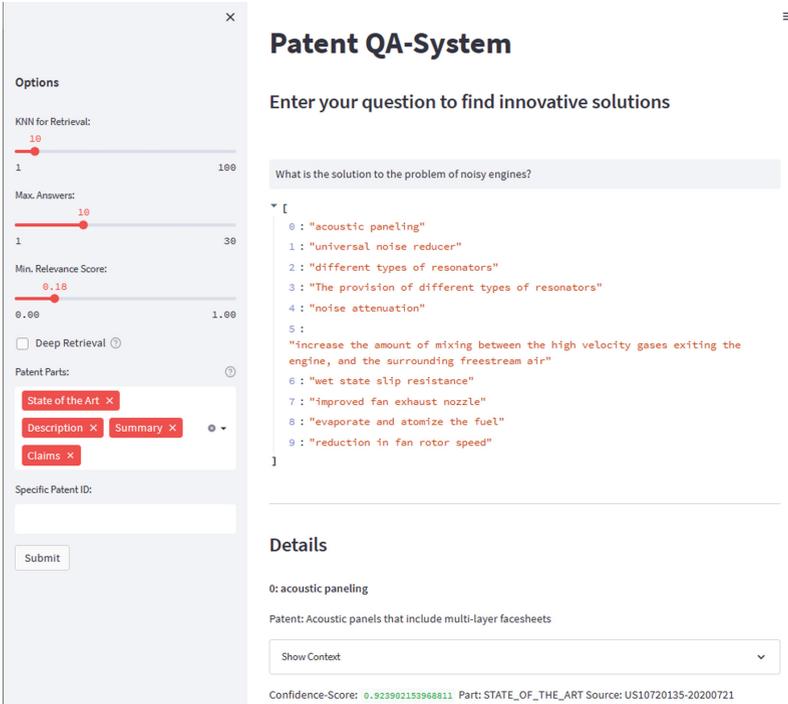


Fig. 6. Screenshot of the QA-System Prototype.

Table 1. Contradictions (batch-size 64, 3 epochs, 31 iterations, 7936 examples).

Base Model	Accuracy	Precision	Recall	F1
all-mpnet-base-v1	0.880	0.862	0.916	0.888
all-distillroberta-v1	<u>0.892</u>	0.881	0.916	0.898
all-MiniLM-L6-v2	0.886	0.860	0.933	0.895
allenai/scibert_scivocab_uncased	0.904	<u>0.892</u>	<u>0.927</u>	0.909
<u>AI-Growth-Lab/PatentSBERTa</u>	0.904	0.901	0.916	<u>0.908</u>
anferico/bert-for-patents	0.878	0.862	0.910	0.885

Parameter Classifier. The training of the binary parameter classifier was carried out with 128 labeled example sentences, which were combined to 7,936 sentence-pairs. For 3 epochs and batch size of 64, again the classifier based on `scibert_scivocab_uncased` achieves the best results in Accuracy, Recall and F1 (0.843) on a test dataset of 200 sentences, as shown in Table 2.

Problem/Solution/Neutral Classifier. The training of the ternary classifier discriminating between the three classes of “neutral”, “problem”, or “solution” was performed

Table 2. Parameters (batch-size 64, 3 epochs, 31 iterations, 7936 examples).

Base Model	Accuracy	Precision	Recall	F1
<u>all-mpnet-base-v1</u>	<u>0.825</u>	0.767	0.918	<u>0.836</u>
all-distillroberta-v1	0.805	0.742	0.918	0.820
all-MiniLM-L6-v2	0.770	0.701	0.918	0.795
allenai/scibert_scivocab_uncased	0.830	<u>0.765</u>	0.938	0.843
AI-Growth-Lab/PatentSBERTa	0.815	0.750	<u>0.928</u>	0.829
anferico/bert-for-patents	0.820	0.752	0.938	0.835

in 3 epochs with a batch size of 32 and cosine similarity loss function. For a training data set of 4,416 sentence-pairs generated by 64 labeled single sentences, the evaluation on a test data set of 119 sentences again showed that the classifier based on `sci-bert_scivocab_uncased` achieves the best values for all evaluated metrics as shown in Table 3. The F1 score is 0.837.

Table 3. Problem/Solution/Neutral (batch-size 32, 3 epochs, 23 iterations, 4416 examples, average “weighted” – which may produce an F1 score not between precision and recall [50]).

Base Model	Accuracy	Precision	Recall	F1
all-mpnet-base-v1	<u>0.828</u>	0.835	<u>0.828</u>	0.825
<u>all-distillroberta-v1</u>	<u>0.828</u>	0.831	<u>0.828</u>	<u>0.826</u>
all-MiniLM-L6-v2	0.736	0.778	0.736	0.733
allenai/scibert_scivocab_uncased	0.839	0.853	0.839	0.837
AI-Growth-Lab/PatentSBERTa	0.759	0.766	0.759	0.756
anferico/bert-for-patents	<u>0.828</u>	<u>0.852</u>	<u>0.828</u>	0.822

The model `scibert_scivocab_uncased` consistently achieves the best results for all three classifying tasks. Comparing the three general-purpose models *all-mpnet-base-v1*, *all-distillroberta-v1*, *all-MiniLM-L6-v2* with those specifically adapted to patents resp. scientific vocabulary (*allenai/scibert_scivocab_uncased*, *AI-Growth-Lab/PatentSBERTa*, *anferico/bert-for-patents*) a slight tendency towards the adapted models can only be assumed. For the general-purpose models, the bigger and slower models tend to show better results than the smaller ones, but even the medium size model *all-distillroberta-v1* shows competitive evaluation scores.

4.2 Evaluation of the Question-Answering System

Comparison of Reader Models. For end-to-end QA system evaluation, precision and recall were calculated based on 15 questions to the system (see Appendix) using the

document sourcing method [32]; i.e., for 15 known solutions from different patents corresponding questions were formulated, sent to the system and the answers checked manually for correctness. A comparison of two language models fine-tuned on the SQuAD 2.0 data set as CE reader shows that the *roberta-base-squad2* model [48], with an F1 value of 0.82, clearly achieves better results than *bert-based-cased-squad2* [49], reaching an F1 of only 0.29 as shown in Table 4. Compared with a state-of-the-art QA approach for identifying specific problem solutions, the F1 value 0.82 of the *roberta-base-squad2* model is high: the ‘‘IDM-Matching’’ procedure of Ni et al. [14], which reaches an F1 value of 0.72 in its evaluation tests, is outperformed. For a meaningful and qualitative comparison, however, both approaches should be checked on the same test collection.

Table 4. Comparison of Reader models.

Model	Precision	Recall	F1
bert-base-cased-squad2	0.33	0.27	0.29
roberta-base-squad2	0.84	0.80	0.82

Comparison of Search Strategies. The comparison of the search strategies in Table 5 shows that the problem/contradiction index, with an F1 score of 0.82, leads to better results than the deep search, directly returning contexts with the highest semantic similarity from the document database (F1 score 0.62).

Table 5. Comparison of Search Strategies (*roberta-base-squad2*).

Strategy	Precision	Recall	F1	SD (Precision)
Deep Retrieval	0.57	0.67	0.62	0.05
PB-Index	0.84	0.80	0.82	0.03

A further analysis of the results shows that the precision is significantly higher when searching with the problem (PB) index ($M = 0.84$; $SD = 0.03$) than with the deep search without PB-index ($M = 0.57$, $SD = 0.05$). The t-value is 3.54. The p-value is < 0.01 . The result is therefore significant for $p < 0.01$.

Results Depending on Patent Section. The comparison of the results per patent section in Table 6 shows that the ‘State-of-the-Art’ (S-o-t-A) section has the highest average relevance score for all examined search strategies (PB-index vs. Deep Retrieval) and relevance thresholds (0.2 vs. 0.5). For a low relevance threshold of 0.2, the section ‘Description’ delivers the largest number of results in absolute figures. However, this number is clearly reduced, if the relevance threshold is increased to 0.5. It can therefore be assumed, that a qualitative evaluation of the ‘Description’ section results would show

a lower precision. A possible reason for the high number of hits in the ‘Description’ section is the fact that it has a longer average text length compared to the other sections, since inventions are discussed in detail here.

Table 6. Results depending on Patent Section (*roberta-base-squad2*).

Section	Strategy	Threshold	Results	\varnothing Results/Query	\varnothing Score	σ^2
Abstract	PB-Index	0.2	8	0.53	<u>0.37</u>	0.02
S-o-t-A	PB-Index	0.2	<u>38</u>	<u>2.53</u>	0.38	0.03
Claims	PB-Index	0.2	19	1.27	0.28	0.00
Description	PB-Index	0.2	72	4.80	0.30	0.01
Abstract	PB-Index	0.5	4	0.27	0.50	0.00
S-o-t-A	PB-Index	0.5	9	0.60	0.63	0.02
Claims	PB-Index	0.5	1	0.07	0.46	-
Description	PB-Index	0.5	<u>6</u>	<u>0.40</u>	<u>0.57</u>	0.01
Abstract	Deep Retr	0.2	18	1.20	0.28	0.01
S-o-t-A	Deep Retr	0.2	54	3.60	0.36	0.02
Claims	Deep Retr	0.2	17	1.13	0.29	0.01
Description	Deep Retr	0.2	<u>33</u>	<u>2.20</u>	<u>0.32</u>	0.01

Table 7 shows that the 15 questions, if results are evaluated manually for their relevance, deliver more relevant results when targeting the ‘State-of-the-Art’ section ($M = 1.93$; $SD = 1.78$) in comparison to the ‘Claims’ section ($M = 0.87$; $SD = 0.98$). The t-value is 2.46. The p-value is < 0.01 . The result is therefore significant for $p < 0.01$. It can also be seen that the ‘Claims’ section ($M = 0.87$; $SD = 0.98$) delivers more relevant results when compared to the ‘Abstract’ section ($M = 0.47$; $SD = 0.41$). The t-value is 1.31. The p-value is 0.099. The result is therefore (weakly) significant for $p < 0.10$.

Table 7. Relevant Results per Section (*roberta-base-squad2*, PB-Index, Threshold = 0.2)

Section	Relevant Results	\varnothing Relevant/Query	SD
Abstract	7	0.47	0.41
Claims	<u>13</u>	<u>0.87</u>	0.98
S-o-t-A	29	1.93	1.78

5 Conclusion

This paper showed that end-to-end QA with transformers and few-shot learning can be successfully applied to identify solutions for technical problems or contradictions in patent texts. With an F1 score of 0.82 the language model *roberta-base-squad2* clearly outperforms the model *bert-based-cased-squad2* ($F1 = 0.29$) as CE reader and should therefore be preferred.

This F1 score of 0.82 for *roberta-base-squad2* results from searching on a problem and contradiction index, prepared using Sentence-Transformer classifiers. Searching directly for relevant patent passages delivers a significantly lower F1 score of 0.62. It can therefore be concluded that “problem-similarity beats passage/context-similarity”. With $F1 = 0.82$ the system surpasses the QA approach of Ni et al. for IDM solution extraction from patents ($F1 = 0.72$) [14]. However, for a better qualitative comparison, the different approaches should be evaluated on the identical test collection.

In the few-shot fine-tuning for the IDM-TRIZ classifiers the model *scibert-scivocab-uncased*, which is pre-trained exclusively on scientific texts, showed the best results. Other evaluated models, pre-trained on patent vocabulary, could not clearly outperform general-purpose language models, which show competitive evaluation results, too.

In an inference analysis it was shown that the “State-of-the-art” section of the patents is particularly suitable for identifying specific problem solutions. Here the number of relevant results is significantly higher than in the “Claims” section, which in turn is significantly more fruitful than the “Abstract” section. In the test environment, it was observed that also the “Description” section generated a lot of results. These even exceeded the number of hits in the “State-of-the-art” section, but achieve a lower confidence score, which can be assumed to result in a lower precision. Presumably, the high number of hits in the “Description” section can be explained by its bigger text length.

6 Limitations

Only a relatively small corpus was employed in this paper for evaluation. However, the QA system’s architecture is in principle well prepared for large corpora due to the use of Dual-Encoders and a passage index.

The QA system’s evaluation used the document sourcing method. The results should thus only be interpreted as an estimation, since on the one hand it is not a representative sample of questions and on the other hand there might have been an unconscious influence on question formulation [32]. A test collection, compiled by several experts with specific domain knowledge, would be a preferable alternative.

Since only a single “off-the-shelf” QA language model (*multi-qa-mpnet-base-dot-v1*) was used for the retriever and two others (*bert-base-cased-squad2* and *roberta-base-squad2*) were compared to each other for the reader, it would be worthwhile for future work to examine other models for suitability or to investigate how further fine-tuning of pre-trained language models affects the quality of the results.

The few-shot fine-tuned IDM-TRIZ classifiers achieved comparatively high accuracy and F1 scores up to 0.9. For a more reliable statement, these results should be tested on

larger data sets in future work. It would also be interesting to investigate the options for a more accurate detection of contradictions and problems that spread across multiple sentences.

Since a quantitative analysis showed that the QA system extracts many answers from the sections “Description” and “State-of-the-art”, the quality of these results and those from the “Claims” section should be compared to each other in subsequent work.

Another potential for follow-up studies are the thresholds such as the confidence score, which were only “guessed” in this paper instead of optimizing them. The same applies to the length of the text passages stored in the QA system’s index.

Appendix: Evaluation Questions for the QA System

1. What is the solution to the problem of noisy engines?
2. What is the solution to the problem that a toilet brush is dirty after use?
3. What is the solution to the conflict between temperature and performance?
4. What is the solution to the problem of insufficient dynamic range?
5. What is the solution to the problem that ventilation affects aerodynamic driving qualities of a vehicle?
6. What is the solution to the problem that gloves are bulky and of a size which is not suitable for being carried in one’s pocket?
7. What is the solution to the problem that palletized goods can be damaged during transport?
8. What is the solution to the contradiction that engines are noisy and affect the comfort?
9. What is the solution to the problem that the frame construction of a go-kart can pose a risk to the protection of the driver?
10. What is the solution to the problem of a spectator losing his seat if he leaves it for even a few minutes?
11. What is the solution to the problem that printing and painting on metal sheets often binds impurities to the surface?
12. What is the solution to the problem that video cassette containers can be protectively packaged and printed at the same time?
13. What is the solution to the problem that toilet seats can be unclean?
14. What is the solution to the problem that drinks can spill while driving?
15. What is the solution to the problem of PCBs colliding with the locking bar when locking magazines?

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TRIZ, Truth and AI

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Abstract. Some schools of thought believe that AI could present a profound change in the history of life on Earth, on the one hand allowing humanity to transcend to a higher level, on the other, leading to our collective downfall. Which view, if either, is correct, and why? If it is the latter, what can we do about it? What does AI actually mean? Are we heading, as yet another school of thought believes, into another AI Winter during which progress will grind to a halt via unrecognised or unsolvable contradictions? What does the whole story have to do with truth? And what might TRIZ be able to contribute to that story?

Keywords: AI · Complexity · Chaos · Goldilocks-Curves · Dunning-Kruger Effect · Law of System Completeness · Contradictions

1 The Problem

1.1 A Subsection Sample

“What we call Man’s power over Nature turns out to be a power exercised by some men over other men with Nature as its instrument... Man’s conquest of Nature, if the dreams of some scientific planners are realised, means the rule of a few hundreds of men over billions upon billions of men. There neither is nor can be any simple increase of power on Man’s side. Each new power won by man is a power over man as well. Each advance leaves him weaker as well as stronger. In every victory, besides being the general who triumphs, he is also the prisoner who follows the triumphal car... Man’s final conquest has proved to be the abolition of Man” [1].

Recent years have seen droves of so-called experts make pronouncements about the positive and negative attributes of AI. On one level, as is the case with all technologies, AI is, from moral and ethical standpoints, neither good nor bad. It only becomes one or the other because of the way Man chooses to use it. While debating the various pros and cons of ‘super-intelligent’ Artificial General Intelligence, what seems clear is that evolution towards its creation is happening anyway. Narrow AIs already do many specific jobs – detecting cancerous cells in x-rays; trading stocks and shares; calculating insurance risk to name but three - better than the most capable human experts. It has become clear that the speed at which new digital technologies are being developed is considerably faster than the capacity of any individual to keep up. More seriously, it is also clear that the

ability of Society to legislate and provide the necessary guard-rails that will prevent AI running amok and destroying all our institutions is an order of magnitude slower again than our individual capacity to keep up. The result is an enormous and growing mismatch between our Space-Age technology, Stone-Age brains and Dark-Age governance.

1.2 The Map is not the Territory

The essential first step towards knowing where humanity is heading and, moreover, to be able to make conscious choices concerning where we might want it to head, is knowing where we are. Knowing where we are is in turn a difficult thing to capture because of the apparent speed new knowledge is being generated. We might argue about precisely when the line between knowledge creation and the capacity of an individual to retain all the available knowledge crossed over, but no-one can be in any doubt that it *has* now crossed over – Fig. 1:

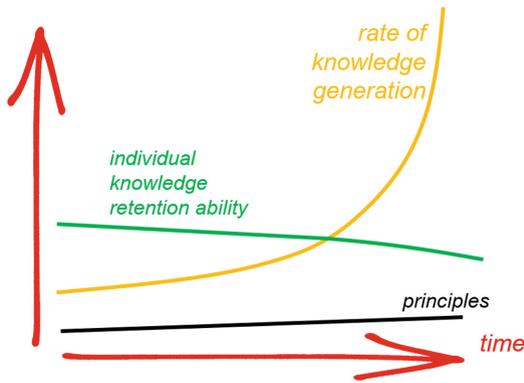


Fig. 1. Knowledge Generation Versus Individual Knowledge Retention Capacity.

The answer to this cross-over conundrum starts with a recognition that, while the flow of knowledge might now be heading exponentially to infinity, much of it turns out to be noise. Knowledge expands exponentially, but, as indicated by the almost flat line at the bottom of the graph, the principles upon which knowledge is built remain largely constant. This is a finding that the original TRIZ researchers discovered by accident, when, for example, realising that, while there are millions of ways of solving problems badly, there are only a very small number of ways of doing it well. More recent TRIZ-based research has further revealed that one of the most important first principles is the evolutionary s-curve, and the related idea that the way the world evolves is through periodic discontinuous jumps that occur when an existing way of doing things hits a fundamental limit, and someone – either deliberately or accidentally – unlocks a new, contradiction-solving way of doing things better. As a consequence of this realisation, the whole job of distilling the world down to first principles becomes much easier: look for the discontinuous jumps and the principles will reveal themselves.

Thus, when it comes to making an attempt to construct maps of ‘where we are’, it becomes possible to recognise that there are four discontinuously different types of

world in which we can find ourselves: simple, complicated, complex and chaotic [2]. What this Cynefin framework also fails to capture is Beer's observation [3] that systems operate on different hierarchical levels, and that the level of complexity found at one level may be different to that found at another. The idea of constructing a map of the world that allows for multiple (usually two) hierarchical levels, has led to the (most recent iteration) Complexity Landscape Model [4–6].

The current AI state-of-the-art places the technology clearly in the Simple and Complicated domains. Instructing an AI to switch on streetlights when the ambient light level falls below a specified threshold amount is an example of a simple problem. The AI 'just' needs to be told what the threshold level is. Instructing an AI to analyse x-rays and find cancerous cells is an example of a complicated problem. The complication here being that the AI currently needs to be trained on hundreds of thousands of examples to 'learn' what is cancerous and what is not. Crucially, in this kind of complicated problem we know that there is such a thing as a 'right' answer, and that we merely need to provide sufficient training data to find it.

Complex problems, on the other hand do not possess a 'right' answer. The controversy relating to the efficacy of mask-wearing during the Covid-19 pandemic offers an illustration. For AI to potentially help generate meaningful solutions to the question of whether or not to wear masks during future pandemics the Complexity Landscape Model is necessary but no longer sufficient. The Map is not sufficiently representative of the Territory. To make it sufficient it is necessary to construct a new map.

1.3 Logos and Mythos

The inspiration behind the Correct-True Map illustrated in Fig. 2 came from a quote by Sufi scholar, Idries Shah [7]. The quote comes from a parable involving a discussion about truth between a judge and a boatman. The insight sparking part of the quote comes from the boatman: "*Alas!*" said the boatman, *'if learning is considered to be dependent on the production of proof, we only have one half of knowledge, and we are surely lost.'*" Truth, in other words, has two orthogonal dimensions. The first – 'Correct' – is the one relating to the scientifically provable 'correctness' of a situation; the tangible, objectively measurable reality of a situation; the 'logos' as defined in Ancient Greece. The sort of thing that today's AI's can in theory be trained to help uncover. But then the second dimension – the non-provable 50% referred to by the boatman – is all about 'truth's that are more metaphorical, or, back to Ancient Greece again for a second, concern the 'mythos'; the knowledge and wisdom that emerges from the Arts and artists like Pablo Picasso with his description of art as 'the lie that reveals the truth'.

Since the eighteenth Century, Society has increasingly separated the logos from the mythos. Or rather, the academics of the world have. Academic progress for the last two hundred plus years has placed a heavy emphasis on specialisation. Such that not only have the Arts and Sciences become separated, but, back to the mask question again, the various scientific disciplines have also become sufficiently separated that a specialist in one domain has little or no idea about what happens in even an adjacent domain. The extreme levels of specialisation found not just in academia, but also across industry are likely the reason politicians get to say things like, 'we've had enough of experts'. The statement is both dumb and Correct. Correct because, per the Dunning-Kruger Effect

[8], every specialist on the planet is sitting on Mount Stupid, confident that they ‘know the answer’ when in fact they only know the answer from their own massively blinkered perspective. In effect, to paraphrase *The Basic Laws Of Human Stupidity* [9], we’re all on Mount Stupid. Here, AI is probably our best hope of progress. It is practically impossible for any expert to gather sufficient inter-domain knowledge to sensibly answer something as ‘simple’ as the mask-wearing problem, but it is eminently possible to train an AI to map all of the relationships between the different domains.

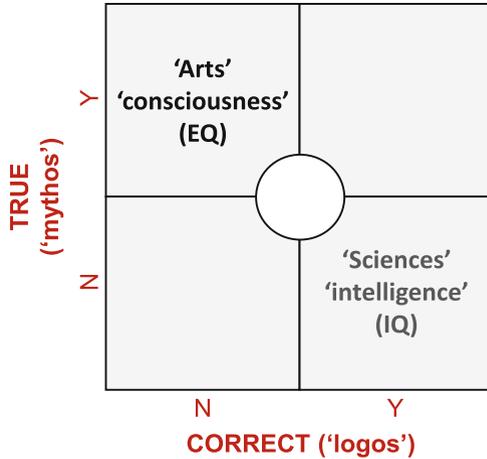


Fig. 2. Correct/True (Logos/Mythos) Framework.

Except, of course, ‘all’ turns out to be an enormous problem thanks to the mythos dimension in the Correct/True Framework. And here the AI capability question gets blown wide open. Will an AI ever be able to create poetry? Will it be able to paint a masterpiece? Will it ever, efficacy aside, be sensitive to the cultural value of mask wearing? Some might say, having used Chat-GPT to write a greeting card poem to ingratiate themselves with a loved one, that, yes, of course, AI’s can already write poetry. But the words written into that card are anything but actual poetry. They are a (literally) meaningless simulacrum. The mythos side of the AI argument will no doubt vehemently argue that this will always be the case. Computers will never *understand* metaphor, or the metaphorical truths contained within the best fiction writing. Parables and ‘fairy-stories’ that have nothing to do with factual correctness, but everything to do with what artists might think about in their quest for meaning in life. Actual art, in other words, sits in the top-left-hand corner of the framework, and it will always rest exclusively within the domain of human creativity.

From a ‘first principles’ perspective, however, the TRIZ community (if there is such a thing and we can finally reach a point where everyone is willing and able to put their ego on one side and sit in the same room together) knows that human creativity is not an infinite unknown. Quite the reverse. There are millions of ways of solving a problem badly, but only 40 ways of doing it well. And 40 is a number that is highly amenable to being programmed. The fact that the most ‘creative’ man-created solutions exhibit

evidence of multiple Principles being used together makes teaching an AI to unlock the ‘right’ combination harder, but nevertheless, knowing that an AI can explore billions of combinations in the time it would take a human to explore one or two, would suggest that sooner or later – and probably sooner – a computer will be able to do at least the generative part of the mythos job.

What will still be extremely difficult is the later wisdom part of the equation. AI works with knowledge. Wisdom requires that knowledge to be contextualised, and that is a much more difficult challenge. Albeit one that, again thanks to a recognition that when distilled down to first principles, recognises while there are currently 8 billion completely unique individuals on the planet right now, the reality is all of us are driven by the self-same, very finite set of values and emotional drives. Not least of which are the six dimensions from which human morality and ethics emerge [10] (Fig. 3):

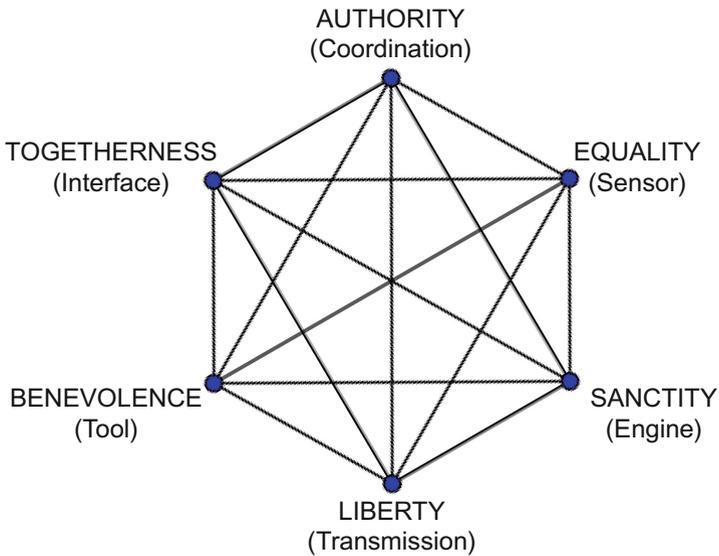


Fig. 3. STABLE System of Human Morality & Ethics.

This STABLE model, perhaps takes us to the real heart of the complex AI future question. It does so because it takes us to the heart of the current human problem. The social-media accelerated problem that has led to seemingly everyone being dragged into online echo chambers that prevent the different sides of an argument from even discussing differences, never mind working together to resolve them. Put people into an echo chamber full of like-minded people for even a short period of time, and they effectively become radicalised to a single way of thinking. One minute a person joins a discussion group to share their thoughts about the use of pronouns, a month later they’re uploading TikTok videos of them aiming an assault rifle at the camera and demanding that the Government bans J.K. Rowling.

The heart of this problem is that all six of the elements of the STABLE model are present in all of us. Any discussion about whether one of the six is more or less important than any other is therefore futile. All such discussions do is in effect try and find an ‘optimum’ balance between each of the six elements. But here’s where all 8 billion people on the planet are different. We’re all the same because we all build our values around the six elements, but we’re all different because we not only prioritise them in different ways but will likely change those priorities depending on our in-the-moment context. When we’re thinking about the education system – certainly today’s version of it – then equality (nay, ‘equity’) is likely to find its way to the top of the priority list, but then tomorrow morning, when I receive another speeding ticket in the mail, I’m suddenly much more interested in my Liberty and how unfair the Authorities are being.

The only meaningful answers to these kinds of moral debate will inevitably have to come from a process of contradiction resolution. The right question, in other words, can never be about, say, Liberty *versus* Togetherness, but rather needs to be about finding a higher-level synthesis that would allow both to still be accommodated.

This thought perhaps offers a clue to how TRIZ might fit into a ‘Correct *and* True’ future. And the AI that may be created to help humanity get there. But before we get to that, it is necessary to add another question into the already complex (if not chaotic) story. A question that forces us to think about directionality, and what do we collectively want humanity to become. Is the future world predicted by C.S. Lewis in 1943 what we want? Or do we want something else?

The answer to such questions is probably beyond where humanity’s collective capability is today. Most people on the planet don’t have an awareness of where we are never mind thinking about where we might want to be. One thing we can perhaps hypothesise in light of the fact that we do have the CLM and Fig. 2 matrix, is that it is generally better for individuals, communities and Society as a whole to be able to be able to operate and thrive in complex and chaotic situations. And it is better to be in the ‘Correct *and* True’ quadrant than in any of the other three.

If we can’t agree on those two things, it is plausible that the current generation of AI creators will destroy Society before our Institutions have the first clue what is coming. If we can agree, there is a possibility that our collective future outcomes have a chance of being more positive. Not a big chance, granted, but a chance nevertheless. One that TRIZ would appear to form an integral part of...

2 Towards an (AI-Integrated) Solution

2.1 Law of System Completeness

...whatever the destination, the TRIZ research tells that that getting from where we are to where we want to be requires the presence of a viable system. Which in turn means that the Law of System Completeness (LoSC) needs to be obeyed. It probably also means that there needs to be a viable system to deliver the logos goals and another, ideally integrated, viable system to deliver the mythos (‘Truth’) goals. Figure 4 identifies what the six essential elements are likely to look like if such a system is to become a reality:

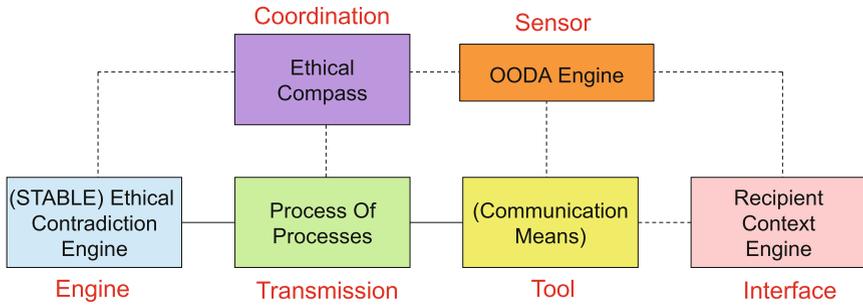


Fig. 4. Law of System Completeness as Applied to a Truth-Seeking Ethics System.

A more detailed description of each element will hopefully help answer the later question about what is likely to happen in the future. Starting with the two elements that are already visibly present:

Tool – The thing that delivers the useful function. This is undoubtedly the part of the system that is currently the most mature, in that since the recent viral growth of awareness in AIs like Chat-GPT LaMDA, Socratic, etc., multiple providers can be seen to have created tools that, depending on the type of query input by a user, will provide responses that are, at least on the surface, credible. Certainly, when it comes to using these tools for Simple or Complicated questions (what is the capital city of Argentina? Or, what would be the best next move to make in this ongoing game of chess?) efficacy is almost guaranteed. Educators of the world already look set to have their world disrupted by these types of engine.

Interface – the thing that the tool works upon in order to achieve the desired useful function. The enormous demand for Chat-GPT-like engines clearly demonstrates the existence of a market demand. And again, when the outcomes being delivered are in response to Simple or Complicated situations, there is no need for a moral or ethical contribution to the answers provided. As soon as a situation becomes Complex, however, the current Interface system limitations quickly become apparent. As indicated by the title, ‘Recipient Context Engine’ it is only possible for an AI to deliver an ethically-sound ‘True’ outcome by understanding the prevailing context of the user. Asking an AI to inform a user whether, say, populist politicians lie is a Simple problem with a clear right answer. Asking the AI whether it *matters* that the populists lie crosses the boundary into Complex and can only be meaningfully answered in the context of the asker. For an AI to satisfactorily capture that context demands a number of capabilities that either don’t yet exist at all or exist only in a formative sense. The company PanSensic [11], for example, has spent the last decade building emotion analytics and psychometric tools in order to glean a better understanding of who a person is, what their values are, and, because the suite of lenses have been designed with innovation guidance in mind, how frustrated a person is (‘frustration is the mother of innovation’ [12]) how open a person is to change. Closer to the cutting edge, the next stage of evolution will see the emergence of capabilities that will not only understand who a person is, but also the kind of words and messages that will most likely spark the desired outcomes.

Transmission – the element connecting the Engine to the Tool, and here described as a ‘Context Engine’. The difference between what is required in the Transmission role and what the Interface needs to do, ‘context’ here means achieving an ability to assess a situation and establish where on the CLM a situation is currently situated, and where on the Correct/True framework the various stakeholders currently reside. Only when both these things are known does it become possible for an AI to ‘know’ what kind of processes to adopt to best ensure the desired outcomes are achieved.

Engine – the element generating the driving force that powers the system. As hinted in the earlier description, when it comes to meaningfully dealing with conflicts between any pair of STABLE elements, there is a need to at least ‘manage’ those conflicts, and better yet, to ‘transcend them. In current AI systems at whatever stage of maturity, this is currently the element that is least well understood. Most AI researchers, seemingly more so than the science and engineering communities at large, would currently appear to have little or no appreciation as to the importance of contradictions, never mind knowing how to deal with them. Humans suffer from several hundred different forms of bias [13] (one of the reasons that capturing Truth is so difficult), but one of the most hazardous when it comes to innovation, or rather the failure to innovate, is Zero-Sum Bias [14], the innate belief that everything in life is win-lose. All the TRIZ research could in effect be seen as a comprehensive refutation of that Bias. Win-win, contradiction solutions are eminently possible. From today’s perspective, it would appear that the contradiction-resolving capabilities baked into TRIZ represent the only means by which this part of the needed system could be delivered.

Coordination – the element concerned with overall directionality and ensuring the other elements within the system are appropriately harnessed and coordinated to deliver the outcomes and to head in the ‘right’ direction. The definition of ‘right’ as hinted earlier, is probably the most significant missing piece in the overall ethical Truth jigsaw. Answering it in a meaningful manner in all probability needs a Society-level discussion rather than, say, the dismal, no-imagination mutterings of the WEF. While it is currently far from clear that such a debate will (ever) happen, what we do have in the meantime is the other key finding of the TRIZ research – the discovery that the overriding innovation driver is ‘increasing ideality’. Mapping this direction by looking at the tangible attributes of a solution (benefits, costs, harm) usually help tackle Complicated problem situations. More recent attempts to incorporate intangible (‘perceived’ benefits...) enable the boundary into Complex to be crossed, and so, in absence of any clearer Societal steer, maybe ‘increasing ideality’ is good enough to ensure that, until such times as clearer answers appear, humanity continues heading in a direction that is at the very least ‘valid’. i.e. better than having no direction at all.

Sensor – the moment a situation enters the Complex domain, there is no longer such a thing as ‘the right answer’ to a given problem. Rather there needs to be a recognition that solutions that work today, may not work tomorrow. Whenever we hear the aphorism concerning the so-called first signs of madness, ‘doing the same thing as you’ve always done and expecting a different result’, we can be certain that whoever says it does not understand complex systems. Systems that can very easily deliver very different outcomes even though everyone in the system is continuing to do the same thing. Per Heraclitus, who did understand complexity, it is not possible to ‘step in the same river

twice'. All of which is a slow way of saying that the Sensor in this system are the feedback loops that inform all the other elements in the system to either keep doing what they are doing, or to start exploring the need to do something else. The reference to John Boyd's OODA model [15] is a recognition, per the fable of two people being chased by a bear, the goal in a complex system is not necessarily to outrun the bear, but rather to outrun the other person. The ability of a team, organisation or government to iterate around the Observe-Orient-Decide and Act cycle faster than their 'competitors' is the needed capability. Again, today, for all practical purposes, it doesn't exist.

2.2 Implications of Missing System Elements

In addition to informing system designers what elements are required in order to controllably deliver intended outcomes, the Law of System Completeness also provides insight into the consequences whenever one or more elements are missing. The S-Field model, of course, tells us that a 'minimum system' need contain only three elements, two 'substances' ('tool' and 'interface' in LoSC terms) and a 'field' (specifically the 'engine' in LoSC terms, although the 'transmission' is implied). The difference between this minimum system and a 'complete' system is that, while it will deliver outcomes, it will not be possible to control them. A lot of 'systems' fall into this category [16]. One might say that all of today's AI solutions also fall into this 'uncontrolled' category in that they deliver outcomes to a user using a solution paradigm, through some kind of process (albeit essentially 'trial and error'), don't have an apparent direction, nor any means of determining whether any movement is towards or away from said direction. Absence of Coordination or Sensor elements mean that the outcomes are uncontrolled. And the fact that the Engine doesn't yet have any contradiction-solving capability means that users and providers will rapidly find themselves stuck with the usual trade-off arguments.

Given, then, that most of the required elements of the Fig. 4 'Truth-AI' system are currently either missing or stuck, examination of what needs fixing informs the next section's discussion the future of AI and which of the pessimists, optimists or C.S. Lewis might be closest to predicting what is likely to happen in the coming years.

3 Timing, Timing, Timing

3.1 The Future is Already Here?

The ubiquity of digital solutions – at the time of writing over 86% of the global population have smartphones – and the ease by which digital solutions can be evolved mean that despite the formative state of AI technologies, three outcome patterns are already becoming apparent. In the West, the apparent absence of a Coordination function in the system is enabling the emergence of two of the patterns. The first is adjacent to the Brave New World of Aldous Huxley and 'what we love will ruin us'. This is the world of being amused to death. Everyone playing Candy Crush instead of engaging with gritty reality. The second, building on the idea that Nature abhors a vacuum, is the scenario in which, per Lewis, a small cabal of very rich and influential people (WEF, WHO) are stealthily heading us in the Lewis direction and, as soon as they think they're ready, will reveal

their hand and create a ‘sovereign individual [17] lead world of masters-and-puppets. Masters who are likely to spark revolution when the puppets realise how easy it is for their access to the digital world to be switched off. In parallel with this evolution direction is Social Media’s inadvertent (?) proof of the Dunbar Number [18] and the creation of millions of micro-tribes at war with one another.

The third scenario is the one we can see beginning to emerge in the East, particularly in China. The growth there of a Social Credit System in effect creates a self-controlling ‘harmonious’ society filled with digital carrots and sticks. A society in which anyone that is ‘bad’ has privileges taken away from them, and one that rewards ‘good’ behaviour by opening more privileges. Such that jaywalking loses you fifty good-citizen-points; while picking up litter gains you ten. Self-organising systems tend to veer in the direction of increasing stability. Which sounds good. When it is people that are things being self-organised, the result is a world akin to Orwell’s 1984. A world of thought police and ‘what we hate will ruin us’. Which probably sounds less good...

3.2 Yes, But...

...whether we believe it is good or not, the higher-level choice between Huxley, Orwell or Lewis the result very definitely doesn’t sound like the sort of world many of us would want to be a part of. Fortunately, (?) the emergence of the Coordination part of the AI/Truth system still needs an Engine to make the system work either effectively or sustainably. Humans love change, they hate being changed. And a system without a change engine will invariably stall. The only questions are how soon, and how much damage will be caused before the contradiction solving Engine arrives. The key hypothesis of this paper turns out to be that the missing Engine now is the one that has emerged from the TRIZ research. The missing Engine is the ability (of either the AI autonomously or guided by human creativity) to find and resolve Contradictions. Which is to say that, ultimately, neither ‘life’ nor ‘society’ can be paralysed by the sorts of either/or choice between 1984 or Brave New World. Nor can it be about and either/or choice between intelligence *or* consciousness, or one on which the myriad Goldilocks Curves continue to be unrecognised or ignored. Meaningful progress happens when ‘we’ recognise these kinds of contradiction are there to be transcended rather than endured.

4 Conclusion

To paraphrase the title of an earlier paper from the SI research team, the wise person never makes predictions, especially about the future. This advice is particularly pertinent when it comes to AI related matters. In humanity’s historical past, the ability of any individual to cause damage to others was miniscule. As technology has evolved, that individual ability has steadily increased to the point where small numbers of resourceful individuals can now create highly non-linear 9/11-like outcomes. But, as even the most ardent terrorist has rapidly understood, access to highly non-linear resources (e.g. nuclear materials) remains, thankfully for the rest of us, extremely difficult. As soon as we venture into the digital world, however, the world in effect becomes flat and almost every individual has access to AI-related resources that, as several recent hacking events have demonstrated,

have the power to destroy economies, bring down governments and see the genocide of tens thousands of people. In a world where the damage-per-perpetrator potential is now effectively infinite, it is a brave person indeed that will stick their neck out to make a prediction of what is likely to happen in the coming years. Seeing ahead months is difficult enough. Probably weeks. The issue here is not just the infinite damage potential, but also the speed at which the harmful act can be instigated. John Boyd was a successful fighter pilot. His big contribution to the state of the art when it comes to conflict is the aforementioned OODA cycle. We can now also see that the OODA cycle time of a resourceful individual is now almost zero. Whereas the equivalent cycle time of the organisations tasked with spotting the troublemakers fast enough to stop them creating havoc is fundamentally much higher. This is an inevitable consequence of intermingling Space-Age technology with Dark Age institutions and Stone-Age brains. One might go so far as to say that until such times as the relative OODA cycle time between troublemaker and trouble-stopper is re-balanced, the only predictable thing is the unpredictability of just about everything. Which probably doesn't help. Except in informing near term AI research priorities.

As to where we go beyond that, let's end with a quote from admittedly polarising ethnobiologist, Terence McKenna, "*We have been to the moon, we have charted the depths of the ocean and the heart of the atom, but we have a fear of looking inward to ourselves because we sense that is where all the contradictions flow together.*" As far as I know, McKenna never became familiar with TRIZ. Fortunately, we did.

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Opening up New Fields of Application with TRIZ Reverse – Conceptual Framework, Software Application, and Implementation Challenges

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Abstract. Instead of a problem looking for a solution, this is where a company develops a certain technology, say a foam metal, and reviews the properties as promising and novel and then gets to the part where one says, who needs it. A solution looking for problems. Instead of necessity is the mother of invention, here invention is the mother of necessity. Especially material companies develop novel, conflict breaking materials after which they need to identify where in which markets it adds value to current solutions. This paper introduces the conceptual framework of TRIZ Reverse and its practical application. Based on three case studies, the procedure – from key word identification to patent database research to industry sector analysis – is outlined. Special attention is given to the cloud-based software Patent Inspiration, which supports the innovation logic of TRIZ. At the end, we identify critical factors for implementation and, based on this, we examine the success potential of the three case studies. The technological fit is a necessary prerequisite, but by far not the only one.

Keywords: TRIZ Reverse · Patent Analysis · Technology Transfer

1 Introduction

When organizations look to either explore the availability of solutions from other domains that might solve their problems, or the presence of problems in other domains that their existing solutions might solve, the current dominant ‘methodology’ is Open Innovation [1]. Various papers critically demonstrates key examples of open design successes [2]. Its basis is effectively to create platforms that allow problem owners and problem solvers to connect in a form of facilitated self-organizing fashion. In the past,

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several management concepts and innovation tools have been developed to support this process. The current paper deals with the reverse invention method called TRIZ Reverse, which has been further developed and is being currently optimized by the HTW Dresden, Germany. It can be used systematically to analyze and exploit patents, and is based on the theory of inventive problem solving (TRIZ).

In this regard, three case studies from different organizations, e.g. HTW Dresden, Max Planck Institute, and Fraunhofer Institute, will be introduced. In all cases, the overall goal is to find alternative industry technology applications for a given patent registration or invention disclosure. It can be shown that TRIZ Reverse provides an effective procedure to conduct a systematic analysis and holistic evaluation. Software-tools like Patent Inspiration [3] are included to accelerate the analysis process and to review the existing patent pool. In order to avoid the rule ‘garbage in, garbage out’, the authors demonstrate the crucial step of key word expansion as well as the visualization options, e.g. code map, for finding new fields of application. The analysis results were used as a starting point for further research activities or validation projects.

Despite these positive results, it is not certain that the inventions will really find their way into practical application. The track record of success of Open Innovation has, however, remained very low since its inception with around 99.5% of projects ending in failure [4]. This figure compares with the 98% failure rate found consistently across the entire innovation spectrum, and in effect means that Open Innovation projects are four times more likely to fail than projects that did not use the method. There are multiple reasons for this, but two will be examined in detail in this paper: Business Fit and People Fit. Regarding the three case studies, it becomes clear that it is still a ‘long way’ from the novel ideas to the final implementation. Moreover, the analysis shows that the risk of failure cannot be ruled out here either.

2 TRIZ Reverse – Conceptual Framework

2.1 Approach

TRIZ Reverse is based on the idea ‘solution seeks problem’. Therefore, new potential problem areas are to be identified to deploy the innovation, starting from a complete understanding of the technical solution. Current research outputs show that this is possible and that the principles that allow the exploitation can be extracted from the use and/or sale of patents. In 2020, the exploitation of patents in commercial terms was 36% in the EU and only 10% of these were deemed insufficient for commercialization [5]. The figures suggest the great opportunity to convert knowledge into marketable technology that contributes to the progress and economic growth.

The scientific foundation of TRIZ Reverse is rooted in the concept ‘reverse inventing’, which refers to the process through which the strengths of a company or research agent are initially tracked and transferred to an abstract form. The market is analysed by seeking the possible beneficiaries of the new technology or innovation [6]. Basically, TRIZ Reverse requires a reduced solution that reveals the IPs and contradictions that relate to the technology. The greatest challenge faced, is the semantics used in the reference documents, since in today’s patent texts – not infrequently for legal reasons – different terms are used in comparison to Altschuller’s time in 1980s.

Today, TRIZ is regarded as one of the most powerful and accepted methods to make systematic innovation [7]. Since the literature meanwhile contains several proposals for potential TRIZ Reverse methodological approaches, it is questionable, why the use of this approach has not yet become ‘mainstream’ in most organizations, universities and/or research institutes. One of the main reasons is the poorly standardization of the procedure associated with an insufficient use of advanced software-tools [8]. This problem, e.g. intelligent search in patent databases [9], has been addressed by a research group at the University of Applied Sciences, Dresden (HTW Dresden).

2.2 Procedure

An important milestone for the development of a TRIZ reverse procedure was the paper on ‘principles-based patent search’ by Mann [10]. It includes step-by-step instructions on how to connect search terms or key words from patents with the inventive principles from Altschuller’s contradiction matrix [11]. While conventional market research tools mainly rely on direct questioning and observation of potential customers, reverse inventing methods prefer to use abstraction. In this context, the TRIZ-Matrix and the TRIZ-Inventive principles serves as a reference to create a search word catalogue that can be used for a systematic patent database analysis.

A first draft of TRIZ Reverse procedure was proposed by Glaser and Miecznik in 2009 as a part of a collaborative case study at Wittenstein SE [12]. The aim was to identify additional business opportunities for ‘a system for the controlled prolongation of limbs’ in order to exploit the market growth potential. In 2010, Bianchi et al. [13] developed a TRIZ Reverse methodology based on this project. The aim of the research team was to support small- and medium-sized enterprises in finding alternative technology applications in a more efficient way. In the past, Popova et al. took up these approaches for further operationalization of the TRIZ Reverse procedure [14].

In Fig. 1, the latest version of this procedure, which has been developed and validated at HTW Dresden, can be seen. Besides the main process steps, the resources, e.g. software-tools, are outlined. Compared to the classic TRIZ, the presently available selection of professional software solutions using a TRIZ Reverse is significantly smaller. For the key word selection and search code creation, the research team has learned to appreciate the open source software Voyant-Tools [15], a web-based reading and analysis environment for digital texts. For the identification of relevant patents and patent clusters, the online analysis tool Patent Inspiration was finally selected.

2.3 Case Studies

During the past years, the research team of HTW Dresden has most of all focused in improving the efficiency of patent analyses performed with TRIZ Reverse as well as delivering a better user experience with the tool solutions provided, e.g. Patent Inspiration. The specified procedure has been applied on patents with entirely different technologies and entirely technology readiness levels (TRL). In Fig. 2, three patents from three different research institutes are outlined exemplarily. In all cases, new fields of application and/or markets could be identified; in two cases, follow-up projects with partners from the industry could be successfully initiated.

#	Phase	Process Step	Resource
1	Real Solution	Selection of Suitable Invention (Patent)	Researcher/ Transfer Org.
2	Abstract Solution	Identification of Inventive Principles	Voyant-Tools
3	TRIZ Reverse	Creation of Search Word Code	TRIZ-Matrix
4	Abstract Problem	Research in Patent Database	Patent Inspiration
5	Real Problem	Analysis of Patent Code Map (Cluster)	Researcher/ Transfer Org.

Fig. 1. TRIZ Reverse: 5-step procedure with resources.

A detailed description of the case studies is provided in Popova and Günther [16]. In order to verify the effectiveness of TRIZ Reverse procedure, the authors conducted frequently meetings with the patent holders and/or transfer managers of the involved organizations. It was of utmost importance to gather feedback on the procedure and tools applied. Additionally, the two researchers were able to objectify the different goals and requirements of the patent holders. Depending on the specific patent exploitation strategy, e.g. finding corporate partner versus starting own business, the individual search codes has to be adapted; further details follow in Sect. 3.

Looking at the most time-consuming parts of the TRIZ Reverse procedure, the greatest efficiency gain lies in the text analysis of the underlying patent or invention disclosure (Step 2). Therefore, an AI-supported software for identifying the inventive principles and engineering parameters of TRIZ intelligently would be desirable. For the patent US10241539B2, in example, the search code ‘network AND feedback AND reliability AND automation’ could be derived by applying the Voyant-Tools. Consequently, this query can be processed with any patent database or software. An overview on the use of Patent Inspiration [3] is provided in the following chapter.

Research Institute	Patent Analysis	Application Field
HTW Dresden , Faculty of Agriculture/ Environment/ Chemistry	<u>DE102017123891</u> : Biocompatible molded part and method of making a collagen-based layered material to develop a stable material	Original Scope: Medical Care New Approach: Consumer Goods/ Packing
Max Planck Institute for the Physics of Complex Systems, Dresden	<u>US10241539B2</u> : Self-synchronizable network: A solution for synchronizing a network comprising a plurality of interconnected nodes	Original Scope: Automotive Industry New Approach: Earth Drilling (tbp)
Fraunhofer Institute for Process Engineering and Packaging IVV, Dresden	<u>Invention Disclosure</u> : Generation of process heat through a mechanical impact pulse for the joining of plastic films, e.g. thin foil	Original Scope: Consumer Goods/ Packing New Approach: Textile Industry/ Fashion

Fig. 2. TRIZ Reverse: Case studies in cooperation with HTW Dresden.

3 Patent Inspiration – Software Application

3.1 Case Study 1: From Medical to Consumer Goods (DE102017123891A1)

Patent Description. Biocompatible molding and process for the production of a collagen-based coating material: The invention relates to a biocompatible molded part made from a collagen-based layered material for use as an implant or cell culture substrate and a method for producing a collagen-based layered material. The biocompatible molded part for use as an implant or cell culture substrate has a collagen-based layered material in which at least two layers of a swellable collagen material that are at least partially superficially adjacent are cross-linked with one another by air drying. The method for providing a collagen-based layered material includes several steps.

Similar Patents. Based on a content parts of the patent, similar patents will identify a list of top 50 closest related patents. This can be searched in all patents, or in a specific category of classification (A. Human necessities, B. Performing operations; transporting, C. Chemistry; metallurgy, D. Textiles; paper, E. Fixed constructions, F. Mechanical engineering ... G. Physics, H. Electricity, Y. General tagging of new technological developments). Similar patents can identify new markets, where the similarity is on the material and the application field is different.

Keyword Expansion. Find Related Terms – Selecting each keyword combination, e.g. collagen layer, can be submitted to a related term identifier. The terms that appear are word combinations with similar context. Collagen layer generates collagen sheet, collagen membrane, fibroblast layer, collagen gel, collagen coating, dermal substitute, collagen matrix, chitin layer, collagen layers, collagenous layer, collagen gel layer, collagen scaffold, collagen substrate, collagen film, etc. All terms are worth to explore expanding the search filter. Unusual wording is potentially used to hide patents, however with related terms, these are incorporated in your search field.



Fig. 3. Industry extraction from patent pool 1 & 2.

Identifying Industries. By identifying patents containing collagen and biocompatible (bio-stable, biocompatible, bio-inert) in Title and Abstract, a list of 2044 patent documents for the start of the research. By filtering a text pattern adjective:* industry and noun:* industry the visualization below (see Fig. 3) shows packaging industry among others. Once packaging industry was identified, a new filter was built with collagen

AND packaging in Title and abstract (969 patent documents). Identifying the industries in Fig. 3 show that removing the biocompatibility from the filter lead to a larger range of industrial application of collagen-based packaging.

Now to explore the type of packaging in the patent pool, the properties and context can be analysed. It illustrates the context in which the packaging is used, distilled by the text pattern noun:* packaging. To distil the properties of the packaging, the pattern adjective:* packaging is used. The resulting visualization is shown in Fig. 4. Note the properties are adjectives part of a property spectrum i.e. rigid, flexible, soft are part of the flexibility spectrum. In order to know what form of collagen product is used, collagen can be taken as adjective and a pattern of collagen noun:* will generate the types/forms of collagen. The word clouds can be utilized to explore new application areas and clients, where the application field benefits from the variation in the patent.



Fig. 4. Context extraction of packaging by pattern noun:* packaging

Analyzing Clients/Competitors. Clients can be identified in the word clouds in the Figures above. Alternatively, a company list can depict the highest activity in the domain (bigger the fond the more patent activity). Selection can also be made based on existing relations, proximity to organizations, research match etc. Once a client is successfully identified, and is non-exclusive, the patent database can be utilized to create a list of competitors in that area of patents. For example, below Fig. 5 shows the competitor list of L’Oreal starting from their patents in the collagen/packaging domain. Thus, the case study identifies patent DE102017123891A1 can be transferred from the medical domain into the packaging/consumer goods domain.

3.2 Case Study 2: From Automotive to Earth Drilling (US10241539B2)

Patent Description. Self-synchronizable network: A solution for synchronizing a network comprising a plurality of interconnected nodes provides a stable synchronized state, especially for large scale networks. Signal transmission speed and the length of each interconnection of the network is configured to cause a delay of the signals received by a node from the other node of the interconnection which is larger than one millionth

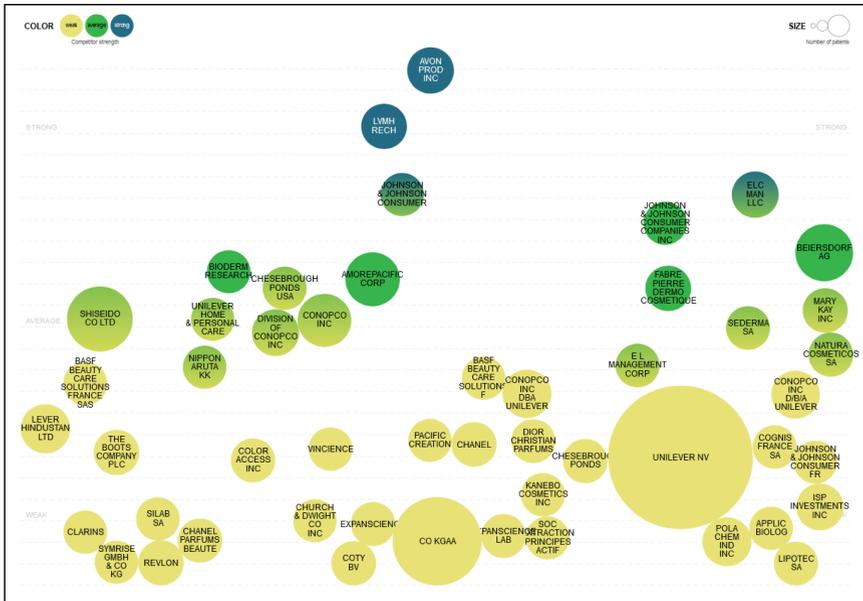


Fig. 5. Competitor analysis: L'Oreal in the collagen and packaging area.

of the free-running period of the controllable oscillator of the receiving node such that Network-wide synchronization of oscillators is achieved for all nodes of the network in a continuous self-organized process in interaction with the other node of the network.

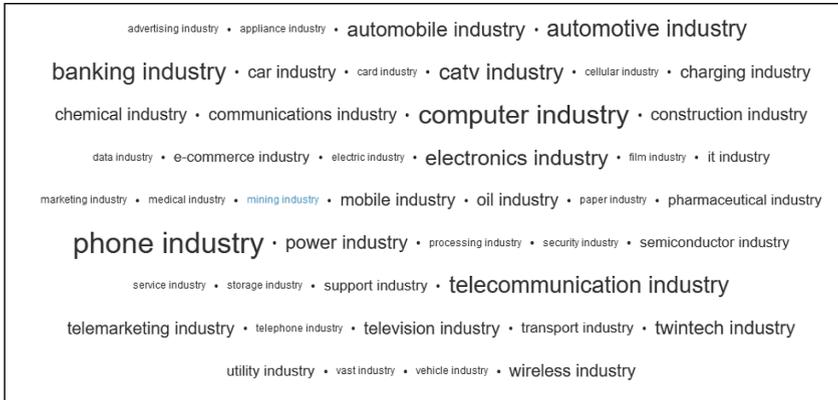
Selection through Industries. As the title of this patent is self-synchronizable network, it provides a good abstraction into where other domains (outside automotive) require or have existing self-synchronizable networks. The filter is therefore made on self-synchro* AND network, resulting in 2096 patent documents. Requesting industries from this filter generates the word cloud in Fig. 6a. As an example mining industry can be selected as a potential market. Not all patents mention the industry, so a related term analysis of the keywords in the mining industry patents can bring a selection of words to review in a text analysis of the patent pool. Figure 6b confirms 11% of the patent pool contain related terms.

3.3 Case Study 3: 'Mechanical Impact Pulse': from Packaging to Textile

Patent Description. The patent approval procedure had not yet been completed at the time of publication. Therefore, no further details regarding this invention will be outlined in this paper.

Keyword Rifle Approach. Instead of the shotgun approach with limited keywords in case study 1 and 2, here a multitude of keywords is used to have a smaller selection of highly relevant patent documents, in this case 328 patents, a rifle approach. The filter is shown in Fig. 7.

CPC Code Map & CPC Domain Map. A different way of identifying new areas of application is the using the Cooperative Patent Classification (CPC) codes. Patent



(a)



(b)

Fig. 6. a. Self-synchro* AND network in what industries? b. Mining industry key words.



Fig. 7. Filter on invention disclosure: Mechanical Impact Pulse.

publications are each assigned at least one classification term indicating the subject to which the invention relates and may also be assigned further classification and indexing terms to give further details of the contents. The CPC system has over 250,000 categories. From this, Patent Inspiration built a 500 x 500 matrix that landscapes the patents in the areas, and on top depicts the keywords of that area, shown in Fig. 8. An example area

can be the fabric, yarn, web, filament in the mid lower region. The area can be zoomed in and patents can be extracted for further investigation and/or be used for brainstorming.

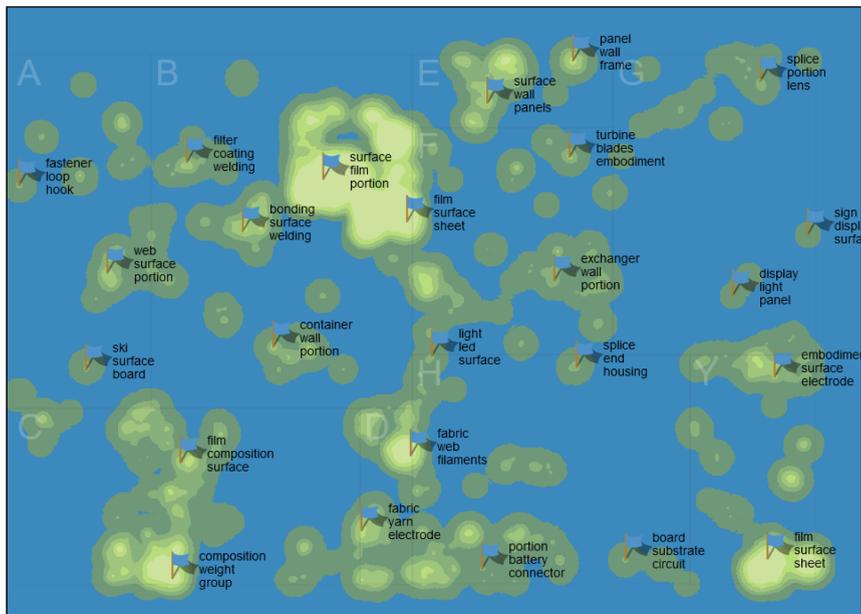


Fig. 8. CPC Landscape in Patent Inspiration.

4 Beyond TRIZ Reverse – Implementation Challenges

4.1 Learnings from M&A

TRIZ Reverse is all about establishing a potential solution-level match between a technology owner and a prospective licensee. It represents a necessary early step in establishing technology transfers that will have an opportunity to become successful. Necessary, but sadly, not sufficient. Research on Merger and Acquisition (M&E) activities in and around the world of business consistently show that between 70 and 90% of relationships end in failure [17]. Regarding the more specific scenario of large organizations acquiring or licensing solutions from smaller, entrepreneurial enterprises (university spin-out, micro-business or SME) – where Open Innovation is frequently cited as the primary methodology for realizing connections – the success rate is considerably smaller. To the point where it has become clear the secret to successful Open Innovation is to ensure it isn't open [18].

A deeper-dive into the reasons for the failure of an M&A attempt reveal that it rarely if ever has anything to do with the technology, at least not directly. There are instances where, particularly in the pharmaceutical sector, more innovation-savvy MNCs have evolved businesses models that see them nurturing multiple incubator organizations

knowing that a percentage will not deliver the promised new drug molecule. And there are situations where a bet on a licensed technology won't pay off because something goes technically wrong during the transition through the Technology Readiness Levels (TRL). Notably, the present case studies do not fall into this situation.

Taking these 'technology failures' out of the equation leaves the large majority of overall M&A failures unexplained. When we dig into the dominant reasons, it becomes clear there are two big areas of failure. The first concerns what might be considered tangible business-related mismatches; the second concerns what might best be called intangible-people issues. Both will be considered separately.

4.2 Business Mismatches

The top five business reasons for the failure of a technology-transfer related innovation initiative are, in descending order of frequency:

- 1) Rule Of Three dynamics
- 2) Industry Cadence mismatches
- 3) Innovation Capability Immaturity
- 4) Innovator's Dilemma issues
- 5) Unlearning Costs

Rule Of Three [19] – Every industry eventually evolves to contain three big players. This first happens regionally, then nationally, then continentally, and ultimately globally. It is very tempting for university spin-outs to target the biggest players to license their technologies to, for the simple reasons they have the most money and access to the biggest group of customers. What could possibly go wrong? Almost everything. The primary job of the two biggest players in an industry is to avoid innovation. Paradoxically, they will tend to have large R&D budgets, but the majority of this activity is about insurance and creating an ability to respond should another player decide to disrupt the organization's current offerings. The third biggest player is the optimal target for the spin-out because this is the player with the best combination of resources and desire to out-compete the two biggest players. The third biggest player tends to be the innovator of the industry. As do the fourth, fifth, etc. players, except their smaller market share means they usually have less resources to commit to acquisition.

Industry Cadence – Some industries innovate faster than others. Every industry has a certain step-change cadence. The automotive industry, for example, tends to launch new models around every five years. In more capital-intensive industries, the pulse rate is usually much slower because the investment in one generation of technology needs to pay for itself before companies can afford to consider replacing it. In mining, one of the slowest industries, the pulse rate is currently around once every thirty years. At the other end of the spectrum, the digital industries expect to make step changes to occur in months rather than decades. The problem for technology transfer attempts here is all about timing. If a technology becomes available for transfer at the wrong time in the investment cycle of the prospective industry, it will be very difficult for the large organization to justify a purchase. Except – importantly – if they perceive a desire to purchase a technology in order to ensure that a) other players don't acquire it, and b) to ensure they can keep it off the market.

Innovation Capability Immaturity – 2012 saw the launch of the Innovation Capability Maturity Model (ICMM) [20]. Its intention has been to help organizations build an ability to innovate more effectively. It currently identifies five distinctly different Levels of Capability (s-curves), where Level 1 is just starting the journey, and Level 5 represents the half-dozen or so organizations on the planet that have evolved genuinely systematic and repeatable ways and means of translating invested dollars into non-linear new value. The message for prospective technology transfer solution providers is to seek to transfer their solutions to large players with at least Level 3 and preferably Level 4 Capabilities. The challenge at this point in time, however, is that over three-quarters of the large organizations on the planet are still at Levels 1 or 2. The heart of the challenge for spin-outs, we realized after publication of the book, was that they in effect at Level 0 on the ICMM. Figure 9 shows the six (0–5) ICMM Levels.

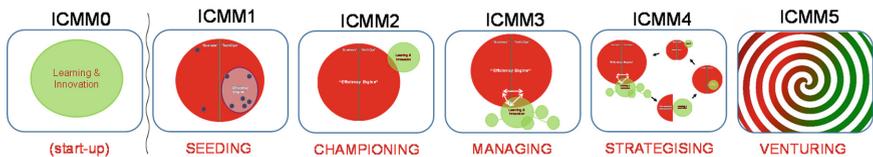


Fig. 9. Innovation Capability Maturity (ICMM) Levels

Innovator’s Dilemma [21] – Christensen’s classic text is in effect a play-book for large organizations, warning them about the disruptive threat caused by small start-up disruptors. As such, it also offers significant insight, when applied the other way around (Reverse Christensen?), as a playbook for spin-outs. In this context, the first thing it would recommend is not turning up at a large company’s door with an offering that is ‘superior’ to that company’s current portfolio of market offerings. Most start-ups emerging from academia usually fail to grasp this paradoxical concept because the very job of academia traditionally has been to move technology forward. The second thing it recommends is presenting an ‘inferior’ solution to the prospective licensee in a manner that helps them off-load their least valuable customers to the new solution.

Unlearning Costs – ICMM Level 3 technology acquirers are generally good at calculating the costs, projected revenues and likely time-to-payback of a technology acquisition. What they are very unlikely to be able to account for are the inevitable costs of unlearning all of the things that they currently know that will eventually become supplanted by the newly acquired technology. Level 3 companies know how to manage ‘sustaining’ innovations, but have no capability to disrupt themselves. Learning these skills is one of the key things that define a Level 4 organization. This problem is clearly related to the earlier ICMM issue, but merits its own place because it currently represents an enormous hole in the knowledge-base of most economic and accounting functions in most large organizations and therefore they have no ability to plan for it.

The good news with all five of these business factors is that they are all objectively measurable and therefore offer those looking to license a technology solution to a third party to make clear Go/No-Go decisions about which of the possible licensees are viable or not. The bad news is that, in combination, the five heuristics will rule out 90 + %

of what might initially have appeared to be a broad range of prospects. If this problem is bad, it is nothing compared to the next five ‘people’ related challenges, because up until very recently, none of these five were even measurable, and consequently, even if M&A professionals thought about them, they would not be able to quantify whether any of them well enough to either support or reject a prospective technology transfer, never mind be able to rank one prospective licensee with another.

4.3 People Mismatches

The top five intangible emotion-related reasons for the failure of a technology-transfer related innovation initiative are, in descending order of frequency:

- 1) Not Invented Here
- 2) Senior-Leadership Team Values Mismatch
- 3) Change Appetite
- 4) Red-World/Green-World Imbalance
- 5) Starter/Finisher Imbalance

Just because a parameter is difficult to measure, shouldn’t preclude making an attempt. The whole measurement industry has been somewhat guilty of existing on measuring what is expedient rather than what might actually be meaningful [22]. The company PanSensic [23] was established to begin tackling the problem. The main resource the company’s technology taps into is the enormous amount of narrative data present in the digital systems within and around an organization, from annual reports to technical reports to, in high trust environments, email and other less formal forms. Because all the five failure reasons have been visibly important for some time, each has been a focus for measurement research activity over the course of the last ten years.

Not Invented Here – A majority of technical professionals are specialists. This is the way society works: companies declare they need specialists, and academia is happy to accommodate the request because that’s the way academia works too. The net result is a self-reinforcing system. The problem arrives when a person who has spent their whole career working in a particular technology domain encounters the TRIZ Reverse solution from a completely different industry. They do not recognize it and tend to therefore become threatened. Will it make their knowledge redundant? Will they lose their job? The easiest way to fight the incoming threat is to criticize it. Ideally to the point where their managers (people who probably don’t have the detailed technical knowledge) reject the new solution simply because the effort to overcome the psychological inertia is not worth the perceived benefit.

Senior Leadership Values – the individuals accountable for a purchase decision of a new technology are critical with respect to how similar or dissimilar their worldview and fundamental values are to the people offering the technology. Psychologist Clare Graves devoted a lifetime to distilling human values down to a first principle level [24]. He identified eight step-change different value systems. Some of these values are very egocentric, others very amenable to cooperation. Some are very calculating, others more impulsive. Every individual has elements of many of the values systems (we are all born with the same brain physiology), but usually one or possibly two dominant values. Overall, we know that the success of communications between different individuals is

heavily dependent on whether the dominant values are the same. If they are not, long-term cooperation activities are highly unlikely to succeed.

Change Appetite – almost every leader in today’s world is expected to say that they want and support innovation. Some of them mean it, but many do not. It is usually possible to analyze public domain narrative (reports, websites, CEO speeches, etc.) and use PanSentic to ‘read between the lines’ in order to establish the actual versus spoken appetite for change within an organization. From the perspective of the inevitable difficulties involved in any kind of disruptive technology transfer initiative, it is clearly preferable for the technology owner to be able to collaborate with an organization that is actually open for change, rather than merely says they are.

Red-World/Green-World – Red World is the world of Operational Excellence, Green World is the world of innovation. The better an organization is at one of those essential business activities, the worse it is likely to be at the other. This is because everything that is ‘good practice’ in one World is likely to be the opposite in the other. Good operational excellence is about following rules; innovation is about breaking rules. Good operational excellence practice is about eliminating variation; innovation is about exploiting variation. And so on. The critical measurement parameter here is the ratio of Red/Green thinking capability inside an organization. When a new technology arrives into an organization, lots of Green thinking is required; in order to work out how to make money from the new technology, demands lots of Red thinking. Which inevitably also means that when a new technology is going to be licensed to an organization, not only do they need the right balance of Green and Red, but also to be able to dynamically manage the inevitable transition from Green to Red.

Starter/Finisher – Individuals tend to be good at either starting new things (‘the creatives’) or finishing them (‘devil in the detail’ ‘closers’), but rarely both. Meaning again that when a disruptive new technology arrives into a licensing organization, they need to have the right combination of starters and finishers. The spin-out tends to have more starters. The licensee needs more finishers, but also needs them to be able to work productively with the starters. This is not as easy as it sounds. In ICMM Level 1 organizations, for example, where the Starter/Finisher ratio tends to be very low, the minority of Starters tend to be labelled as ‘viruses’ by the dominant Finisher community. The idea being that, like all viruses, the best thing to do is eliminate them.

5 Conclusion and Outlook

In this paper, we have focused on two objectives. Firstly, we demonstrated – based on three comprehensive case studies – how the TRIZ Reverse methodology can be applied efficiently in order to find new fields of applications for existing technologies. Additionally, we demonstrated the efficiency gain that results from the use of software, e.g. Patent Inspiration for in-depth patent database research. Some novel findings were thus obtained: The Case Study 1, based on the patent DE102017123891A1, showed the opportunity of applying the new collagen-based layered material not only in medical care/testing, but also in consumer goods industry/packaging. In the Case Study 2, based on the patent US10241539B2, we could identify mining, earth drilling and vibration management as a potential new application for a self-synchronizable network. Case

Study 3, based on an invention disclosure, considered the alternative use of ‘mechanical impact impulse’ technology in the textile/fashion industry.

Secondly, we analyzed in-depth the implementation challenges of the identified new fields of application. After conducting the Business Fit tests (see Chapter 4.2), two of the three candidates fail on at least one of the tests. The Earth Drilling opportunity (Case Study 2) principally fails on the Cadence-related timing test. The textile industry opportunity (Case Study 3) principally fails on the ICMM Level test, in that even though the textile – or at least fashion – industry has a high change cadence (dominated by bi-annual or possibly quarterly cycles). Case Study 1, relating to FMCG packaging, however, passes all five of the Business tests and produces a list of candidate large organizations where a meaningful technology transfer has a good chance of being successful. It therefore remains exciting to observe how the three technologies will continue to develop and if the People Fit tests (see Chapter 4.3) will be passed or not.

Regarding further research, the parent topics of Reverse Engineering and Open Innovation will stay in focus. Given the fact that ‘only three to five percent of the patents applied for, lead to economic benefits’, e.g. in Germany [25], the process outlined here offers an immense potential for profit generation for all actors involved in the area of innovation, knowledge, and technology transfer. Furthermore, the German Economic Institute (IW) estimates that ‘the economy is sitting on unrealized assets of at least eight billion euros’ [26]. It is necessary to develop promising technology transfer tools, e.g. TRIZ Reverse, to open up new fields of application for given technologies (inventions or patents). In this context, the growing use of generative AI tools, e.g. Large Language Models (LLM) for patent analysis, lead to potential synergies between LLM and TRIZ [27]. However, this will be not sufficient to be economically successful since Business Fit and People Fit is just as important as Technology Fit.

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A Multi-stage AI-Based Approach for Automatic Analyzation of Bike Paths: Stage 1 – Road Surface Detection

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Abstract. This paper presents a system that uses a multi-stage AI analysis method for determining the condition and status of bicycle paths using machine learning methods. The approach for analyzing bicycle paths includes three stages of analysis: detection of the road surface, investigation of the condition of the bicycle paths, and identification of substrate characteristics. In this study, we focus on the first stage of the analysis. This approach employs a low-threshold data collection method using smartphone-generated video data for image recognition, in order to automatically capture and classify surface condition and status.

For the analysis convolutional neural networks (CNN) are employed. CNNs have proven to be effective in image recognition tasks and are particularly well-suited for analyzing the surface condition of bicycle paths, as they can identify patterns and features in images. By training the CNN on a large dataset of images with known surface conditions, the network can learn to identify common features and patterns and reliably classify them.

The results of the analysis are then displayed on digital maps and can be utilized in areas such as bicycle logistics, route planning, and maintenance. This can improve safety and comfort for cyclists while promoting cycling as a mode of transportation. It can also assist authorities in maintaining and optimizing bicycle paths, leading to more sustainable and efficient transportation system.

Keywords: AI · Machine Learning · Image Recognition · CNN · Automatic Detection · Conditions Analysis · Bicycle Paths · Surface Condition

1 Introduction and Related Work

1.1 Introduction

The research project Automatic Bike Path Analysis (ABPA) is being implemented by Hochschule Furtwangen University together with Outdooractive and Hochschule Offenburg. Within the project, information on the condition and state of bike paths is collected

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and analyzed using an AI-based approach. This information can subsequently be used in the areas of bike logistics, route planning and path maintenance. This paper presents the conceptual approaches of the project, with a focus on the developed three-stages analysis approach for determining the surface condition of bike paths. The study aims to investigate how an image analysis procedure can be developed to analyze and classify image material. The research question to be addressed is how a AI-based analysis procedure can be developed to enable efficient and reliable performance. Various methods and technologies will be employed to allow for automatic and efficient processing of large amounts of image data to obtain information about surface quality. The main objective of this research is to develop an efficient and reliable AI-based analysis method to determine the condition and quality of bicycle paths. By collecting and analyzing information about the bike paths, decisions can be made and targeted measures can be taken to improve the bicycle infrastructure sustainably and meet the needs of cyclists.

The paper focuses on the development of the first analysis stage of the project, which is the capture of the road surface. This stage has already been completed. The subsequent stages of the research project are currently being addressed, and as a result, no results are available yet.

1.2 Related Work

In the development of new mobility concepts, bicycles, e-bikes (pedelecs), and cargo bikes have become indispensable. With the constantly increasing number of cyclists, the demands on bike paths and all other routes that can be used by bicycles are also increasing. The growing number of e-bikes and pedelecs in recent years has led to new requirements for the use of bike paths.

Automated and continuous real-time analysis of bike paths does not exist in Germany to date. The condition of the paths is currently determined through reports or targeted inspections. For example, the General German Bicycle Club (ADFC) offers a way for cyclists to report the condition of bike paths, but this is not automated. Cyclists submit reports, such as a missing sign, pothole, or other ideas for improving bike paths, via an online platform [1].

Another method is the measurement and analysis using a specialized measuring vehicle that drives on specific bike paths. However, this approach does not allow for continuous and efficient analysis of the condition and quality of the bike paths, as the measuring vehicle is not constantly in use and also incurs high costs [2].

Efforts have been made to collect data on bike paths using bicycles equipped with sensors. These sensors can record various data, including road surface conditions, air quality, and even noise levels. Although this approach can be useful, it requires a substantial investment in specialized equipment and can only cover a limited geographical area [3].

There has been an attempt to utilize algorithms and data from smartphone-equipped bicycles to capture information about bike paths. This approach has shown promise in providing a more automated and efficient method for analyzing the condition and quality of bike paths. For this attempt the researchers used acceleration sensors of smartphones [4].

At University of Engineering and Technology Taxila, there was research on state-of-the-art deep learning models (YOLOv5, SSD-mobilenetv2) for real-time pothole detection on edge devices. Despite YOLOv5's high mAP@0.5 of 95%, it exhibited miss-classification and no long-distance pothole detection. Therefore, YOLOv4 was concluded as the best-fit model for accuracy, and Tiny-YOLOv4 for real-time detection (90% accuracy, 31.76 FPS). The proposed approach aids road maintenance authorities in efficient infrastructure repairs and has potential applications in self-driving and automation. Future extensions include detecting other pavement distresses, road depressions, quality classification, and depth estimation of potholes, while accuracy limitations can be addressed through modifications in real-time deployment [5].

For the ABPA project AI is the best practice method, because of the large and complex datasets. In the field of image classification, Convolutional Neural Networks (CNNs) have proven to be very successful. Several research studies have focused on the application of CNNs to various problems. One such study is the thesis work of Sidiropoulos, which was carried out at the Hamburg University of Applied Sciences. The work, entitled "Application of deep neural networks for bicycle detection and classification," deals with the development and implementation of a neural network for image classification and object recognition.

The work describes the process from data acquisition and manipulation to the creation of simple CNNs with few layers, up to the complex implementation of a residual network. The goal of the work is to develop a cost-effective solution for a bicycle counting system. The software should be able to detect passing bicycles through a live transmission from the camera and count them depending on their direction [6].

2 Method

The ABPA-System is composed of several components, including a smartphone app, a cloud-based control system and various microservices for data storage, analysis, and provisioning. To generate data, smartphones are attached to the handlebars of test users' bikes and video data is recorded. These recordings are centrally stored and subsequently analyzed using AI.

2.1 Data Management

The project's data management covers the aspects of data model, generation, storage, access and safety. At Furtwangen University, the data generated by smartphones is stored on a central server. The data model is based on two entities: Records and Location Data. These two elements contain a mixture of structured meta and geodata that are associated with recorded, unstructured video data. This enables effective analysis and utilization of the collected data.

2.2 Data Access

RESTful web API server based on the Node.js framework Express is used. This server enables not only the storage, but also the distribution of data by means of communication

via different requests. In doing so, it connects to an artificial intelligence (ABPA-AI) system and transfers the necessary data to it, such as geodata, video files and other information received by means of a special smartphone app. This data is finally inserted into a SQL table to provide a complete database for the ABPA-AI.

Security is the focus of the Express Server’s work. To ensure that only authorized users have access to the data, authentication is required. For this, a JSON Web Token (JWT) is used, which is an open standard, and provides an easy way to authenticate and transfer information about a user.

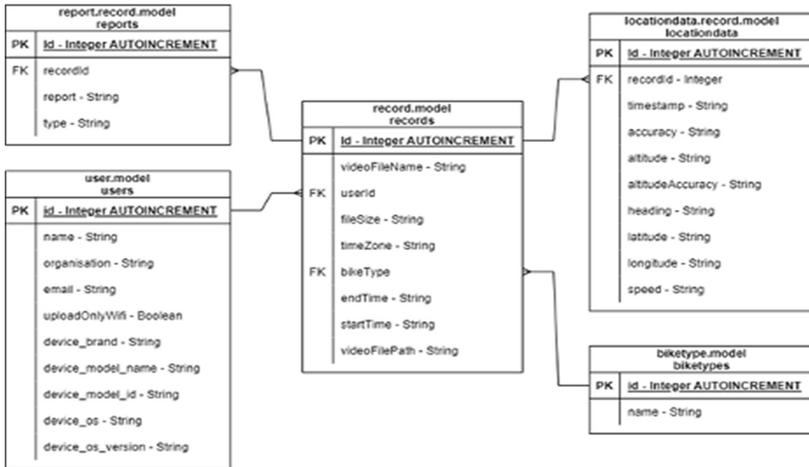


Fig. 1. ER-Diagram of the SQL Database.

The structured data resides on a central server within an SQL database, the architecture of which is depicted in the Entity-Relationship (ER) Diagram in Fig. 1. This data is accessed and retrieved through SQL queries. The unstructured data - the video files - have been given a lot of attention. These are small in numbers, in comparison to the records and location data, but individual videos have high data volumes. Some videos quickly reach several gigabytes, many videos together already terabytes, which is why a highly scalable solution for the storage is necessary. Currently, the videos are stored on a dedicated dynamic server, which we will refer to as the NAS (Network Attached Storage).

In order to cope with the increasing amount of data from new videos in the future and at the same time to minimize the management effort and costs caused by the company’s own server, the company is switching to an object store in the cloud. This data can be accessed via Internet communication technologies such as REST API.

In our journey towards system optimization, we are transitioning our Express server to NestJS and incorporating an additional image preprocessing service into our architecture. The server is going to send data to the image preprocessing microservice via a GraphQL API. The image preprocessing service turns the video files into images and crops out unwanted image elements among other processing steps. Once processed,

the image information (file name and directory) is returned to the server. The server then initiates the ABPA-AI through another GraphQL API, which leads to the final classifications that are then stored in the SQL database.

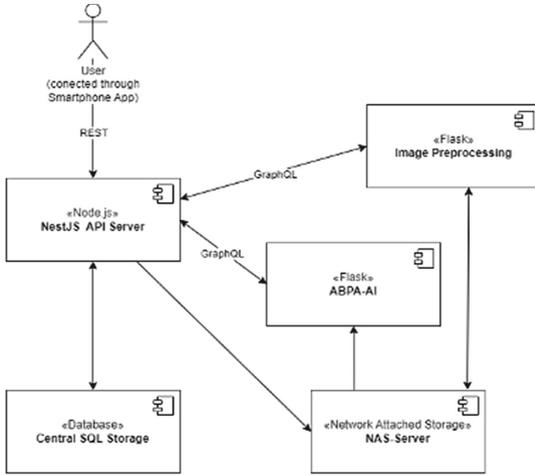


Fig. 2. Model view of ABPA System.

This enhanced architecture will be demonstrated in an accompanying Module view (see Fig. 2). Please note that, as this project is ongoing, the actual implementation may slightly differ from the proposed architecture. However, this description serves as a comprehensive framework that is guiding our development trajectory.

2.3 Data Collection

To successfully train an AI model, a comprehensive data foundation is essential. The better the processing of the data, the better the results achieved by the AI. In addition to locating and collecting training data, additional preprocessing steps are required to create a meaningful information base.

Initially, the AI model used in the ABPA project was trained using open-source datasets, as no proprietary video data was available at that time. The utilization of open-source datasets allowed for the initiation of the training process and the development of the AI model without relying on proprietary resources.

Although open-source datasets may have certain limitations, they were complemented by additional processing and integration of self-generated image material to expand the data foundation and enable more specific classification. Alongside the advantages, there were also challenges to overcome. The quality of the data could vary, necessitating careful verification and filtering to separate blurry or unreadable images and utilize only relevant and high-quality data for training.

The employed dataset includes the classification of three surface conditions: paved unpaved, or cobblestone surfaces. It should be noted that weather-related aspects, such

as rain or dirty road surfaces, are not included in the dataset. Before the open-source datasets, which were available in the form of videos, could be read into the model, they had to be divided into individual frames. This allowed for the generation of approximately 90 thousand images for training. Subsequent processing steps include cropping, relevant image sections and filtering out blurry and unreadable images. Although these preprocessing measures reduced the training data by around 40%, this loss is compensated by the increasing quality of the data.

In addition, the data foundation was supplemented with video material recorded using the ABPA app, which is centrally stored. The development of the app facilitates the process of recording bicycle routes and transmitting them to a central system. The app is user-friendly and does not require any specific technological knowledge or skills. Utilizing smartphones as recording devices, users can capture videos of bicycle routes in a fast and uncomplicated manner. The videos are then automatically transmitted to the system, where they are subsequently analyzed using an algorithmic procedure. A key advantage of utilizing smartphones lies in the ability to collect a large amount of data through multiple route recordings, enabling improved training of the AI. The results in higher accuracy and reliability of the algorithmic procedure.

Thus, the training material consists of both open-source data and self-generated image material captured using the ABPA app. Incoming videos are continuously processed and incorporated into the existing data to achieve the largest possible data foundation. This also includes a broader classification framework, as weather-specific aspects are gradually incorporated into the training of the AI model in this step, allowing for a more specified classification.

Overall, the combination of open-source datasets and self-generated image material from the ABPA app proved to be an effective strategy for constructing an extensive and diverse data foundation for training our AI model. Despite the challenges and limitations associated with open-source datasets, careful preprocessing and the integration of additional data established a solid basis for improving the accuracy and reliability of our algorithm.

2.4 Multi-stage Analysis

The ABPA projects features a pivotal component that involves an AI-based analysis procedure for capturing and evaluating information about bicycle routes, particularly pertaining the to their condition and surface quality. This information is analyzed and evaluated through a three-stage process, which encompasses the analysis of surface quality, condition, as well as additional features and characteristics, such as the analysis of road and path boundaries (see Fig. 3).

This process enables the collection of comprehensive and precise information about bicycle routes, which is of utmost significance for future decision-making and actions. Below, we describe each of the three stages in greater detail.

Stage 1: Surface Detection. In the first stage of the analysis procedure, recorded video data is used to detect and classify the surface of the bicycle route. Various visual features are examined to determine the surface characteristics, including texture, color, shading,



Fig. 3. ABPA Analyzation Stages.

and edges. Analyzing these features enables the classification of the surface into different categories. Ultimately, the different surfaces are categorized as either “paved”, “unpaved” or “cobblestone”. This allows for the determination of the underlying substrate of the bicycle routes. This stage utilizes AI-algorithms, such as convolutional neural networks (CNNs) and image processing techniques, to extract and analyze the visual features of the recorded video data.

Stage 2: Examination of Condition. In this stage a comprehensive analysis of the condition of the roadway is conducted. The video data captured through the ABPA app is utilized to assess the current state of the bike path. The analysis focuses on potential problem areas that may compromise road safety, such as potholes, cracks, or other objects on the bike path. By identifying these issues, the ABPA project can contribute to improving road safety on bike paths by enabling responsible organizations and governmental agencies to quickly identify and address them. For the second stage, the SSD MobileNet V2 Object Detection Framework is employed. This framework provides high accuracy and efficiency in object detection. It is based on a Single-Shot Detector (SSD) approach, enabling rapid and precise object detection. By utilizing the framework, we can reliably identify potential problem areas on the bike paths, such as potholes or obstacles.

Stage 3: Detection of Surface Characteristics. In the third and final stage, the captured data is examined for specific characteristics and properties of the subsurface. These properties may have an impact on the rideability and safety of the bike path. Examples of these properties include roadway width, the presence of physically separated bike lanes, barriers, or other structures. These properties are detected and labeled using AI applications. For this stage, we also employ the SSD MobileNet V2 Object Detection Framework. By utilizing this framework, we ensure reliable and fast detection of road characteristics such as bicycle lanes and barriers. This contributes to a comprehensive assessment of bicycle paths and enables targeted measures to enhance traffic safety and user-friendliness.

This work focuses on the development of the first stage of analysis in the project, which has already been completed. In this stage, the emphasis was on developing algorithms for the detection and classification of the road surface. Currently, the subsequent stages of the project are being addressed, including the examination of the road condition

and the detection of surface characteristics. These two stages are still in the development phase, and as a result, final results are not yet available. Efforts are being made to develop algorithms and techniques using object detection to analyze the road condition and identify specific surface properties.

2.5 Analysis Methods

An AI model has been trained which is capable of partitioning incoming video data into individual frames and reliably analyzing and evaluating the ground conditions and characteristics. In this process, classification is carried out into either paved or unpaved surfaces. For the analysis, a dedicated AI system consisting of powerful components was developed by the research team, which works up to 30 times faster than conventional computers during AI analyses.

The machine learning framework used in this process is TensorFlow, an open-source framework developed by Google for executing machine learning algorithms. By connecting a powerful GPU, as is the case in this project, training image classification models is significantly accelerated. Another significant advantage of using TensorFlow is the use of the open-source deep learning library Keras, which explicitly builds on TensorFlow and provides additional capabilities that simplify programming of neural networks.

Convolutional Neural Networks (CNNs) were utilized for the development of the proposed method, as they are well-suited for processing image and video data and have proven their effectiveness in applications of image recognition, computer vision, and machine learning. In a CNN, the training data is filtered as input through multiple layers of neurons, with certain processes performed on the data in each of the layers. The Convolutional Layers analyze the incoming images for features and extract them into a result matrix, which is then sorted based on its importance and relevance in the Pooling Layers. In the final layer, the input data is classified into the aforementioned categories.

2.6 Training Data

The first stage of analysis aims to detect and classify the surface condition of the path. This model has been trained to recognize three different surface types: asphalt, cobblestone, and unpaved paths (see Fig. 4).



Fig. 4. Example of training data frames.

To train the model, large amounts of image data were required. Approximately 90 thousand images were used for the first stage of development. With the help of these data, it was possible to automatically detect and classify the surface condition of paths. By using the open dataset “Road-Surface-Type-Classification” from the data science platform Kaggle, the first stage of the procedure could be carried out faster and easier. However, care was taken to ensure that the datasets used were sufficiently large and representative to ensure high accuracy in detecting the surface condition. Another advantage of using datasets is that the model is already capable of analyzing initial images even before being “trained” by additional images and metadata.

3 Results

As a result, the model can be quickly deployed, and the results of the initial analyses can be immediately utilized. To evaluate the performance of the model, 20% of the training data that did not influence the training process of the model was used for testing. The performance was assessed based on the F1-score, and a confusion matrix was created on a class level to measure the accuracy of individual classes (see Fig. 5). This approach allowed for the identification of the strengths and weaknesses of the model, enabling targeted improvement to be made to the model’s weaknesses, and overall performance to be improved.

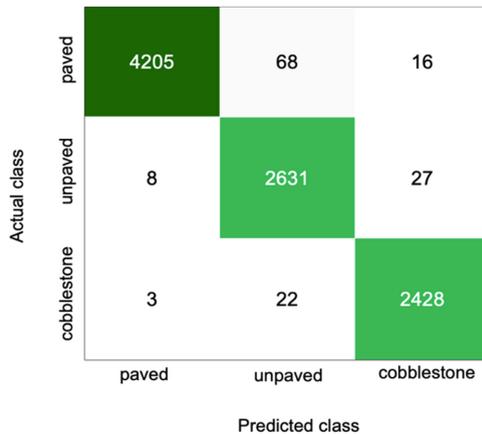


Fig. 5. Results of the confusion matrix presented as a heatmap.

The initial analysis results, which included classification into categories of paved, unpaved, or cobblestone surfaces, showed promising results. The AI model was able to correctly classify surfaces in over 95% of cases. However, as the current dataset does not include some weather-related aspects, such as wet surfaces, it is regularly updated with self-captured images via the ABPA app, and the model is retrained based on new data. Additionally, all other categories resulting from the inclusion of ABPA video data in the dataset are incorporated into the AI model’s training. Common classification errors are also analyzed to identify and optimize categories that may be more error-prone.

Data is being collected for analysis stages not yet completed, including data that contains identified problem areas or characteristics. Moreover, synthetic data is generated for suitable surface damage or objects that should be recognized by the ABPA-AI, allowing for preliminary training without the need for large amounts of data.

4 Conclusions

The presented paper demonstrates the feasibility of an AI-based approach for analyzing bicycle paths, with a focus on the first stage of analysis - the detection of the road surface. The low-threshold data collection method and the use of convolutional neural networks (CNNs) have proven to be effective in reliably detecting and classifying the surface condition. For authorities responsible for maintaining bicycle paths, the results offer a more efficient way to assess and monitor their conditions. They can respond more quickly to problems and invest in maintenance more purposefully. Additionally, the analysis results can be used in the fields of bicycle logistics or route planning, ultimately improving safety and comfort for cyclists and promoting cycling as a mode of transportation.

The study is part of a larger research project aimed at collecting and analyzing information about the condition and quality of bicycle paths using an AI-based approach. The project's three-stage analysis approach provides a comprehensive method for determining the surface condition of bicycle paths and enables efficient and reliable performance. Using various methods and technologies for the automatic and efficient processing of large image data sets, the information can subsequently be used as a basis for decision-making and action to improve bicycle paths and meet the needs of cyclists in the future. The results of this research project can ultimately contribute to a more sustainable and efficient transportation system. The results of the research project are being examined with regard to scalability and transferability. The concept and findings of this study can also be applied to other types of roads or different types of infrastructures. For instance, the developed analysis approach could be used for monitoring and assessing pedestrian pathways or motor vehicle roads. There are already ideas for further follow-up projects. One example of this is research into an additional analysis stage to identify obstacles for barrier-free mobility. However, other research topics are also being considered. For instance, the recordings could be examined to determine whether further information can be extracted and utilized.

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Intelligent Character Recognition of Handwritten Forms with Deep Neural Networks

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Abstract. The automatic processing of handwritten forms remains a challenging task, wherein detection and subsequent classification of handwritten characters are essential steps. We describe a novel approach, in which both steps - detection and classification - are executed in one task through a deep neural network. Therefore, training data is not annotated by hand, but manufactured artificially from the underlying forms and yet existing datasets. It can be demonstrated that this single-task approach is superior in comparison to the state-of-the-art two task approach. The current study focuses on hand-written Latin letters and employs the EMNIST data set. However, limitations were identified with this data set, necessitating further customization. Finally, an overall recognition rate of 88.28% was attained on real data obtained from a written exam.

Keywords: Intelligent Character Recognition · Handwritten Character Recognition · Automated Form Processing

1 Introduction

Despite the prevalence of digital technology, paper forms continue to be used in various contexts, often due to legal requirements or user preferences. Many applications still rely on paper forms that are filled out by hand, such as surveys, job applications, medical records or government forms. Automating the processing of these forms can save time and reduce errors compared to manual data entry [1, 2].

Other applications for automated form processing is the processing of health records [3], the processing of bank cheques [4] or the processing of job application forms [5]. Our use-case is the processing of printed exams, where the possible answers are given by capital Latin letters (“A”, “B”, ..., “Z”), which must be entered into a table. For further processing, the letters in the table must be recognized by our system (see Fig. 1).

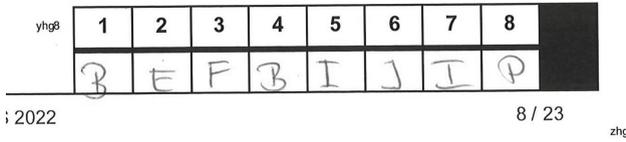


Fig. 1. A table is printed on the lower right side of the paper. Each column represents one question. Each question must be answered by a capital Latin letter.

Automated form processing is strongly related with Character Recognition, which can be categorized into (a) the recognition of machine printed characters, which is substituted by the term Optical Character Recognition (OCR) and (b) Handwritten Character Recognition (HCR). HCR can further be divided into online- and offline systems. In general, online systems use the runtime input (e.g. the trajectory of the input pen), whereas offline systems are based on pixel images, often obtained by scanning a printed page [6–9].

Whereas HCR focuses more on the classification part of the cropped image itself, Intelligent Character Recognition (ICR) is a broader term that addresses the character recognition task in different conditions, e.g. in forms, on plates, in pictures (called “text in the wild”) [10, 11].

Common approaches of HCR in forms and ICR involve six different processing steps (see Fig. 2): (1) data acquisition, (2) preprocessing, (3) segmentation, (4) feature extraction, (5) classification and (6) post-processing [2, 6, 7, 12–16]. The next section summarizes the Literature concerning each of the six processing steps.

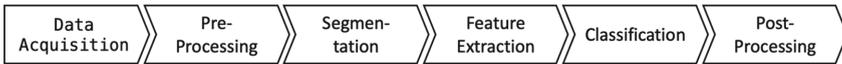


Fig. 2. The six processing steps for Intelligent Character Recognition (ICR).

2 Related Work

1. Data Acquisition: The form to be processed is scanned or photographed. The result is obtained as an bitmap image of formats like JPEG, PNG etc. [9, 17]. (Whether lossless compression is necessary depends on the further process steps).
2. Preprocessing: Various techniques, such as binarization, complement, size normalization, morphological operation, noise removal using filters, thinning, cleaning techniques, filtering mechanisms, thresholding, and skeletonizing techniques are applied to eliminate undesirable elements from the image [18, 19].
3. Segmentation: The preprocessed image is decomposed into sub-images containing the individual characters. If tables are used, parallel lines and the horizontal and vertical space can be used as features to extract the table regions [20–23]. As of 2014, the “Regions with Convolutional Neural Network (CNN) features” method (R-CNN) has been developed [24], which locate single or multiple targets in digital images. This

approach has been evolved towards Fast-R-CNN [25] and Faster-R-CNN [26] models, which are also called target detection models [27]. These models can also be used to detect the position and the structure of tables in image-based documents [28, 29]. Meanwhile more complex models like YOLOv5, YOLOv7 [30] or Detectron2 [31] became popular for detecting targets in images, e.g. a fine-tuned YOLOv5 network has been trained for License Plate Recognition [32, 33] or for detecting Sui script characters in endangered archives [34].

4. **Feature Extraction:** From the decomposed sub-image a vector of features is derived. These features can be categorized in Global-Features (Fourier Transforms, Wavelets, Hough Transforms, etc.), Statistical Features (Zoning, Crossing and Distances, etc.) and Geometrical Features (Strokes, Chain Codes, etc.) [7, 35]. However, these features are strongly related to the underlying classification method and with the upcoming of the CNN and its variants, feature extraction is applied implicitly by the CNN itself in the convolution layers.
5. **Classification:** The extracted features are mapped to a specific character. There are various techniques used for classification, which can be categorized into Artificial Neuronal Networks (ANN), Kernel Methods like Support Vector Machines (SVMs), Statistical Methods, Template Matching Techniques and Structural Pattern Recognition [11, 14, 35]. However, in recent times ANNs became more popular and they outperform SVMs: the current 8 best image classifiers for EMNIST-Letterset [36] all are ANNs [37], archiving an accuracy from 95.96% to 93.65% [38–42]. Even less complex ANN-Models consisting of only 6 CNN-Layers and 2 Dense-Layers combined with Batch-Normalization- and Max-Pooling-Layers achieve a 90.59% accuracy on the EMNIST-Balanced Letterset [43].
6. **Post-processing:** After character classification, several techniques can be implemented to enhance HCR accuracy. One of these techniques involves using multiple classifiers to classify the image, which can be utilized in parallel, cascading, or hierarchical ways [44]. To further refine HCR results, contextual analysis may be conducted by considering the document and geometrical context of the image to minimize the risk of errors.

3 Datasets

The approach presented here uses ANN for the classification task. However, for training the ANN much training data is required and even specialized data augmentation methods which use trained decoder networks to generate variations of the sample characters require 200 and more samples for each class [40]. Therefore, it is advantageous to be able to use existing datasets. For Latin letters, the EMNIST-Letterset [36, 45] became popular and is also used by our approach. There exist different subsets of the EMNIST-Letterset, but the “EMNIST Balanced Letter” dataset consisting of 3000 samples (shape of 28×28 pixels) for each of 47 classes fits best to our classification problem. The 47 classes represent the characters ‘0123456789ABCDEFGHIJKLMNPOQRSTUVWXYZabdefghnqrt’. Samples of the lowercase letters ‘ijklmopsuvwxyz’ were merged with the class of their corresponding uppercase letters. However, in our approach only characters A-Z are to be detected (Fig. 3).

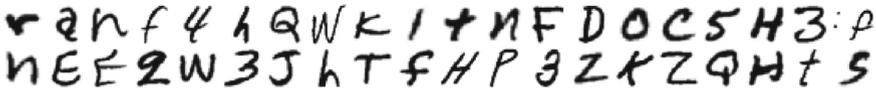


Fig. 3. The first 40 characters from the EMNIST Balanced Letterset. Each sample has a shape of 28×28 pixels.

4 Initial Approach

4.1 Architecture

Our initial approach for recognizing the handwritten letters of the exam show in Fig. 1 was based on the six previously described steps as follows:

1. Data-Acquisition is done with the help of a document scanner, which generates 300dpi image of the page in PDF format. If the page contains grey-scaled colors only (e.g. the student writes with a black pencil), the scanner automatically binarizes the image whereas colored pages (e.g. the student writes with a blue pencil) are stored with the according RGB information.
2. Pre-processing: Our form is provided by a table consisting of two rows and up to nine columns. The table is always printed at the lower right edge of the paper and for easy detection, we added two unique meaningless abbreviation “yhg” and “zhg” at the upper left and lower right side of the table (see Fig. 4) serving as markers. With the help of existing OCR application like tesseract [46], these markers and their position can be detected and the table can be cropped from the whole page at the markers position. Then, all cropped images are converted into gray-scale images and stored without compression as images in PNG format.

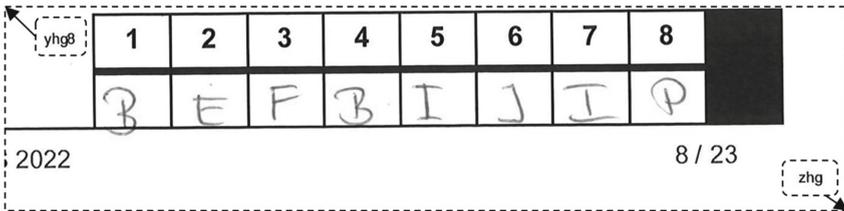


Fig. 4. Segmentation of the table is based on text marker detected with tesseract [46].

3. Segmentation: As the position of the table is known due to the markers and the shape of the table is well defined, the position of each cell can be calculated and its content can be cropped. Each cropped image of each table cell is then resized to 28×28 pixels (according to the EMNIST dataset) and stored as a PNG image (Fig. 5).

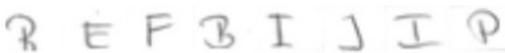


Fig. 5. Segmentation of each letter by cropping the hardcoded the positions of the cells.

4. Feature Extraction and Classification are both performed in one single task by a CNN similar to the one presented in [43]. In order to be comparable with existing approaches, we used all 47 classes although we only need to recognize the 27 classes A-Z. The CNN was trained on the EMNIST Balanced Letter Dataset consisting of 3000 samples (shape of 28×28 pixels) for each of the 47 classes. 2600 samples were used for training and for validation (thereof 80% training, 20% validation). 400 samples were reserved for testing. An accuracy of 89.23% for the validation and 89.02% for the testing-dataset was achieved. (Our accuracy is below the 90.56% presented by [43], however no pre-processing was executed and the CNN was adapted to 28×28 image size) (Fig. 6).

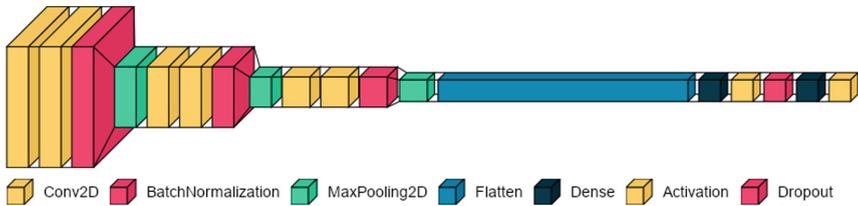


Fig. 6. The architecture of the CNN: Every two convolution layers are followed by Batch-Normalization and MaxPooling, Softmax is used for Output Layer. Detailed description in [43].

5. Post-Processing: The classified letter with the maximal probability is chosen and no further post-processing is executed. Figure 7 shows the result applied to the first eight samples of the EMNIST data set.

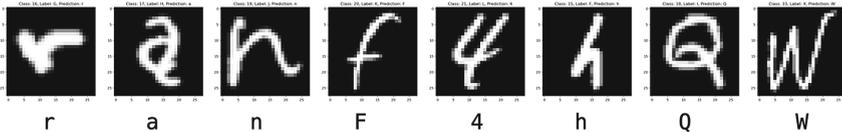


Fig. 7. The first 8 letters of the EMNIST dataset and their predicted character by the CNN. All predictions are correct, letter 'f' and 'F' are accumulated in one class.

4.2 Results

Using the proposed approach above for classification of the letters in our exam, the CNN achieved an accuracy of only 44.46% (5 epochs, no data augmentation). However, comparing the EMNIST-letters (Fig. 7) and the cropped letters (Fig. 8) show, that the cropped letters are smaller since the writers usually don't exploit the full cell size. In order to improve the cropping, a region of interest (ROI) extraction approach similar to the one used for the EMNIST-Letterset could be used [36], but due to artefacts derived from the cell borders and accidentally drawn dots and dashes this approach is error-prone. However, it turned out that this effect can easily be compensated with data augmentation

by zooming out the images of the training set with a factor up to 3, which improved the accuracy up to 81.93%.

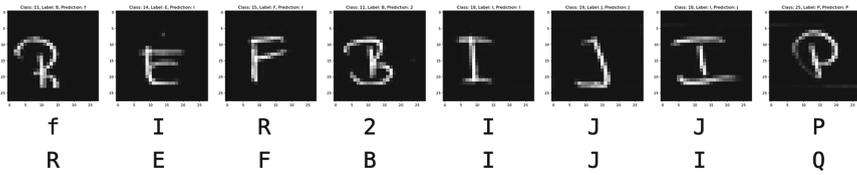


Fig. 8. Eight letters cropped from the table and their predicted classes. First line shows the prediction without data augmentation, second line with data augmentation.

Further investigation revealed the following remaining problems:

- **Cropped letters:** Letters are not written exactly inside the table cell, but protrude from the bottom or top of the cell (e.g. the first letter ‘B’ in Fig. 8).
- **Unaligned cells:** The paper was scanned at an angle and the cropped images contain border line artefacts from the table (e.g. lower side of the last cell containing the ‘P’ in Fig. 8).
- **Misplaced letters:** From the 2646 cells of 49 exams 86% (2285) are written inside the table cell correctly. 14% of the letters are written outside the table, because the user corrected himself. From these 2285 letters 1872 (81.93%) letters are classified correctly with the CNN. However, the letters outside the table haven’t been segmented and classified (Fig. 9).

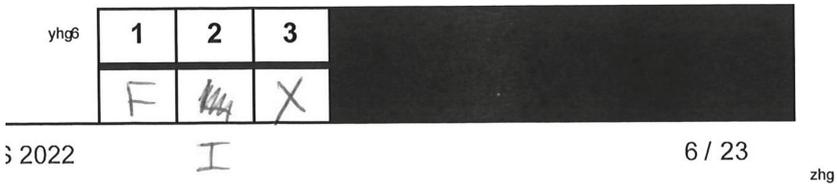


Fig. 9. Misplaced letter: ‘I’ is written below the table.

The overall recognition rate incorporating the misplaced letters calculates to 70.75%.

5 Advanced Approach

5.1 Architecture

To overcome the segmentation problem motioned above, a more advanced approach has been developed, which improves the segmentation of the letters and handles the placement of the letters above or below the table. A YOLOv5 model was used as target detection model and trained to detect the letters in, above or below the table. In order

become independent from hardcoded cell positions and sizes, the model was trained to detect the printed digits above the letters, too (Fig. 10). In the Post-Processing step, the position of each digit is determined and the letter in the corresponding column can be derived. If the model detects more than one letter above or below the digit, the detection with the highest probability is taken. (Since the EMNIST-LetterSet doesn't contain printed digits, for classifying the digits a separate CNN similar to the one presented in Sect. 4.1 was trained with printed digits).

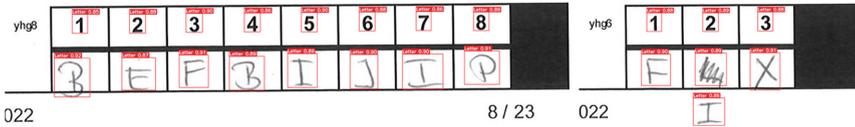


Fig. 10. Segmentation of digits and the letters with the YOLOv5s model. Letter outside the table are detected, too (right).

For training the YOLOv5 model, 756 letters were marked by hand and aggregated in on single class. A YOLOv5s (small) model with an image size of 640 pixel was trained in 100 epochs. A mean Average Precision (mAP) with Intersection over union (IoU) larger 0.5 was achieved in 99.5% of all samples of the validation set (mAP_ > 0.5 with 99.5%) and all digits were detected correctly. The detected letters are then cropped, resized to 28×28 shape and classified with the trained model presented in Sect. 4.1. However, the letters cropped with the YOLOv5 model fit in size to the training letters, so no zoom out during the data augmentation was necessary. Letters or digits left or right outside the text markers position (e.g. 'yhg8' and 'zhg') are ignored, if they might occur.

5.2 Results

Using the YOLOv5s model for segmentation, we detected 2634 out of all 2646 (99.54%) letters, 12 letters were not detected (e.g. the corresponding digit was not found, because it was painted by the writer). From the 2634 detected letters only 1733 (64.79%) were classified correctly. Figure 11 shows the cropped images and their predictions.

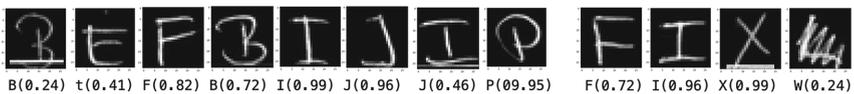


Fig. 11. Classification of the segmented images and their probabilities. Left: The artifacts caused by the cropped table borders create classification issues ('B' and 'J' with low probabilities < 0.5) Right: If two letters occur in one column, the one with higher probability ('X' instead of 'W') is taken.

Using the new approach, nearly all (99.54%) letters are detected, but the classification accuracy of each letter decreases from 81.93% down to 64.79%. Further investigation reveals, that the YOLO-network crops the letters in full size, which leads to more artefacts

inside the cropped images caused by the table borders (Fig. 11, letter ‘B’ and letter ‘I’). These lines are represented by high values, but not part of the EMNIST training dataset, so that their impact is high, which leads to higher rate of wrong classification. The overall recognition rate decreases to 65.50%.

6 Final Approach

6.1 Architecture

To overcome the classification and segmentation problem, we generated our own training data by using the EMNIST dataset and projected the letters into the table cells at randomized positions. Both, the segmentation and the classification task are executed by the YOLO-network. A variety of empty tables were scanned and into, below and above the empty tables arbitrary letters from the EMNSIT dataset where projected. The letters (28×28 shape) were resized with bilinear interpolation to fit to the table size. To increase variety, resizing was executed horizontally and vertically in a random way and random rotation up to 10 degree was executed. Additionally, the letters were eroded with a 3×3 kernel in 1 or 2 iterations to make the stroke thinner. To enable the recognition of digits, a digit was syntactically generated and projected into each sample. The bounding box of the letters and the digit were calculated and stored in the corresponding label file. Figure 12 shows one sample of the generated dataset including the calculated bounding boxes.

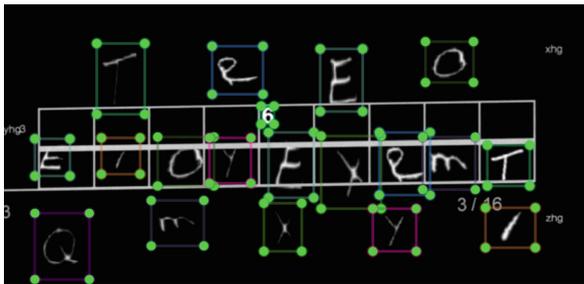


Fig. 12. 18 letters and one digit are projected into the table cells with random spatial deviation. The bonding boxes are calculated during the projection.

6.2 Results

For training 12533 samples were generated and the YOLOv5s model was trained during 100 epochs. A bounding box regression loss (box_loss) of 1.3%, a classification loss (class_loss) of 1.5% and a mean Average Precision (mAP) at IoU (Intersection over Union) threshold of 0.5 (mAP > 0.5) of 91,1% was reached. Figure 13 shows the classification results with the trained YOLO-model of one sample.

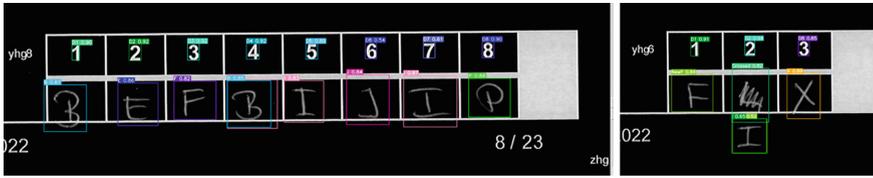


Fig. 13. Segmentation and classification of the letters with the trained YOLOv5 model.

From 2646 letters 2631 letters (99,4%) were detected, 2235 (84.95%) of these letters were classified correctly leading to an over-all recognition rate of 84.46%.

6.3 EMNIST Shortcoming

When the incorrectly classified letters are analyzed, the following causes are detected:

1. Letter 'O' and digit '0': Frequently instead of letter 'O' the digit '0' was recognized. It turned out that in the "EMNSIT Balanced Letter" dataset letter 'O' and digit '0' look the same (Fig. 14, line 1 and 2).
2. Letter 'I' and 'L': Frequently, letter 'I' was classified as 'L'. In the "EMNIST Balanced Letter" dataset letter 'l' (lowercase 'L') was merged with the class of letter 'L' (uppercase 'L') and letter 'i' (lowercase 'I') was merged with 'I' (uppercase 'I'). However, it turned out that by some writers 'I' (uppercase 'I') and 'l' (lowercase 'l') look equal (just a vertical stroke). This leads to the effect, that letter 'I' is frequently classified as 'l' (lowercase 'L') which belongs to the class 'L' (uppercase 'L'). Figure 14, line 3 and 4 illustrates the problem.
3. Letter 'F': Frequently, letter 'F' was recognized with low probability or even wrong classified. We observed, that some writers write the letter 'F' like a 'T' with a horizontal stroke in the middle (Fig. 15, middle). However, the EMNIST data set does not contain this shape of 'F', which leads to wrong classifications.
4. Crossed out letters: Crossed out letters are not part of the EMNIST data set, but they are still classified by the system. Some of these are classified even with high probability, because no negative examples were trained.

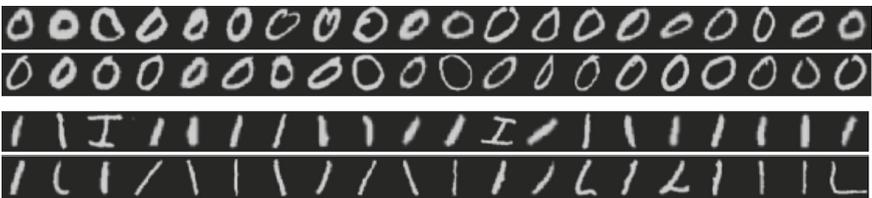


Fig. 14. First 20 samples of class 'O' (first line), of class '0' (digit 0) (the second line), of class 'I' (third line) and of class 'L' (fourth line) from the EMNSIT Balanced Dataset.



Fig. 15. Crossed out letters are falsely classified (left). The letter ‘F’ comes in two shapes (middle, right), but only one shape (right) is part of EMNIST data set.

To overcome these limitations, we switched to the “EMNIST By_Class” dataset, which doesn’t merge small and big letters. From this dataset we extracted 2400 samples for each of the following letters only: ABCDEFGHIJKLMNOPQRSTUVWXYZ. Numbers and small letters are omitted. Further on, we added 240 own written samples of letter ‘F’ in shape presented in Fig. 16 (first line) in a new class called F2. Additionally, 250 samples of own generated crossed out letters were added (Fig. 16, second line).



Fig. 16. New added classes: ‘F’ in alternative style (first line) and crossed out letters (second line).

Using the customized data set, the YOLOv5 model was trained again similar to Sect. 6.1. Based on this new trained model, from 2646 letters 2637 letters (99.66%) were detected, 2336 (88.59%) of these letters were classified correctly leading to an over-all recognition rate of 88.28% (Table 1).

Table 1. Comparison of the different approaches.

Used Approach	Dataset for training	Overall recognition rate
Fixed cell cropping, CNN for classification	EMNIST Balanced Letter	70.75%
YOLOv5 based cell cropping, CNN for classification	EMNIST Balanced Letter	65.50%
YOLOv5 for segmentation and classification	EMNIST Balanced Letter	84.46%
YOLOv5 for segmentation and classification	Customized dataset	88.28%

7 Conclusion

The current state-of-the-art methodology for recognizing handwritten characters in forms involves the execution of segmentation, feature extraction, and classification stages as distinct tasks. However, the use of a CNN enables the simultaneous execution of both feature extraction and classification stages in a single task. In this research article, we demonstrate that all three tasks, namely segmentation, feature extraction, and classification, can be effectively executed through a single deep neural network. The study employed the YOLOv5 model, which necessitated the synthetic generation of training data from the underlying form and the EMNIST data set. Using this approach, the recognition rate could be increased significantly and even letters written outside the form could be recognized correctly. However, our analysis revealed multiple limitations associated with the aforementioned data set. As a result, we developed a customized version and demonstrated its efficacy in improving the recognition rate up to 88.28% .

Obviously, the recognition rate is not high enough to execute fully automated exam correction. To overcome this limitation, we developed an interactive system that superimposes proposed letters on the corresponding bitmap for subsequent human verification. In cases where incorrect corrections are made, a human operator is required to manually enter the accurate letter. Despite the need for human intervention, this system considerably reduces the time required for correction by a factor of approximately five. Additionally, to ensure further accuracy and provide a means for self-verification, the bitmaps along with the final determined letters are transmitted to the examinee via email.

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Innovation Logic: Benefits of a TRIZ-Like Mind in AI Using Text Analysis of Patent Literature

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Abstract. This paper describes a TRIZ-like innovation methodology; Innovation Logic. The three steps of the method are WISH; what are the desired values, SHOP: where can areas be identified for tech transfer and CREATE: variation of properties for better function. The paper demonstrates the benefit of using innovation logic within the application of AI and text mining in the worldwide patent database. A strong ‘Rosetta stone’ effect is the translation of functions into verbs, properties into adjectives and context into nouns. The paper furthermore discusses context relating mechanisms and special text patterns that facilitate the application of Innovation Logic in patent literature. The tool used for the implementation of Innovation Logic into the patent database is Patent Inspiration, selected for its unique liberty in conduction advanced text analysis.

Keywords: Innovation Logic · Artificial Intelligence (AI) · Text Patterns · Patent Research · TRIZ · Inspiration · Artificial Creativity · Patent Inspiration

1 Innovation Logic – Text Patterns

1.1 Introduction

Innovation logic is a methodology that like the TRIZ method was mainly built based on patent literature research [1]. Patent text analysis tools have confirmed property function relations within patents [2], one of the pillars of the method. Innovation Logic for new product or process innovation and problem solving is condensed in three distinct steps: wish, shop and create.

Wish. Wish is the part of innovation logic where customer or client requirements are researched. They are classified in the four value factors: performance, harm, interface and cost [1].

Shop. Shop is the taking these wishes as well as any challenge connected to our product or process and abstracting the challenge into a formula that connects the challenge to other industries or domains. An open innovation map is built surveying all industries that can bring inspiration toward solving each specific challenge.

Create. Create is the part where properties of your system are challenged. By varying properties the resulting new system can create new or improved functions. Several tools can indicate what variations are beneficial. The simplicity of this approach and wide applicability across industries has shown great benefit over the more learning-curve intensive methods, where the complexity does not necessarily result in enhanced outcome [2]. Its simplicity furthermore brings easy integration across industries, as well as in the translation to text analysis or AI.

1.2 Text Patterns in Innovation Logic

Within Patent Inspiration [4] semantic text analysis can identify three patterns as noun:*, adjective:* and verb:*, with the “.*” as an indication of search nouns (and not the word noun). In the same way number:* will research numbers. (e.g. ISO number:* will identify ISO norms). As an example case study, the patents with ‘artificial intelligence in title and abstract were selected, a pool of 67553 patents. Figure 1 shows the top 100 *verbs* in the same sentence with artificial intelligence, the functions. These visualizations are word clouds, the larger the font, the more hits relatively.

advantaged • analysing • annotating • approved • asking • attacked • authorized • awakening • binding • caching • categorizing • chatting
 cloud • clustering • compiling • conflating • consulting • crawling • crowdsourcing • debugging • decrypting
 deducing • denoising • **deployed** • encoding • encrypting • endowing • explaining • explored • exporting
 forecasted • formulated • framing • grabbing • highlighting • hosting • importing • inferring • interworking • iterating
labeling • laying • leveraging • locking • log • mastered • mined • named • networking • parked • parsing
 perfected • personalized • pooling • pose • posting • **preprocessing** • pre-processing
 querying • questioning • queuing • ranked • reform • replying • researched • retraining • reviewing • routing
 segmenting • seted • standardizing • stimulate • stretching • substituting • succeeds • summarizing • surveying
 tagging • targeted • **text** • thinking • treating • trusted • understood • unlocking • validating • vectorized • voice

Fig. 1. *verb:** in same sentence with “artificial intelligence” pool.

Wish. Finding the performance of a product is distilled by identifying its functions. As functions are expressed in verbs, one can query: *verb:** in the same sentence with *product*. For harm elements patterns like *decrease noun:** or *avoid noun:**. Some terms will generally find their place in this category such as *environment* friendly*, being environment friendly or environmentally friendly etc. For interface patterns that bring good results are *easy to verb:**, or *self**. The cost elements can expressed as *verb:** *cost* or *noun:** *cost* [2].

It is important on what part of the patent the research is performed. Title and abstract will give a summary, claims the solution and the description depicts the problem and a more textual version of the solution. As an example, Fig. 2 shows a convenience pattern as *easy to verb:**

easy to achieve • easy to adapt • easy to add • easy to align • easy to analyze • easy to apply • easy to cause • easy to change • easy to check • easy to class
 easy to clean • easy to collect • easy to comprehend • easy to control • easy to converge • easy to count • easy to crack • easy to create • easy to customiz
 easy to deploy • easy to detect • easy to determine • easy to develop • easy to distinguish • easy to expand • easy to express
 easy to find • easy to generate • easy to grasp • easy to have • easy to identify • easy to implement
 easy to integrate • easy to interfere • easy to learn • easy to loosen • easy to maintain • easy to measure • easy to modify • easy to mount
 easy to move • easy to navigate • easy to observe • easy to obtain • easy to occur • easy to operate • easy to perform
 easy to play • easy to popularize • easy to predict • easy to process • easy to produce • easy to provide • easy to pull • easy to put • easy to read
 easy to realize • easy to receive • easy to recognize • easy to refit • easy to remember • easy to replace • easy to reuse • easy to search
 easy to see • easy to select • easy to sell • easy to set • easy to show • easy to slip • easy to store • easy to take • easy to track • easy to train • easy to transfer
 easy to understand • easy to update • easy to upgrade • easy to use • easy to verify • easy to visualize

Fig. 2. *Easy to verb*:* pattern in artificial intelligence patent pool.

Shop. There are several approaches to automate analogy across products and processes [5, 6], however the simplicity of text patterns outweighs the inaccuracy of automation. If the list of problems to be solved connected to a problem is not given, a text pattern *noun*:* *problem* and *verb*:* *problem* can already indicate a series of problems in the product patent pool. Secondly, modifiers (*increase noun*:*, *decrease noun*:* or *stabilize noun*:*) indicate abstract challenges ideally suited to for open innovation mapping.

If a set of challenges is selected, their abstract formulation is used to build a new filter. (e.g. controlled release). Within the pool of patents around e.g. controlled release, there are several approaches to identify the other domains or industries.

1. *noun*:* *industry* and *verb*:* *industry*
2. *noun*:* in title
3. CPC Code analysis
4. code map [3]
5. domain map [3]

Once the domains are identified, the solutions can be explored, or subgroups can be questioned in terms of technologies (*noun*:* *technol** or *verb*:* *technolo**) or effects (*noun*:* *effect* or *adjective*:* *effect* or *verb*:* *effect*).

Depending on the challenge at hand, further slicing and dicing can be performed on materials, elements, units etc. [3] to explore the potential technology import into your specific domain. Figure 3 shows the pattern *noun*:* *industry* in the artificial intelligence patent pool, showing where AI is mainly deployed as referenced in patents.

Create. Create is based on the property-function relations and varying properties to gain new or improved functions. Patent analysis to support innovation or engineering design is an active domain [4], however rarely the core property-function relation is explored and implemented. Earlier research [2] indicated the pattern *adjective*:* *to verb*:* uncovers those relations across industries. For any product the following patterns work:

- *adjective*:* *product*: a list of properties of that product. The adjectives can than furthermore be clustered in property spectra (i.e. flexible, bendable, jointed, etc. within

aerospace industry · agriculture industry · ai industry · automation industry · automobile industry · aviation industry · banking industry · beverage industry · breeding industry · business industry · car industry · card industry · care industry · casting industry · chemical industry · clothing industry · communication industry · computer industry · computing industry · construction industry · consumer industry · defense industry · design industry · device industry · education industry · electronics industry · energy industry · engineering industry · enterprise industry · entertainment industry · entity industry · equipment industry · estate industry · fashion industry · film industry · financial industry · food industry · gaming industry · gas industry · goods industry · health industry · healthcare industry · hospitality industry · hotel industry · information industry · insurance industry · intelligence industry · interaction industry · internet industry · it industry · logistics industry · machine industry · machining industry · management industry · manufacturing industry · media industry · mobile industry · movie industry · music industry · oil industry · organization industry · payment industry · petrochemical industry · petroleum industry · power industry · process industry · processing industry · production industry · recognition industry · recreation industry · restaurant industry · robot industry · security industry · semiconductor industry · service industry · services industry · shipbuilding industry · skeleton industry · software industry · spa industry · steel industry · target industry · taxi industry · technology industry · telecom industry · telecommunication industry · telecommunications industry · television industry · testing industry · textile industry · tobacco industry · transportation industry · travel industry · trucking industry · twintech industry · utility industry · visualization industry · water industry

Fig. 3. Text pattern *noun: * industry* in the AI patent pool.

a flexibility spectrum). Principles, trend steps and heuristics, can easily be brought back to property changes, expressed in adjectives [6, 7].

- *adjective: * product* over time [3] will indicate trend lines or the time certain property variations in your product appear within the patent literature.
- *noun: * product* will indicate the context in which the product is used. Instead of a property *flexible* toothbrush a *noun: * toothbrush* gives the context, e.g. *dog* toothbrush. There is always a degree of overlap as some words can be interpreted as both a noun as an adjective.
- *verb: * in the same sentence with product* will list the functions of the product. In a more advanced way, adjectives can be connected to verbs, as depicting which property enables the product to perform a new or better function.

Figure 4 shows the different properties of the algorithms by applying *adjective: * algorithm* pattern. Figure 5 shows the pattern *noun: * algorithm* indicating the different context of the algorithms.

boost algorithm · adaptive algorithm · artificial algorithm · based algorithm · bayesian algorithm · classifier algo
control algorithm · deep-learning algorithm · evolutionary algorithm · fitting algorithm · fuzzy algorithm
genetic algorithm · greedy algorithm · hash algorithm · intelligence-based algorithm
intelligent algorithm · interval algorithm · iterative algorithm · k-means algorithm
hine-learning algorithm · matching algorithm · meta-learning algorithm · multiple algorithm · new algo
| algorithm · parallel algorithm · predetermined algorithm · random algorithm · recursive algorithm · rule-based ε
algorithm · statistical algorithm · traditional algorithm · trained algorithm · traversal algorithm · visual algo

Fig. 4. *adjective: * algorithm* pattern showing the properties of the different algorithms.

ai algorithm · analysis algorithm · classification algorithm · clustering algorithm · colony algorithm
 control algorithm · core algorithm · data algorithm · decomposition algorithm · descent algorithm · detection algorithm
 diagnosis algorithm · encryption algorithm · enhancement algorithm · estimation algorithm · evaluation algorithm · extraction algorithm
 forest algorithm · fusion algorithm · generation algorithm · identification algorithm · learning algorithm
 machine algorithm · matching algorithm · mining algorithm · model algorithm · network algorithm
 optimization algorithm · path algorithm · planning algorithm · prediction algorithm · processing algorithm
 propagation algorithm · recognition algorithm · recommendation algorithm · regression algorithm · scheduling algorithm
 search algorithm · segmentation algorithm · selection algorithm · similarity algorithm · software algorithm · swarm algorithm
 target algorithm · tracking algorithm · training algorithm · tree algorithm · vision algorithm · yolo algorithm

Fig. 5. noun:* algorithm pattern showing the different context of the algorithms.

1.3 Special Text Patterns

Patterns can be very domain specific and can be beginnings or endings. Figure 6. Shows an example special pattern, the pattern self* in the AI patent pool. More examples of special patterns that rely on the structure of language are given below:

**lity*: what are all reliability, flexibility, controllability, etc.

**less*: what was trimmed out, wireless, frameless, etc.

*self**: selfcleaning, etc. identify self-functions.

*anti**: identifying harms or problems.

**ase*: enzymes end with -ase.

**ene*: most polymers end with -ene.

**mab*: Monoclonal antibodies end with -mab.

self · self-adaptation · self-adapting · self-adaption · **self-adaptive** · self-adjusting · self-administered
 self-assessment · self-assessments · **self-attention** · self-aware · self-checking · self-cleaning
 self-consistent · self-contained · self-control · self-correction · self-defined · self-describing
 self-diagnosis · self-directed · **self-driving** · self-encoding · self-executing · self-explanatory · self-generated · self-healir
 self-help · selfie · self-improvement · self-improving · self-inspection · self-learn · **self-learning** · self-lockil
 self-management · self-monitoring · self-organization · **self-organizing** · self-propelled · self-reported
self-service · self-sufficient · self-supervised · self-supervision · self-teaching · self-test · self-training

Fig. 6. Example special pattern, the pattern self* in the AI patent pool.

2 Innovation Logic - AI

2.1 Related Terms

Even though context is the differential factor of two domains, by comparing context around a word to which other words have the closest context, related terms can be identified. The patent database is exemplar for this AI due to its richness in scientific knowledge. For example, using Antimicrobial as the related term, will result in identification of terms such as antibacterial, antifungal, bactericidal, antibacterial agent, bacteriostatic, anti-biofilm, fungicidal material, anti-fungal effects, bacteriocidal properties, antialgal, microbicidal, biocidic, anti-algal etc.

The benefit of related terms is to be able to identify all related keywords to your patent search, as it is not evident that antibacterial means biocidic. A second benefit can be to reflect on why some words are present that at first view look like they have no place in the list. For example, when searching for related terms to *mineral exploration* one of the terms down the list appears as *precision agriculture*. The connection between mineral exploration and precision agriculture has identified a fertile analogy for technology transfer (drones, mapping, soil scans etc.). Figure 7 shows related terms to ‘artificial intelligence’ as a way of defining the concept.

approximate reasoning • artificial neural networks • computational intelligence • computer science • data mining
 decision theory • expert system • expert systems • fuzzy logic • fuzzy logic systems • fuzzy neural networks • fuzzy set theory
 y systems • human intelligence • inductive logic programming • inference engines • intelligent systems • knowledge acquisition
 knowledge engineering • knowledge-based • knowledge-based systems • learning methods • learning system
 arning systems • learning techniques • machine learning • machine learning algorithms
 machine learning approaches • machine learning component • machine learning techniques • machine-learning
 natural language processing • natural language understanding • neural nets • neural network techniques
 neural networks • reinforcement learning • rule-based reasoning • rule-based system

Fig. 7. Related terms to artificial intelligence.

2.2 Competing Companies

Finding competing companies, on a very specific domain is not easy. Companies compete in some domains but not in others. How to identify the closest competitors to a specific patent portfolio is important. Based on the pattern of classification codes the company’s patents are in, and combined by their patent content, closest matches are identified in *competitor analysis* [3]. Finding competitors of your clients can identify new potential clients. The patent data analysis is the only accurate competitor identifier based on their (patented) technology. If a better or cheaper supplier is sought, similarly, competitors of your supplier can be better, closer, greener or cheaper suppliers.

2.3 Similar Patents

Similar to *related terms*, every patent is indexed in terms of its properties e.g. context, content, classification, etc. Based on the properties, the patents with closest match are listed in a list of top 50 similar patents [3]. So every patent document is given a form of ‘digital’ fingerprint based on the content. The patents with a similar fingerprint are identified.

3 Current Developments and Opportunities

3.1 The Interface

Many impressions of AI mostly rely on the correct interpretation of full text or conversational input, and the output being in a human like answer format. Although some of the answers are mediocre, the user is mostly content with the format in which the answer is given. Further developments will focus on the human like interface of the knowledge tool.

3.2 Mapping Tools

Within the potential interface, AI can be reduced to gluing all report steps into a premade innovation report without any user interaction. Problems can be distilled from a company’s patent pool on a given product. The software can identify similar domains, and propose the differences as design specs as described in Patent US8600735B2 Directed variation of systems and processes.

3.3 Automated Idea Generation

With Innovation Logic property variations, hundreds of product variations can be proposed. There are several ways to filter the morphological variations [9, 10]:

1. based on values (wish) in which results can be organized by more performance, less harm, easier or more cost effective
2. based on their existence in other domains, if the patterns of property -function relations have shown benefit in other industries.
3. based on evolution patterns in technology, similarly to TRIZ-trends, if the variation is more recent in other domains or follows a more complex property step, that benefits the user.

4 Conclusion

To enter AI and text pattern fields with prior knowledge in Innovation Logic or other TRIZ-related methods proves beneficial. If text mining technology is allowed in an organisation’s searching of documents, TRIZ-like minds know to think in terms of.

- function that are enabled by properties, in verbs and adjectives.

- trend steps in property variation on degree of complexity (e.g. full-hollow-porous-capillary).
- trimmed out items in **less* or **free* (e.g. jointless, leadfree etc.).
- value categories e.g. *easy to verb* in convenience.
- abstract problem formulations to connect to other domain solution space.
- industry defining adjectives for market exploration (e.g. food industry or pharmaceutical packaging).

The benefit of AI and text mining tools into patents bring the combined strength of the worldwide knowledge into the patent data derived innovation logic [1].

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AI Based Pointer to Geometric Effects

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Abstract. The aim of this work is to rediscover one of TRIZ's best-known tools, the Pointer to geometric phenomena and effects. It is part of a large group of pointers that also includes that to physical effects, to chemical effects and to specific technologies. They were introduced by Altshuller as direct tools for solving a problem. Easy to use but difficult to construct, these tools largely remained on paper, with the exception of the pointer to physical effects, which instead has had numerous software implementations, including recent ones. Studies on the geometric one, on the other hand, are stuck in 1989, in the never-translated book by Vikentiev and Yefremov. The authors' work started from there, translating it from Russian, recovering what had already been done and developing it at its weakest points. In the absence of a rigorous theoretical basis, they worked on a definition of geometry and the nature of the relationship between the geometry of an element of the system and its functionality. The concept of multilevel shape and topology was introduced, and material was added to the list of pointers. For the construction of the libraries that enable the pointer to function, a systematic working methodology was developed that benefited from the latest text mining technologies, including large language model, named entity recognition, syntactic parsers, and others. These were appropriately combined to recognize design features and geometries from natural language documents taken from patents. In this paper we show both the methodological path to build the library and a demonstration of how to integrate libraries of geometric effects within dynamic pointers to existing physical effects.

Keywords: CAI - Computer Aided Innovation · AI - Artificial Intelligence · Problem-solving · Pointer to Physical Effects · Pointer to Geometric Effects · TRIZ · Patents

1 Introduction

There are several pointers in the TRIZ methodology toolbox: Pointers to physical, chemical, and geometric phenomena and effects, Pointers to specific technologies that can have a wide range of applications. Pointers are probably the easiest tools to use in TRIZ, but they are not easy to create [1].

The only tool that has had any luck to date is the Pointer to Physical Effects, while of the others there are no noteworthy implementations. A Pointer to Effects is a tool

[2] whose purpose is to suggest to the problem solver one or more physical, chemical, geometric, or technological effects with which he can realize the design function. To make it work, it is necessary to have a special library that links the effects database to the functions. In almost all state-of-the-art implementations [3–11], the operating scheme is similar and is based on Function Oriented Search (FOS) [12]. The user selects a function from a list of predefined verbal actions, or from a combination of technical parameters plus one of the following verbal forms “increase, decrease, maintain or measure” [13] to obtain the list of effects relevant to it.

To date, there are tools that only work with physical effects, while chemistry and geometry have been strongly neglected.

Furthermore, the association between functions and physical effects in the vast majority of applications does not take into account the application context in which one is operating and does not disambiguate between the different meanings a verb may have. Moreover, if the desired verb is not found, one must look for a ‘neighboring’ verb that will not always be truly relevant. In addition, the expression of the target function for the sake of simplicity is in any case simplified and reduced to a simple verbal action (e.g., flying at low altitude becomes flying, breaking without making noise becomes breaking, etc.).

To overcome these limitations, at least partially, dynamic versions of the pointer to (physical) effects have also been proposed, capable of linking the function and the physical effect from a technical text (patent or scientific literature) by means of textual analysis with syntactic parsers and dependency patterns [5, 14].

The idea of exploiting already existing solutions to extrapolate function-effect pairs is terribly topical if we consider the sudden progress in the field of Artificial Intelligence (AI) that is changing the world of Computer Aided Innovation (CAI) and, in general, of all activities in which Problem-Solving techniques are applied.

The use of Artificial Intelligence makes it possible to rediscover tools that are now obsolete or tools that had little luck in the past, due to the limitations of the means available in the era in which they were conceived, giving them new life through integration with modern technologies that restore their credibility and make them extremely suitable for the contemporary world.

We can think, for example, of how thanks to word embeddings [15] Gervasoni was able to reduce the verbal forms of English (over one million) to a predefined set of functional actions, i.e. capable of producing an effect on the object that receives this action; the functional actions are about 100,000, ordered hierarchically according to semantic relations, sorted into classes of meaning according to Beth Levin classification. The study of the semantic relationships between functional verbs used in the patent database also made it possible to calculate the conceptual distance of a verb with the other verbs in the DB, regardless of the semantic relationship it may have with that verb.

The possibility of being able to make use of a tool like this is the basis of the rediscovery of the pointer to geometric effects proposed in this work.

The aim of this article is to revive this TRIZ tool by restoring the dignity and credibility that this pointer variant was never able to enjoy. This research is a demonstration of the feasibility of the project and brings a real-life example of how with modern technology it is possible to largely overcome the limitations of past methodologies.

The content of this article is structured as follows. Sect. 2 is dedicated to the state of the art of geometric effect pointers. In Sect. 3, the methodological proposal for the creation of a pointer to geometric effects in a modern key using Artificial Intelligence technologies is described. In Sect. 4, the implementation of the methodology within software is hypothesized. Section 5 concludes the article with an explanation of the limitations of the methodology and possible future developments.

2 State of the Art of Pointers to Geometric Effects

The first and last real attempt to create a database of geometric effects dates back to 1989, when T. L. Vikentiev and V. I. Yefremov published in the Soviet Union the book “The curve that will always go to your rescue. Geometry for inventors” as part of A.B. Seljuckij’s collection “The rules of the game without rules” [16], which was only available in Russian and is difficult to find today. Apart from this work, with the exception of a few other scattered publications by the same authors, there are almost no other references to this tool, which has in fact been completely abandoned.

In the aforementioned book, Vikentiev and Yefremov devote a chapter to each of the geometries selected to compose the database of geometric effects, then divide them into separate paragraphs according to the respective functions these geometries can perform. For each of these functions, at least one example from the patent world is also given. The book never gives a strict definition of what a geometric shape is, there are spheres, ellipses, parabolas, the hyperboloid, just as sand and in general granular bodies, brushes and related structures, various types of helix, and non-orientable surfaces such as the Möbius strip and Franz Reuleaux’s triangle are also considered geometric shapes.

The text is full of examples, but the contents do not follow a coherent and scientific organizational logic, sometimes lacking comprehensibility, especially when reference is made to patent applications without an image of the patent being shown.

To date, it is complicated to access images of Soviet Union patents because SU patents are often reported in incomplete form on international patent portals, especially as regards images. These patents can be found only by combining searches from different national databases exclusively in the Russian language such as the official website of Russian Federal Institute of Industrial Property (<https://new.fips.ru/registers-web/>) or Yandex patent database (<https://yandex.ru/patents>).

The number of geometric effects contained, which in total amounts to about 30 different geometries, although small, is still significantly large to explain how a geometric effects pointer might work. His idea of relating a function to a geometry, then digging through patent sources to find concrete examples, is also extremely interesting and absolutely topical. Furthermore, the idea of including geometries not conventionally considered as such, like the brush, in his database is very original and opens the way for a whole series of geometric shapes to be included in a new database that do not necessarily have to be the classical ones. It may therefore be worth thinking about exploiting the technologies available to the contemporary world, first and foremost Artificial Intelligence, to attempt to carry out a task that can now be done much more efficiently and in proportionately less time.

The work proposed by the authors takes into consideration only a few geometries; it is therefore intended as a purely didactic purpose, as a first step towards a more comprehensive work that takes into consideration the thousands of geometries that could potentially enrich the library. For each of the geometries listed above, in each paragraph the authors describe a different function that can be performed by exploiting this geometric effect and give at least one patent taken as an example. The approach followed in constructing the library is therefore to start with a chosen geometry, identify a number of patents in which it is employed and finally extract functions (expressed as functional verbs) from these.

For the sake of conciseness, we have been mainly concerned with explaining the technical feasibility of an actualization of Vikentiev's work in the AI era, postponing in-depth studies of the more conceptual and methodological aspects underlying this work to future publications. Only the authors' thoughts on how a functional design geometry should be defined, how a function should be expressed, what the relationship between geometric effect and physical effect is and in what ways the geometric effect can be integrated into a dynamic pointer will be mentioned here.

3 How to Build a Dynamic Pointer to Geometric Effects Today

Let us now describe the steps of our innovative methodological proposal for the construction of a modern pointer to geometric effects. First, it is necessary to define exactly what will be considered a "geometric effect" and, therefore, to define the limits of which geometries can be included in the effects database.

3.1 Towards a Definition of Geometric Effect

In the TRIZ literature there is no proven definition of a Geometric Effect, just as the state of the art lacks a complete library of geometries, but only sporadic examples appear, which, in most cases, cannot be traced back to a strict definition of geometry.

It is therefore necessary to put forward an initial hypothesis towards a definition of a geometric effect. Let us consider that each element of a technical system contributes alone or in combination with others to the fulfilment of one or more functions. How does such an element do this? The geometric effect helps us to answer this question.

Each designer projects a part of the system with a specific shape and then decides which material it should be made of and by which manufacturing process. The manufacturing process affects the properties of the part based on how its constituent elements are distributed among each other within the part. Think for example of a carbon fiber composite and the study that is done to give it stiffness in specific directions.

For simplicity's sake, we will call the external geometry of the part "shape" and "topology" the distribution of the part's constituents within it. Topology, as biomimetics teaches us [17], can be seen at many different levels of detail (macro, meso, micro, etc.). The geometric effect tells us how a part can contribute to the fulfilment of a function, enabling a specific behavior or physical property, regardless of the material it is made of, thanks to the combination of its external shape and the topology(s) with which the internal material is distributed.

The concepts of topology and shape, as well as the material, do not depend on the scale with which the system is analyzed, but are intrinsic characteristics of each component or its parts.

According to FBS theory, the function is the goal of the product, which is realized by a behavior, that is, the way in which the various components of the system (structure) act with each other. The novelty introduced by the authors lies in the representation of a functional model of the system in which I no longer have to explain how the geometry of an element affects its behavior, (and with these the goal), but how its shape, its topology along with the material it is made of, independently determine its final behavior. Depending on the obviousness of this link, the behavior can be reported more or less explicitly. The proposed tool was structured according to this assumption [18].

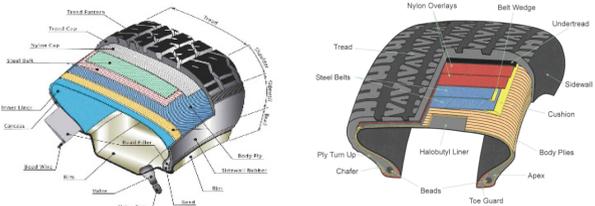
Enabling effect	Examples
External Shape	
Topology (Filling)	
Material	

Fig. 1. Examples of enabling effects for reducing wheel vibration.

Material, shape, and topology can be individually decisive in enabling the main function, or they can be dependently connected to each other. For example, let us imagine that we need to find a solution that enables a wheel to reduce vibrations due to uneven terrain. The designer can act on the material by choosing a more or less rigid compound, or by choosing to use several materials such as steel wire, rubber and ply. He can act on the shape by changing the wheel diameter and modifying its tread by adapting them

to different ground conditions. Finally, it can work on the wheel topology by choosing between tubeless, solid or honeycomb topologies. An example is shown in Fig. 1.

Let us then consider the wing of an airplane and its function of lifting the aircraft into the air. In this case, the material and topology, while clearly important in reducing the weight of the wing, certainly play a secondary role compared to the external shape of the wing. It is precisely the shape of the airfoil that allows for a greater pressure area under the wing and a lower pressure area above the wing, thus enabling the physical effect of lift and thus fulfilling the main function of the component, which is to enable flight.

3.2 Creating a Geometric Effects Library

The collection of effects built by Vikentiev and Yefremov required a lot of work in terms of time to search and select the most suitable patents for its purpose. Nowadays, AI tools allow this information to be extracted much more easily and quickly.

In order to create a library of geometric effects, it is necessary to know how to extract sentences from a corpus of documents that contain descriptions of how a component of a technical system, through its geometry/shape/topology, is able to perform a function. It is therefore first necessary to isolate the sentences that contain the objective function and then to cross-reference the parts of the text that express this function with those that contain the geometric relation.

As far as function management is concerned, we made use of the library of functional verbs constructed from the patent DB and which has already been described in the article [15]. The system handles about 100,000 functional verbs linked to 2000 main verbs selected from Beth Levin's classes. The greatest limitation of this system is that it is currently only possible to select a single verb and not an actual complex sentence in which to specify the action plus the adverb of manner, of time, of place, of quantity, of evaluation as well as expressions specifying its meaning and mode of application. Despite this limitation at this early stage of development, the system we had at our disposal was nevertheless sufficient to build an initial library to test the system.

The main advantage of this function management system, although limited, is that for each proposed verb we are always sure to get a solution as well as a list of other related verbs to use as additional triggers. In fact, when the user enters a verb, the system can calculate the distance to other verbs already in its database and suggest a list of further functional verbs that are close in meaning. In this work, this tool was used to create an automatic expansion of the source verb.

As regards the handling of geometries, we initially only had Vikentiev's 30 geometries available. To these were added the regular geometric figures that are easier to find in the literature. In order to complete the list with the unconventional geometries, which are the vast majority, it was necessary to come up with an innovative search method. To accomplish this task, we made use of tools called NER - Named Entity Recognition. These tools are very useful for automatically recognizing the presence of a technological feature within a sentence written in natural language. There are many of them but none of them are already capable of recognizing our entity. It is therefore necessary to train them by providing a dataset appropriately tagged with lexical expressions indicating a geometry.

Since there is no strict definition of geometry, the selection of the dataset was particularly onerous. To speed things up, a Large Language Model (LLM) from Open Ai was used, which was queried as to which geometries were the most characteristic and iconic for each branch of knowledge, science, and technology.

The last step was to find out when the desired action and the geometry coexisted in the same sentence and were causally connected. If the geometries were connected to the verb in the sentence, constituting the real enabler for the function, they were added to the database of geometric effects.

Some examples of the type of sentences needed to create the library of Action-Effect relations are reported in Table 1.

Table 1. Extracting the link between function and geometric effect.

EP4134557	The screw (3) according to claim 1 or 2, wherein an auxiliary threaded portion (35) is spirally disposed on said shank (32)
CN104766676	The stranded cable of claim 1, wherein each of the plurality of first frangible composite wires and the plurality of second frangible composite wires is helically stranded to have a lay factor from 10 to 150
DE19629824	Instead of a single-screw worm could also be used here as a conveying spiral or screw conveyor
EP2231427	shock-absorbing damper (12), a load-bearing spring element (14) designed preferably as a helical compression spring
JP2022120306	the insulative layer includes an insulator spirally wound around the inner conductor and interposed between the inner and outer conductors
CN202355861	A spiral condensing pipe is communicated between the distillate collecting ball and the communicating pipe
KR10-2418718	a flexible duct having a hermetic structure formed spirally and formed to have a tubular shape so that a fluid moves therein
CN200958733	the plane of the spiral lamp tube body and the top surface of the lamp tube seat, a very large heat dissipation space is formed
WO2020/043591	An inductive chargeable energy storage device according to any of claims 1-7, wherein said conductor is a planar spiral coil conductor
DE102004007590	Buffer conveyor according to claim 1, characterized in, that the spiral conveyor (2) is rotatably provided
KR10-2016-0129450	A bolt with an anti-loosening function, characterized in that a helical coupling can be achieved
EP0828425	edible food container formed by wrapping an elongate strip of uncooked bread dough around a conically shaped mandrel to form a plurality of spiral turns

(continued)

Table 1. (continued)

CN204881933	The utility model provides a novel dynamometer , includes the drum, places coil spring, dowel steel and the couple in the drum
EP0185801	The concrete mixer truck according to claim 1, characterized in, that the counterflow spirals (26, 27) have the same slope as the mixing spirals
WO2013/191523	A protective cap which is spirally coupled to the main body of the main body and is moved up and down by a rotation operation to open and close the lipstick
EP0159764	The spacing means (16) includes a helical portion (18) having a pitch and a diameter, each of which is at least twice the pitch and diameter of the at least one thread (22) on the shank

Shapes and topologies are then extracted from the lexical relations. As an example, we list in Table 2 the relevant patents that appear in the effects database in relation to spiral or helical shapes and the respective functions that the neural network was able to extract.

The search for a shape such as a ‘spiral’ within patents produces results that in almost all cases correspond to the macroscopic domino, i.e., spiral-shaped components. To show how the search must also include topology, we can imagine decomposing a copper cable. It is in fact composed of several wires twisted into a spiral shape to form strands, which are then joined together to form the macroscopic cylindrical cable. In this way, by segmenting the cylindrical cable into many strands, one can increase the density of currents due to the skin effect, and at the same time, the spiral arrangement of the bundle of wires allows one to increase the cable’s mechanical strength.

Another example of spiral application in the microscopic field is represented in Fig. 2 by the molecular structure of keratin. In its α configuration, consisting of intertwined helices, it is present in hair and nails and confers elasticity, while in contrast in its β configuration, which is planar, it confers hardness to animal claws and scales.

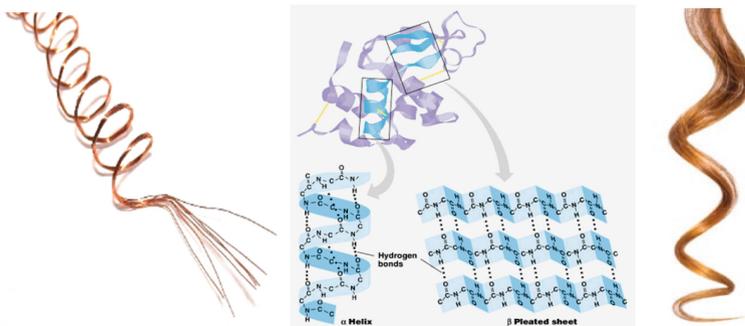
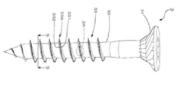
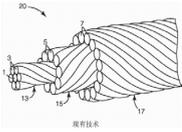
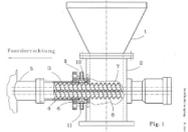
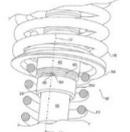
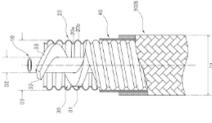
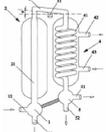
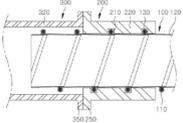
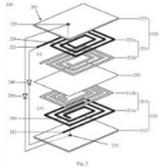
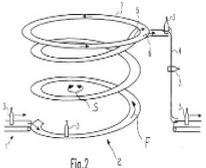
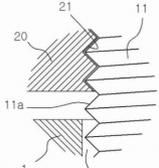
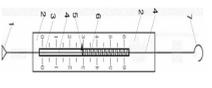
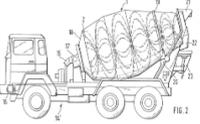
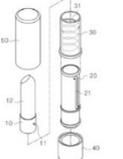
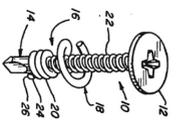


Fig. 2. Stranded copper cable, α -keratin and β -keratin, curly hair. The helical topology allows greater elasticity than the harder planar topology.

It is clear from this example how long and complex the construction of a geometric effects library is. For each shape, it is necessary to reconstruct the set of related functions, and from there a manual sifting to accept or not accept this relationship and express it in the most suitable lexical form.

Table 2. Functions performed by the helix/spiral shape.

To screw	To improve cable lay factor	To convey	To improve shock-absorbing of a damper
			
EP4134557	CN104766676	DE19629824	EP2231427
To insulate	To condense / distillate	To increase the flexibility of a duct	To increase heat dissipation
			
JP2022120306	CN202355861	KR10-2418718	CN200958733
To increase the electrical conduction	To create a conveyor buffer	To ameliorate the helical coupling	To contain
			
WO2020/043591	DE102004007590	KR10-2016-0129450	EP0828425
To measure force	To mix	To move up/down	To improve the grip in the coupling
			
CN204881933	EP0185801	WO2013/191523	EP0159764

4 System Implementation

Once the library of functions and geometries has been populated, it is possible to computerize them within a pointer to geometric effects. Since a dynamic pointer to physical effects already exists, it was simply enriched at this stage by adding geometries, topologies (and in the future, materials). Geometries and topologies are suggested in the form of graphic triggers, using images taken from patents and literature.

This operating scheme allows the user to start from the search for a function and from it derive a set of images with the geometries that enable it to be realized. Having supplied the required function as input in the form of a functional verb, the system navigates through its library, suggests the verbal predicates closest to it and then returns a pool of images of geometric effects that may constitute a trigger for the user.

Let us consider, for example, searching for solutions to increase the flexibility of a component. By typing ‘Bend’ into the search bar, the system will list several other functional verbs similar to the concept of bending that the user can select, such as ‘Bow’, ‘Curl’, ‘Tilt’, ‘Slide’, ‘Straighten’, ‘Buckle’, ‘Collapse’, ‘Stretch’ or ‘Twist’. The output will list a set of images such as a flexible duct, a compliant mechanism, a collapsible phone, a Roman armour, an origami, a roll-up shutter, a spring, a folding chair, the scales of a fish, a collapsible coffee capsule, a stranded rope, and a flexible tripod (Fig. 3).

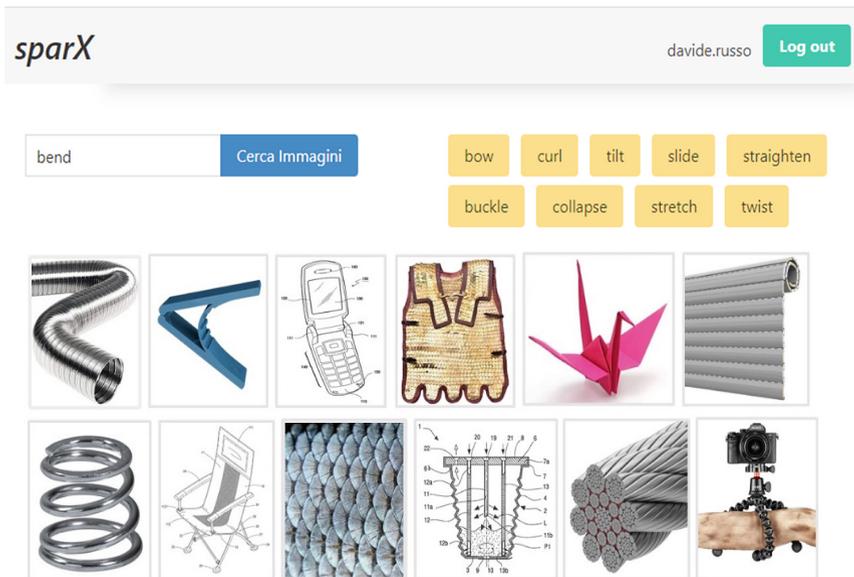


Fig. 3. System implementation and research results of the ‘Bend’ function.

The software platform is designed to perform validation tests. When an image suggests an idea for a solution, the user simply selects it to access the form in which is

described the solution found. The authentication and access log system records all these actions and then provides statistics on the results.

5 Conclusions

The aim of this work was to demonstrate that one of the TRIZ tools par excellence, the pointer to effects, is a tool that still has significant room for development. Inspired by methodological paths that were already outlined many years ago, and re-purposing them in the light of the most modern text mining technologies, a set of IR technologies and strategies was proposed to extract technical suggestions from the reports contained in patent texts in a more complete and faster manner.

This path, which began with the development of the pointer to physical effects, has seen in this work the evolution towards the pointer to geometric effects. The greatest difficulty encountered is the lack of a definition of what a pointer to geometric effects should be. Hence the methodological proposal to divide geometry into shape and topology. A definition of how a component enables a behavior to perform a function based on its outward shape, the topology with which it is arranged within and the materials of which it is composed was also provided.

Although the foundations have been laid for the construction of a pointer and a software implementation of it has been shown, the work is still at an experimental stage and the effects library is far from being complete. For this reason, it was considered premature to start a large-scale experimentation even though the platform hosting it is already prepared for this purpose. One of the main advantages of this modern pointer to geometric effects is that it does not require knowledge of the fundamentals of TRIZ to be used, as it can act as an effective trigger for any type of user who needs a tool to support innovation and problem solving.

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Assessing the Environmental Performance of the Food Industry Using Unsupervised Machine Learning

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Abstract. Due to the growing world population, the environmental impact of food production and consumption has increased, and traditional analytic methods have become automatically insufficient to assess the environmental performance in the agri-food sector. In the food industry, environmental impact assessments have usually been conducted on one representative of each food category, which does not provide a complete comprehension of any potential differences in environmental impacts within products in the same category. This paper seeks to answer the following question how to deploy unsupervised Machine Learning algorithms in order to evaluate the environmental performance of food products belonging to the same category? To answer this question, an academic case study has been carried out in which we applied unsupervised ML algorithms on the environmental impacts of an existing Life Cycle Assessment (LCA) dataset of 80 pizzas representative of the 2010 French retail market in order to cluster the LCA's values and create multiple groups, which would help to determine which pizzas varieties will have the highest impact on the environment. Spectral Clustering with 3 clusters yielded the highest silhouette score of 0.5885, indicating its superior performance in partitioning the reduced data into meaningful clusters compared to K-means and DBSCAN. The study found that the environmental impact of pizzas was significantly influenced by the presence of beef and “Edam cheese”, as well as ingredient production, solid board, and plastic film packaging, while slight changes in ingredient processing can have an impact on the overall usage of ingredients and energy consumption during manufacturing.

Keywords: Machine Learning · Environmental Performance · Sustainability · Food Industry · Clustering Algorithms · Unsupervised Learning · Life Cycle Assessment

1 Introduction

The impact of the food sector on sustainability cannot be overlooked as it is a significant consumer of primary resources. The production of food significantly drives environmental issues at a global level. Achieving a sustainable food system is daunting, as it

entails dealing with a vast range of diverse and complex factors. The food-processing sector accounts for approximately 20% of greenhouse gas emissions and is expected to grow to meet the world's food demand. Furthermore, the food industry generates a significant amount of waste throughout the supply chain. Different subsectors of the food industry have varying environmental impacts, with beef production being the most resource-intensive and generating the most greenhouse gas emissions [1]. In their paper [2] aims to guide readers in transitioning from conventional methods to the latest and most advanced automated processes in the food sector. While several techniques have been developed to tackle the emerging challenges in this industry, Artificial intelligence (AI) and machine learning (ML) present tangible opportunities to embrace state-of-the-art technology. [2] mentioned that the industry presents a multifaceted and nonlinear strategy that can be addressed effectively through the implementation of autonomous and reliable technologies such as AI and traceability. AI, a mathematical method, offers intellectual capabilities and intelligent solutions to overcome numerous challenges the food industry faces. Given the dynamic, uncertain, and complex nature of manufacturing systems, ML algorithms offer the potential to learn from these systems and adapt to the evolving environment relatively quickly, often outpacing traditional methods. This adaptability provided by ML algorithms can play a significant role in addressing sustainability goals [3]. Another study [4] emphasized the growing interest in utilizing AI/ML for green manufacturing and sustainable development, indicating that these technologies can optimize material usage, reduce energy consumption, and minimize environmental impact. AI/ML exceeds traditional methods in assessing the environmental performance of a food supply chain by handling large and complex datasets, recognizing patterns, adapting and continuously learning, automating tasks, integrating diverse data sources, and scaling to different levels. Furthermore, in assessing the environmental impact of food products using life cycle assessments (LCAs), selecting a single representative product for an entire food category is common practice. However, this approach may overlook the variations in environmental impacts between different products within the same category [5]. In summary, the food sector's impact on sustainability is significant, and addressing its challenges requires the adoption of advanced technologies such as AI and ML. These technologies offer opportunities to optimize processes, enhance traceability, and contribute to sustainable development. Additionally, there is a need for improved assessment methodologies, including the application of machine learning, to account for variations in environmental impacts within food categories.

This paper tackles the deployment of unsupervised machine learning algorithms for evaluating the environmental performance of food products belonging to the same category. The objective is to use ML algorithms to identify patterns and relationships among various environmental indicators and their impact on food products. The ultimate goal is to develop a comprehensive evaluation framework that considers the environmental performance of food products holistically and provides a basis for comparison and ranking within a category. The paper seeks to explore the feasibility of this approach and identify the key challenges and opportunities in its deployment.

This paper aims to answer the following question: how to deploy unsupervised ML algorithms in order to evaluate the environmental performance of food products belonging to the same category?

What is the difference between traditional approaches and ML in terms of environmental performance assessment results?

This paper is structured as follows. The first part is an overview of the methodology employed. The academic case study is explained in the next section. The case study's findings are then discussed in the discussion/results section and then we examine the various methods described in the case study and compare them to other research papers. The paper reveals crucial conclusions and insights for further research.

2 Materials and Methods

The objective of this study was to cluster the LCA's values and create multiple groups, which would help to determine which pizzas varieties will have the highest impact on the environment. To achieve this, we developed an approach based on unsupervised machine learning methods, which is presented in Fig. 1 The approach involved applying unsupervised ML algorithms to an existing Life Cycle Assessment (LCA) dataset of 80 pizzas. The LCA dataset provided information on the environmental impacts of different pizza varieties. By applying unsupervised ML algorithms to this dataset, the researchers were able to cluster the LCA values and create multiple groups which allowed us to determine which pizza varieties had the highest environmental impact.

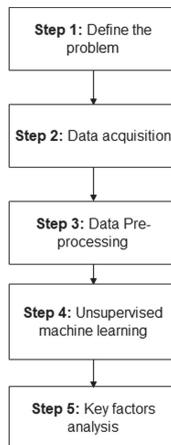


Fig. 1. Methodology.

Define the problem: The first step involves clearly articulating the issue or challenge that needs to be addressed.

Data acquisition: The second step is to collect the data for the study. The process of collecting and acquiring raw data from various sources.

Pre-processing: Once the data is collected, it needs to be pre-processed to prepare it for analysis. This involves cleaning the data to remove any errors or inconsistencies, transforming the data into a usable format, and selecting the appropriate features (i.e., environmental impact indicators) for the analysis.

Unsupervised Machine Learning: Unsupervised learning is a type of machine learning in which the algorithms are used to identify patterns and structure in the data without prior knowledge of their labels or categories.

Key Factors Analysis: This step involves analyzing the collected data to identify the most important factors that contribute to the environmental impact of each pizza variety. The results of this analysis will help to identify the factors that have the greatest impact on the environment.

3 Case Study

3.1 Define the Problem

The case study focuses on the environmental impact assessment of pizzas using life cycle assessment (LCA) as a method for environmental evaluation. The study aims to assess and compare the environmental impact of 80 pizzas representative of the 2010 French retail market. The chosen product for assessment is industrial pizzas due to their high consumption worldwide, large range of recipes, and various storage conditions (fresh or frozen), distributors, and nutritional content. The system boundaries for the assessment include ingredient production, manufacturing, transport of the pizza, distribution, and use stages. The study assumes that all the pizzas were produced in France during the year 2010. The functional unit chosen for comparison is 1 kg of ready-to-eat pizza, which is considered as the pizza after cooking at the residence of the consumer.

3.2 Data Acquisition

In order to perform our case study, we obtained an existing dataset of 80 pizzas from the 2010 French retail market. This dataset was collected by the original authors and includes information on the environmental impact of the pizzas based on a Life Cycle Assessment (LCA). The data collection methods for various aspects of pizza production and consumption were described in [5]'s paper. This step involved estimating ingredient weights from packaging, using technical data sheets or expert consultation for manufacturing data, measuring packaging weight experimentally, assuming transport distances, estimating storage and consumption from scientific literature for distribution data, using data sheets of household appliances for use data, and performing environmental impact characterization using LCA methodology with SimaPro software.

3.3 Data Pre-processing

The data pre-processing step would involve extracting the total LCA values for all the production steps (Ingredients, Manufacturing, Packaging, Transport, Distribution, and Use) from the dataset. These total LCA values would be calculated by adding the individual LCA values for each environmental indicator across all steps of pizza production. The unnecessary data that is not relevant to the analysis would be removed, and the remaining data would be transformed into a csv format. Additionally, in their paper, [5] mentioned two scenarios of the pizza storage. We processed the CSV data

file to include both scenarios (long-term home storage and short-term home storage) for each type of pizza, incorporating the respective LCA values for the 16 environmental indicators. After obtaining the data from the CSV file, we applied data normalization using the `StandardScaler()` method from the pre-processing module. This scaler was fit to the data and then used to transform the data, resulting in normalized values for each data point. Data normalization is advantageous as it scales the data to a standard range, typically between 0 and 1 or with a mean of 0 and a standard deviation of 1, which can help in addressing issues related to differing scales or units of measurement in the original data.

PCA is then instantiated to obtain the principal components (transformed features) from the standardized data. The explained variance ratio is calculated using PCA's `explained_variance_ratio_` attribute, which represents the proportion of total variance explained by each principal component. The cumulative sum of the explained variances is also calculated. A bar plot is created to visualize the individual explained variances for each principal component, and a step plot is created to visualize the cumulative explained variance. The plot presented in Fig. 2 helps to understand the contribution of each principal component in explaining the variance in the data.

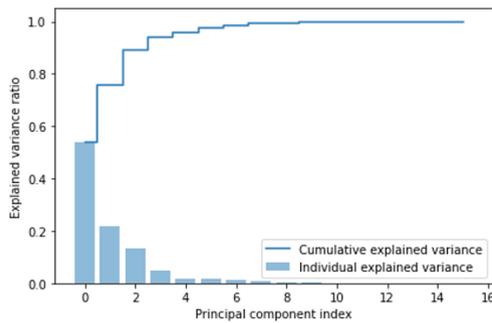


Fig. 2. Explained variance ratio by principal component in PCA analysis.

Based on the bar plot and step plot presented in Fig. 2, it can be observed that the first two principal components explain approximately 75% of the total variance in the standardized data. This suggests that a significant portion of the data's variability is captured by these two components. As a result, choosing to retain these two principal components for further analysis may be a reasonable approach. Furthermore, the step plot shows that the cumulative explained variance increases rapidly with the addition of the first two principal components and then levels off. This implies that adding more components beyond the first two may not contribute significantly to explaining additional variance in the data. Therefore, retaining these two components may be a reasonable trade-off between capturing sufficient information and reducing the dimensionality of the data.

3.4 Unsupervised Machine Learning

In the case study, unsupervised learning algorithms were used to analyze the environmental impacts of the 80 pizzas in the LCA dataset. The unsupervised learning algorithms were applied to this dataset to identify any hidden patterns or groupings of pizzas based on their environmental performance.

Algorithm Selection. We applied three commonly used unsupervised learning algorithms, namely K-means, DBSCAN, and spectral clustering, to identify patterns or groups within the data. K-means is chosen for its robustness to dataset size, as its accuracy is not significantly influenced by the dataset's scale. DBSCAN is preferred for its ability to detect clusters with large density variations and irregular shapes, making it suitable for datasets where clusters may have different densities and complex geometric structures. Spectral Clustering is advantageous because it constructs an adjacency structure from the original dataset, allowing it to identify clusters without imposing a predefined shape or structure, thus adapting well to datasets with arbitrary shapes and inherent structures [6]. Clustering algorithms were chosen as they group data points that are similar or share common characteristics, allowing us to identify subsets of pizzas with similar environmental performance.

Model Training. We applied the selected unsupervised learning algorithms to the pre-processed data and trained the models to identify patterns or clusters within the data.

K-means clustering is an unsupervised learning algorithm used for grouping data points into clusters based on their similarity [7]. We applied the K-means clustering algorithm to a dataset of pizzas after reducing the dimensionality of the data using Principal Component Analysis (PCA). First, we used the 'KMeans' function from the scikit-learn library with parameters set to 'init="k-means++", n_clusters=3, n_init=4'. This allowed us to initialize the K-means model with the 'k-means++' method, set the number of clusters to 3, and perform 4 initializations to find the optimal cluster assignments. We fit the K-means model to the reduced data, which assigns each data point to one of the three clusters.

DBSCAN is an unsupervised learning algorithm that clusters data points based on their proximity and density [8]. We utilized the DBSCAN clustering algorithm to group pizzas in a dataset after reducing the data's dimensionality using PCA. Subsequently, we employed the 'DBSCAN' function from the scikit-learn library with parameter values of 'eps = 0.4, min_samples = 2, algorithm = 'ball_tree', metric = 'minkowski', leaf_size = 90, p = 2'. We then fitted the DBSCAN model to the reduced data, which assigned each data point a cluster label, where -1 denoted noise.

Spectral clustering is an unsupervised learning algorithm that clusters data points based on their similarity using an affinity matrix and graph Laplacian. We employed spectral clustering to group pizzas in a dataset after reducing the data's dimensionality using PCA. We used the 'SpectralClustering' function from scikit-learn with parameters such as 'n_clusters = 3, eigen_solver = "arpack", assign_labels = "discretize", random_state = 0'. The spectral clustering model was then fitted to the reduced data, assigning cluster labels to each data point.

Model Evaluation. During the model evaluation step, the silhouette scores were calculated for various clustering algorithms, including Spectral Clustering, DBSCAN, and

KMeans. The silhouette score is the most direct and used approach, which serve as a measure of cluster quality. A higher average silhouette coefficient indicates effective clustering and assists in determining the optimal number of clusters, denoted as k [9]. The silhouette scores were printed for each algorithm and parameter combination, providing insights into the effectiveness of the clustering algorithms in partitioning the reduced data into meaningful clusters. Notably, among the three options, the spectral clustering with 3 clusters achieved a silhouette value of 0.5885, which was higher than K-means (0.535) and DBSCAN (0.586).

3.5 Key Factors Analysis

Cluster Selection. Based on our analysis, we deduce from the final step that the spectral clustering algorithm yielded the most favorable outcomes when implemented with three clusters. The next step involves selecting the cluster that has the highest environmental impact. The Fig. 3 illustrates the representation of the various clusters for cases where 2, 3, 4, and 5 clusters were utilized with the spectral clustering algorithm.

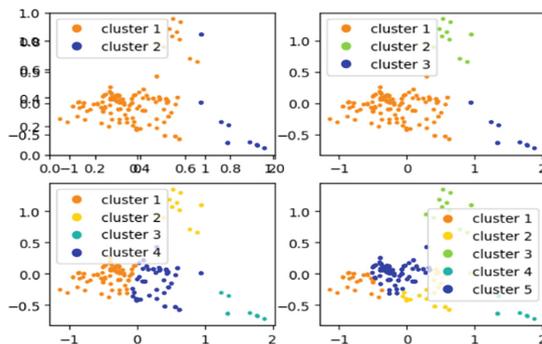


Fig. 3. Pizza clustering results using spectral clustering algorithm for LCAs values in each case.

In order to effectively display the outcomes of the Principal Component Analysis (PCA) for all 16 variables, we utilized the “biplot” function. This function generates a biplot, which is a graphical representation that combines both the scores of the PCA components and the coefficients of the original variables in a two-dimensional space. By plotting the data points and arrows representing the variables’ coefficients on the same biplot, we are able to visually capture the relationships between the variables and the PCA components, providing a comprehensive overview of the PCA results. The Fig. 4 shows the results:

PC1 represents the environmental impact because of the fact that it is a linear combination of all 16 variables. Which means that the closer you are to 1 in the pc1 axis, the higher is the environmental impact. Based on this analysis, we can conclude that the first cluster Fig. 3 (case with 3 clusters) has a relatively lower impact compared to clusters 2 and 3. Based on the analysis in Fig. 3, it is observed that Cluster 2 shares more similarities with Cluster 1, as they are considered as one cluster in the outcomes of the

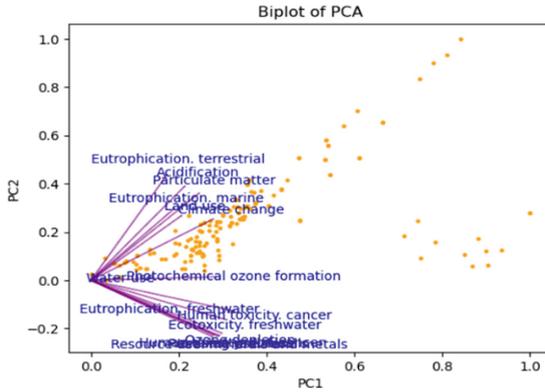


Fig. 4. Biplot of the PCA results.

algorithm for $K = 2$ with K the number of the clusters. Therefore, the third cluster is identified as having the greatest environmental impact.

Pizza Profiling. The phase of Pizza profiling in the chosen cluster involves analyzing and characterizing the pizzas that belong to the selected cluster. This phase focuses on identifying and analyzing the characteristics of these pizzas, such as their ingredients, production methods, packaging materials, and other relevant factors.

The Nutritional Properties. The selected cluster from the previous steps comprises a total of twelve pizzas, namely pizza 45, 46, 47, 48, and 73, which are applicable for both short-term home storage and long-term home storage. Hang on our calculations and comparison of the nutritional average values of the six pizzas with the average values of all the rest of the other pizzas in terms of fat, energy, sugar, protein, fiber, dough, meat, and fish, we found that these six pizzas have higher values, particularly for meat and fish, as well as energy content. Specifically, Pizza 46 has the highest energy value and the second highest fat content among all the pizzas in the table. Additionally, when we found that the six pizzas have higher values, especially for meat and fish, this suggests that these pizzas may contain more meat and fish ingredients, which are generally associated with higher environmental impacts due to factors such as land use, water use, greenhouse gas emissions, and energy consumption associated with animal agriculture.

Recipes. In term of recipes, it appears that the six pizzas have a distinct ingredient profile compared to the other pizzas in the table. One notable difference is that beef is only present in these six pizzas, whereas the other pizzas feature vegetarian, ham, or fish toppings. Beef production is known to have a significant environmental impact due to factors such as deforestation, greenhouse gas emissions, water use, and energy consumption. Therefore, the inclusion of beef as an ingredient in these six pizzas could be a contributing factor to their higher environmental impact compared to other pizzas. In addition, among the 15 pizzas, of all the 80 pizzas, that contain “edam cheese”, two of them are from the six pizzas with the highest environmental impact.

Packaging. Based on the calculations of nutritional properties and packaging data, it appears that the six pizzas also have a higher average usage of Solid board and Plastic film

packaging compared to the other pizzas. Solid board is typically made from paperboard and is often used for pizza boxes, while Plastic film is a type of plastic material used for wrapping or covering food items. The production of paperboard and plastic film involves resource extraction, energy consumption, and emissions associated with manufacturing processes, as well as potential waste generation and disposal concerns. Therefore, the higher average usage of Solid board and Plastic film packaging in the six pizzas with the highest environmental impact could contribute to their overall higher environmental impact.

Manufacturing. The manufacturing data for the pizzas in the given datasets includes some indicators. By calculating the average of these indicators for each pizza, we found that the values for the six chosen pizzas are moderately similar to the values for the rest of the pizzas (74 in total), with slight differences observed in the first two indicators. These findings suggest that, on average, the manufacturing processes for the six pizzas with are comparable to those of the other pizzas in terms of mass of ingredients processed, energy consumption for ingredient processing. However, there may be slight variations in these two indicators, the six pizzas in this case have a highest value comparing with others, indicating potential differences in ingredient usage and energy consumption during the manufacturing processes.

Use/Transport. Upon analysis, it was found that the average values of these indicators extracted from the life cycle inventory (LCI) data for the six chosen pizzas are similar to the average values for the rest of the pizzas. This indicates that there are no significant differences in packaging waste and transportation between the two groups.

4 Discussion of Results

This study undertook an investigation into the environmental impact of various pizzas using unsupervised learning and data analytics techniques, specifically focusing on their Life Cycle Assessment (LCA) values. The dataset underwent pre-processing and dimension reduction via Principal Component Analysis (PCA), followed by clustering using three distinct algorithms the Kmeans, DBSCAN and Spectral clustering. After calculating the silhouette value which is an indicator to evaluate the performance of the clustering, the spectral clustering algorithm with three clusters has reach a value of 0.5885, comparing to Kmeans (0.535) and DBSCAN (0.586), was identified as the best-performing algorithm in terms of clustering quality. We then proceeded to assess the environmental impact of each cluster. By using Principal Component Analysis (PCA) and plotting the results on a biplot, we visualized the relationships between the variables and the PCA components. The first principal component (PC1) represented the environmental impact, as it was a linear combination of all 16 variables. Closer proximity to 1 on the PC1 axis indicated a higher environmental impact. Depending on this analysis, we concluded that the third cluster had the greatest environmental impact, as it exhibited higher values on the PC1 axis compared to clusters 1 and 2.

To address and minimize the environmental impact associated with pizza production, particularly for the six pizzas classified within the selected cluster exhibiting the

highest environmental impact, we conducted a comprehensive analysis of their nutritional properties, recipes, packaging, manufacturing processes, and use/transportation methods. This analysis aims to present a formal and coherent evaluation of these pizzas, considering various factors relevant to their environmental impact. We deduced that the inclusion of beef as an ingredient, along with the presence of “edam cheese”, contributes to the higher environmental impact of these six pizzas. The resource-intensive and energy-intensive practices involved in producing these ingredients also result in an overall increased environmental impact. In addition to the aforementioned factors, the environmental impact of the six pizzas is further influenced by their packaging choices. The use of solid board and plastic film packaging contributes significantly to their overall environmental impact. Furthermore, when examining the manufacturing processes of these pizzas, it becomes evident that they share similarities with other pizzas, albeit with minor differences. These discrepancies primarily manifest in ingredient processing, leading to variations in both ingredient usage and energy consumption during the manufacturing phase. Consequently, these variances play a role in determining the overall environmental impact of the pizzas under consideration.

In brief, the six pizzas with the highest environmental impact contain higher amounts of meat, particularly beef, and utilize more solid board and plastic film packaging. Thus, alternative protein sources with lower environmental impacts, sustainable packaging options, optimized ingredient processing methods, and energy-efficient technologies can be considered. Although no significant disparities were found in transportation between the six pizzas and others, there are still opportunities to reduce the environmental impact through the use of fuel-efficient vehicles or consolidation of shipments.

Comparing with [5]’s work, the two passages share a common topic of discussing the environmental impact of pizzas, but we approach it from different angles. [5] conducts a study that used Life Cycle Assessment (LCA) to evaluate the environmental impact of 80 different pizzas, considering factors such as the type and amount of ingredients, cheese, distributor, and sector (fresh or frozen), and investigated the link between environmental indicators and nutritional and composition indicators. On the other hand, our study describes a project that used data analytics techniques, specifically Principal Component Analysis (PCA) and clustering algorithms, to investigate the environmental impact of pizzas based on their LCA values, with a focus on identifying the characteristics of pizzas with the highest environmental impact. In terms of findings, both studies have reported that pizzas with meat toppings generally have a greater environmental impact compared to those with vegetarian toppings. However, our study notably emphasizes the impact of beef on the environment, indicating that beef has a more significant impact when compared to other meat toppings such as ham, fish, and chicken. Moreover, the first study found that the type of cheese used on pizzas also has an impact on the environment, with hard cheeses having a greater impact than soft cheeses, but the current study highlights the potential environmental implications of semi-hard cheeses like edam cheese. Furthermore, the first paper reported that the duration of storage of pizzas has a relatively minimal impact on the overall environmental impact of the pizza. This was shown by an increase in the storage time of fresh and frozen pizzas resulting in only a maximum increase of 0.25% and 28%, respectively, in the environmental impact of the pizzas. However, the recent study revealed that the duration of storage used for

pizzas can also play a crucial role in determining their environmental impact. In this regard, it was found that five out of the six pizzas types examined were frozen, while only one was fresh. These differences in the duration of storage could have varying impacts on the overall environmental impact of the pizzas. To summarize the results, in this paper, we have effectively answered the research questions posed in the paper. Firstly, we provided a detailed account of how unsupervised learning algorithms were applied to the LCA dataset of 80 pizzas in the case study. By using spectral clustering, K-means, and DBSCAN, and we identified the hidden patterns or groupings of pizzas based on their environmental performance. We further discussed the results, highlighting the spectral clustering algorithm with 3 clusters as the best performer with a silhouette value of 0.5885. Secondly, we tackled the difference between traditional approaches and ML in terms of environmental performance assessment results. By analyzing the findings of the study, and comparing them with previous research to shed light on this difference.

5 Conclusion

In conclusion, this project highlights the use of unsupervised learning and data analytics in assessing the environmental impact of food products such as pizzas as they are powerful tools that can be used to analyze complex datasets and identify patterns that may not be immediately obvious. In the case of assessing the environmental impact of food products, these tools can be particularly useful in identifying key factors that contribute to the overall impact of the product. Spectral clustering is another unsupervised learning technique that can be used to identify clusters of similar data points in a dataset. In this context of assessing the environmental impact of pizzas, spectral clustering was used to identify clusters of pizzas that had similar environmental impacts. This allowed us to identify the cluster of pizzas with the highest environmental impact, which were found to contain higher amounts of meat and fish, particularly beef. However, it's important to note that the study is limited by the available data on the pizzas analyzed, and it may not be representative of all pizzas or food products. Additionally, future researchers could also test and compare other ML algorithms in this context. Moving forward, further research can explore the application of data analytics techniques in assessing the environmental impact of other food products and consider additional environmental factors.

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Multi-domain and Heterogeneous Data Driven Innovative Problem Solving: Towards a Unified Representation Framework

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Abstract. The exponential increase in the amount of knowledge produced has sparked an interest in the TRIZ community in using artificial intelligence and natural language processing to systematize various steps of the process. However, exploiting large volume of multi-domain and heterogeneous data sources simultaneously is still a work in progress. We propose a general knowledge formalization framework to represent information relative to various data sources. By having formalized representations of various knowledge sources, we can establish stronger links between otherwise unrelated sources and thus pair innovation problems with multi-domain solutions and uncover potential hidden solutions that are hard to discover otherwise. A demonstrative case study related to efficient energy generation is provided to illustrate possible uses of the framework. We noticed that the formalization of some data sources (such as web content) can be challenging since their structure varies wildly. Also, contrary to established sources (patents, scientific articles), web sources can contain a lot of noise or false information.

Keywords: TRIZ · Natural Language Processing · Knowledge Management · Knowledge Engineering · Artificial Intelligence · Deep Learning · Information Retrieval · Knowledge Representation

1 Introduction

In today's world, it has become harder for companies to gain a competitive edge and stay relevant in their respective industry. Having a clear research and development strategy that results in meaningful and impactful innovations is a very effective way to stay competitive. However, finding solutions to innovation problems can be very unstructured and unproductive while incurring significant costs. Many methods and tools have emerged in order to try and systematize various aspects of this process. TRIZ (Theory of Inventive Problem Solving) [1] created by Genrich Altshuller is a theory and a set of tools that aims to systemize the process of innovation by carefully analyzing and manually extracting knowledge from human innovative activities documented within patents. While many companies have successfully used TRIZ in their innovative process, many critics of the method believe that it is too complicated to use and requires a high level

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of proficiency. Others point out the fact that while the TRIZ method and philosophy are still relevant, some of the tools that were constructed with dated knowledge need to be updated. Rapid development in computer science both on the hardware and software front have sparked an interest in a new concept of computer aided innovation (CAI). The first attempts of integrating computer-based approaches for TRIZ appeared with the popularization and evolution of knowledge management techniques. Many propositions have been made to implement some TRIZ tools and concepts in order to make the method easier to use. These approaches made considerable improvements to the method's usability but still require a considerable amount of time to establish, do not generalize very well beyond their intended use cases and do not allow for large data coverage. Recently, with the accelerated rate of data production and emergence of AI (artificial intelligence) based techniques for data processing and exploitation, a subsequent portion of the TRIZ community aimed at combining TRIZ with AI and notably NLP (Natural Language Processing) techniques in order to further augment the ease of use and to exploit the vast amount of data available. While many valuable contributions have been made in this direction, there are some areas in which further research is needed. The current approaches either focus on one source of data (patents, scientific articles ...), on a portion of those sources (abstract, claims ...), or on a specific application domain. In addition, there is a necessity for a system that allows for scalable and continuous knowledge building and linking. Finally, there is little work done on web articles from reputable websites as a source for finding solutions to innovation problems alongside traditionally used data sources. The aim of this paper is to fill this research gap by proposing a conceptual knowledge formalization framework to unify the representations of heterogeneous potential sources of solutions for innovation problems (patents, scientific articles, web articles) and representing multiple domains. This framework can also allow for incremental knowledge building and data linking when used with other techniques.

After this introduction, we go through a review of relevant literature. Then, we present the methodology that we followed to build the proposed framework. Next, we present the framework. We then provide a case study to illustrate some of the possible uses and applications of the framework. Finally, we present conclusions and perspectives related to this work.

2 Literature Review

In this section, we will try to walk through relevant literature that presents research aiming to use CAI to implement, improve upon, or augment TRIZ.

One of the main strengths of the TRIZ method is the ability to go from a specific problem, reformulate it as a generic problem, find a generic solution, and then map that solution to a set of potential specific solutions [2]. The level of abstraction required to implement this process, however, is very high and thus it can induce confusion in non-seasoned practitioners. The time required to understand the various aspects of TRIZ causes newcomers that want to apply it to feel that the method is too difficult to learn [3].

Considerable advancement in computer science has sparked the interest of the TRIZ community to create tools and software-based solutions in order to ease the use of the

method and lower the learning curve. This research direction is usually referred to as CAI (computer aided innovation). One of the earliest mentions of this concept is in the work of Ikoenko et al. [4]. The author defines the computer aided innovation potential directions as either the computerization of the less obvious steps of the classical TRIZ method or as the development of efficient tools for functionality-based information retrieval. The origins of the CAI concept is closely linked to software that adopted the TRIZ method [5].

Various aspects of computer science have been integrated over time into a multitude of CAI approaches. While exploring the integrity of the scientific literature of TRIZ CAI is out of the scope of this paper, it is important to mention some contributions in the field in order to have a clearer view of its evolution. Previous works will be grouped by techniques or aspects used alongside TRIZ. Since many works often use multiple works and techniques, we will use the main CAI related aspect of each method as the grouping criteria.

2.1 Ontologies and Knowledge Management

In the context of information theory, an ontology can be defined as an ensemble of concepts and the expression of relationships between these concepts [6]. Following this definition, the TRIZ method can be formalized through an ontology that represents its concepts as well as their relationships. The work of Zanni-Merk et al. [7] is a comprehensive attempt to develop an ontology for the TRIZ method with a focus on the problem formulation phase. The ontology was then used as a foundation for the development of CAI software solutions [8]. In [9], the authors propose a multi-agent platform for industrial knowledge managers that relies on an ontology to express relationship between the TRIZ related concepts in the database. These contributions focus mainly on the TRIZ process but do not address how to exploit heterogeneous textual data sources.

2.2 Classical Text Mining

Text mining is a computer science field that incorporates various techniques such as data mining, natural language processing and knowledge management in order to uncover underlying information, links, and trends in unstructured textual data [10]. In the context of our paper, we denote as “classical” all text mining-based approaches that do not include a machine learning aspect (we will subsequently introduce this notion). Souili et al. [11] proposes a SAO (subject-action-object) text mining method to automatize the extraction of IDM-TRIZ (A less abstract variant of the TRIZ method) [12] concepts from patents. The method focuses only on patents and does not address other types of data. The work of Yoon et al. [13] aims at identifying evolution trends from patents by extracting binary relations and using a combination of rule base and taxonomy semantic similarity approach. This approach also exploits only patents and uses a rule base system that is difficult to generalize to other data sources.

2.3 Machine Learning and Its Subsets

Unlike traditional text mining techniques, machine learning based ones introduce the notion of “learning” where a computer program detects patterns in data and thus is

able to adapt to new data without further explicit instructions, we call this program a machine learning model [14]. In the context of a TRIZ CAI approach, the model will learn the underlying patterns related to a portion of the TRIZ method applied to a portion of existing data and thus be able to apply that method to unseen data. One of the first mentions of machine learning based TRIZ CAI is in [15] where the authors used NLP (natural language processing) and a neural network trained on a set of manually labeled patents in order to classify patents by their level of invention. While this method is one of the first to use neural networks, it focuses on one specific data type.

Methods like Word2vec [16] and its variants that allow the creation of vector representations of words (called embeddings) useful for many NLP tasks.

Hanifi et al. [17] integrates Doc2vec (a paragraph level vector representation of text) to obtain vector representation of sentences extracted of scientific article sources and compute the cosine similarity between them and a “what-cause” question in order to retrieve sentences that could contain relevant answers. This approach works for both patents and scientific articles but considers them two separate types. Also, Doc2vec does not offer contextual embeddings.

The rise of data production rate and the rapid evolution in computing hardware propelled Deep learning, which is a subset of machine learning, to the forefront of artificial intelligence methods. The field of NLP benefited from a series of breakthroughs in the deep learning world. In particular, the transformer architecture [18] that introduces the notion of attention. Models based on this architecture such as BERT [19] allowed for the creation of contextualized embeddings of text, meaning that a word will have a different embedding depending on the context. In addition, these models outperform traditional machine learning approaches in a multitude of NLP tasks, especially when they are trained on a very large text corpora [20]. Naturally, many in the community proposed various approaches and methods using these techniques. In [21], the authors propose a BERT based summarization model to automatically extract TRIZ contradictions from the state-of-the-art section of patents.

While this method is very efficient for extracting contradictions from patents, it does not work very well for other data types. In [22], a classification model trained on only Chinese patents data is introduced to classify them according to TRIZ inventive principles. In [23] a three-step approach based on TRIZ technological evolution parameters, a Deep neural network, and contradictions to output generic solutions to contradictory parameters is presented. Only patents are used to demonstrate the method and other heterogeneous data types are not addressed.

By examining the aforementioned approaches in the field of TRIZ CAI, we can identify interesting research gaps:

- To the best of our knowledge, no method used a unified representation of heterogeneous data sources and types as a basis for the analysis.
- The methods that aimed to propose formalized representations either worked on formalizing TRIZ concepts or a specific data type (e.g., patents).
- There is a missing link between works that focused on more formalized approaches (ontologies and knowledge management techniques) and recent methods that mainly rely on artificial intelligence-based approaches.

The aim of this paper is to address these gaps by providing a conceptual unification framework that allows the representation of multiple types and sources of information (patents, scientific articles, web articles) covering multiple domains. This framework can serve as a basis or be used alongside other TRIZ CAI systems and thus allow for the creation of scalable solutions.

3 Methodology

In the next section, we will go over the methodology used to create the proposed framework. The following diagram (Fig. 1) offers a global overview.

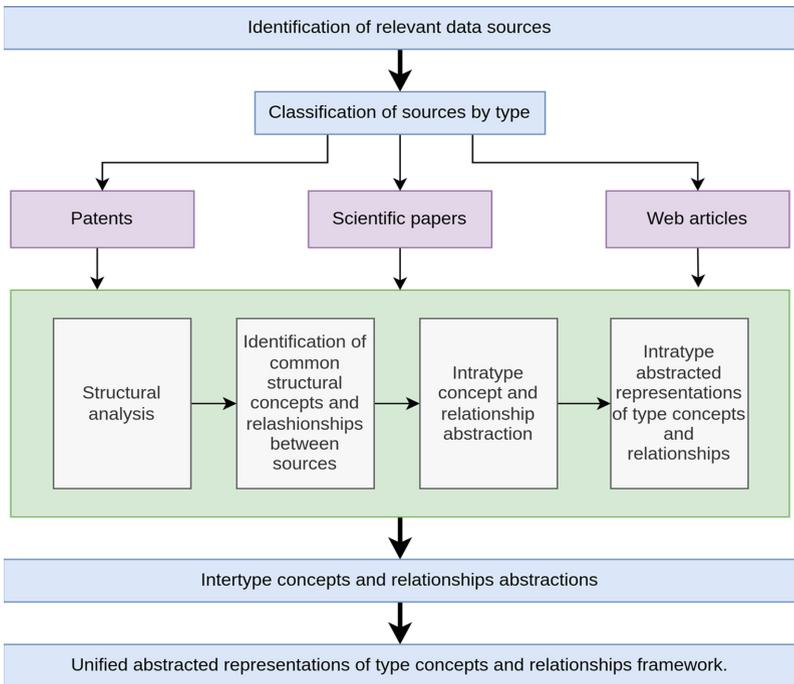


Fig. 1. Diagram representing our methodology.

In order to better understand the steps taken, we will explore each of them individually.

3.1 Identifications of Relevant Data Sources and Classification

The first step consists of identifying relevant data sources that contain document types that we want to work on. The following is a non-exhaustive list of data sources grouped by the type of data they offer.

Patents

- USPTO (The United States Patent and Trademark Office): The USPTO offers open access to a multitude of data related to US patents in many formats. It is one of the biggest and most reliable sources of free full text patent data available.
- EPO (The European Patent Office): The EPO has a collection of patents published in Europe. They have a dedicated bulk datasets dedicated to text mining and analytics usage.

Scientific Articles

- Semantic scholar: An AI based research engine started by the Allen Institute for AI. It offers a bulk dataset as well as an API (Application programming interface) to full text of open-access scientific papers.
- Elsevier Scopus API: An API provided by Elsevier to access metadata and data of papers indexed by Scopus as well as full-text journals published by Elsevier.

Web Articles

- theengineer.co.uk: A website focused on the latest developments in engineering and covering many sectors such as aerospace or biomedical.
- techxplore.com: TechXplore is a website that covers the latest engineering, electronics, and technology advances.

3.2 Intratype Unification

In this step, we work on each data type separately. We first look at the structure of various sources that provide the same type of data, for example, the USPTO data has a specific structure defined in a Document type definition file (DTD). Web articles present a particular challenge in this regard since they do not have a formal specific structure, however, thanks to semantics existing within reputable web sources, we are able to extract an underlying structure. We then identify common structural concepts and relationships between intratype structures. For example, all indexed scientific papers will have a DOI, and all patents will belong to an IPC domain. For similar but not identical concepts and relationships, we create more abstracted representations by finding generic characteristics that apply to all identified entities. The output of this step is an intratype abstracted representation that unifies documents of diverse sources but of the same type.

3.3 Intertype Unification

Using the results of the previous step, we reapply the same idea of creating abstracted representations but this time the goal is to unify concepts and relationships of all data types. The main consideration here is that our abstracted representations need to be generic enough to represent all studied data types but not too generic so as to minimize the loss of information.

The culmination of this process is a unified representation framework for heterogeneous multi domain data. This framework will be presented in the next section.

4 Results and Discussion

We will now present our proposed framework that is illustrated in Fig. 2 and provide a complementary discussion.

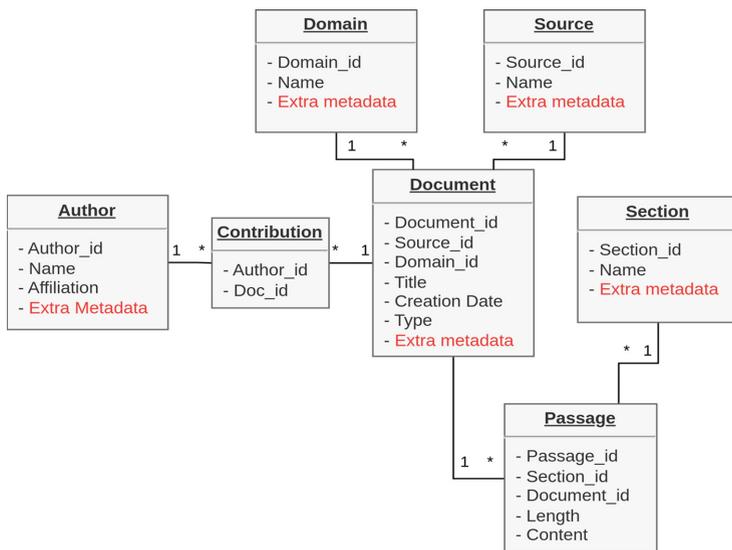


Fig. 2. Our proposed unified representation framework.

The document concept represents the central entity of our framework. All of the data types studied in this work can be represented as a document having certain attributes such as a title, a creation date and a type (patent, scientific paper, web article). A document has a specific source, belongs to a particular domain, and is the result of the contributions of one or many authors. Authors can contribute in one or many documents and are affiliated to an entity (depending on the type of document and the status of the author, this affiliation can be to a university, a research institute, a company...). Since our documents contain textual data, this data can be further subdivided into sections. A section represents a distinct subdivision in the textual data of a document. Within document sections we can also identify passages. In the context of this work, a passage is defined as a collection

of one or multiple sentences having a specific length and belonging to a specific section of a specific document.

The “Extra Metadata” attribute denotes all metadata that is specific to a type of data that we studied and that we did not abstract but want to keep. An example is the application date in a patent that we can link with the submission date for a scientific paper but has no equivalent in web articles. Finding abstracted representations for these attributes can be the subject of future work.

Since web articles are less structured than scientific papers or patents, they represent the biggest challenges for our framework. For example, Web articles do not have well defined sections and some of them do not have any at all, we circumvent this limitation by defaulting them to a singular section, but more elaborated approaches are needed to have a better representation.

In the following section, we will illustrate one possible use case of our framework through a demonstrative case study.

5 Case Study: An Efficient Energy Generation System

Finding innovative ways to efficiently generate energy while reducing the use of finite resources is a high priority goal for society. Many companies and research institutions from various domains are working on various approaches to achieve this objective. In this demonstrative case study, we use our framework alongside other techniques in order to propose a potentially efficient energy generation system.

We start by exploring our various data sources by looking for documents that contain the following keywords: (“efficient” and “energy” and “generation”). We then select a sample of 4 documents of each type (Patents, Scientific articles, Web articles) using recency and relevance as our main criteria for a total of 12 full-text documents. While a more real-life use case will require more documents, the selected sample is sufficient for a demonstrative case study (Table 1).

Next, we represent each document using our framework and keep concepts relevant to our current use case. We focus on the following concepts:

Document_id, Source_name, Type, Title, Creation_date, passage_id, passage, length. We perform some pre-processing to clean the text before splitting it into passages. For the passages, we chose 100 words as the maximum length and ensured that no sentences were cut midway. We then formulate a natural language query that expresses a contradiction: “how to improve efficiency without increasing resource usage?” To find passages containing potential answers to our question, we use a pretrained Sentence-BERT [24] model, a BERT based model that allows for sentence-level embedding generation for tasks such as semantic textual similarity. Finally, we select the highest scoring passage from the top two documents of each type. Below we showcase passages that seemed more in line with our query, and we choose one from each source type:

- **Title:** “*New findings pave the way for stable organic solar cells that may enable cheap and renewable electricity generation*” (<https://techxplore.com/news/2023-04-pave-stable-solar-cells-enable.html>)

Table 1. List of used documents.

Document id	Source	Creation date	Type
EP4174308	EPO	03-05-2023	Patent
US20220018603	USPTO	20-01-2023	Patent
US20230031272	USPTO	02-02-2023	Patent
EP3907876	EPO	10-11-2021	Patent
https://doi.org/10.1002/adma.202301404	ADMA	31-03-2023	Scientific paper
https://doi.org/10.1016/j.xinn.2023.100423	ScienceDirect	13-04-2023	Scientific paper
https://doi.org/10.1016/j.ijhydene.2023.03.405	ScienceDirect	27-04-2023	Scientific paper
https://doi.org/10.1016/j.solmat.2022.112178	ScienceDirect	16-01-2023	Scientific paper
https://techxplore.com/news/2023-04-rechargeable-battery-food.html	TechXplore	13-04-2023	Web article
https://techxplore.com/news/2023-04-pave-stable-solar-cells-enable.html	TechXplore	19-04-2023	Web article
https://techxplore.com/news/2023-05-conversion-efficiency-thermoelectric-devices.html	TechXplore	01-05-2023	Web article
https://www.sciencedaily.com/releases/2023/04/230406113936.htm	ScienceDaily	06-04-2023	Web article

– Passage:

- Overall rank: 5
- Content: *“Due to the recent improvements in the efficiency with which solar cells made from organic (carbon-based) semiconductors can convert sunlight into electricity, improving the long-term stability of these photovoltaic devices is becoming an increasingly important topic. real-world applications of the technology demand that the efficiency of the photovoltaic device be maintained for many years. to address this key problem, researchers have studied the degradation mechanisms for the two components used in the light-absorbing layer of organic solar cells the ‘electron donor’ and ‘electron acceptor’ materials”.*
- **Title:** *“Valuable metal recycling from thin film CIGS solar cells by leaching under mild conditions”* (<https://doi.org/10.1016/j.solmat.2022.112178>).

– Passage:

- Overall rank: 8
- Content: *“it has also been shown that selective leaching of a considerable amount of mo is possible by leaching with 0.5 m nitric acid and a l ratio of 1*

3 cm²/ml for 6 h, however, optimization is needed for minimizing further any simultaneous leaching of ag.the optimum result, a 100% efficiency for ag and 85% of in, was achieved when leaching with 2 m hno₃ and a l l 3 cm²/ml for 24 h. a successive 24 h leaching step under the same conditions gave limited benefits in increasing the leaching yield of indium”.

- **Title:** “Accurate independent 2-dof sun-tracking device” (US20230031272).

– Passage:

- Overall rank: 9
- Content: *“this is an intermittent open-loop control with a forward half-step setting and reduces the loss of efficiency to about one-fourth as compared to an on-time setting.as an illustrative embodiment, it is reasonably sufficient to set a daily rotation from 5 h before noon to 5 h afternoon depending on the location.the basic mechanism of devices realizing the principle of exact sun-following takes a form of a 2-axis gimbal”.*

A deep analysis of the extracted content from the patent and the scientific article requires a high level of domain knowledge. However, we can notice that the content extracted from the web article is more accessible for non-specialists. This property can be useful when inventors look for solutions outside their domain of expertise. After examining all 12 passages we noticed a link between the passages we showcased above: Although the documents come from different domains, they are all presenting solutions to improve various aspects of the efficiency of energy generation systems using the sun as a source. Using TRIZ inventive principle number 5: “Merging” or “Consolidation”, we can imagine a solar based energy generation system that combines the tracking capabilities of “US20230031272”, the stability and efficiency of the cells proposed in “<https://techxplore.com/news/2023-04-pave-stable-solar-cells-enable.html>” as well as the metal recycling method presented in “<https://doi.org/10.1016/j.solmat.2022.112178>”.

Thus, not only were we able to use otherwise unexploited sources of information, but our framework also allows the linking of the knowledge existing in multi-domain and multi-type data. In this instance, we can establish a link between the three documents that inspired our solution via the query that we made and the inventive principle that we used. Such links can facilitate the generation of inventive solutions to problems.

6 Conclusion and Perspectives

As the amount of data becomes larger and more complex, exploiting all accessible sources of knowledge becomes more important. Web articles can be a complementary source of knowledge. In this paper, we presented a novel unified representation framework for heterogeneous and multi domain data types. This framework allows for the simultaneous exploitation of different data types that contain knowledge useful for innovation related activities without abandoning their respective complementary information. As we showcased in our simple demonstrative case study, the chosen design allows for

easy extension and integration of the framework with other methods or approaches and can serve as a foundation layer. Some Current limitations of this work are the loss of information incurred by the lack of formalism of web articles. Also, the absence of non-textual data (mainly images) should be addressed.

In future work, we have identified two main directions. The first is the extension of the framework to represent more concepts and relationships, this could be achieved by establishing methods to structure web articles and thus create a richer intratype abstraction for web articles as well as automating link creation between different concepts. The second is to integrate our framework as a foundation for TRIZ CAI approaches to further demonstrate its usefulness and scalability. Recent advances in large language models can be used on top of the framework to address interesting innovation related use cases.

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Navigating the Knowledge Network: How Inter-Domain Information Pairing and Generative AI Can Enable Rapid Problem-Solving

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Abstract. This study introduces a novel methodological framework that leverages generative AI to retrieve scientific articles pertinent to engineering problems, framed within the context of TRIZ-based contradictions. The process entails searching scientific literature databases by keywords and subsequently prioritizing the resulting articles based on their pertinence to the research subject. Large Language Models are then employed to analyze a refined selection of articles, extracting features and amalgamating individual findings into a summary. Furthermore, we present a strategy towards inter-domain information search. The presented strategy has the potential to be generalized and applied to various domains, facilitating knowledge transfer and problem-solving across different fields.

Keywords: Generative AI · TRIZ · Engineering problem solving · Inter-domain information pairing · Semantic similarity

1 Introduction

The high-level objective of this research is to propose an inter-domain information pairing framework that leverages both TRIZ (Theory of Inventive Problem Solving) [1] methodology and Large Language Models (LLMs) to accelerate problem-solving in emerging fields. This research expands on a proposal from TFC 2022 [2] suggesting that classical TRIZ might not adequately address the quantum industry's emerging challenges due to new frontiers of knowledge and scale, and that this approach could potentially help expedite problem-solving in burgeoning fields like quantum computing [3], quantum detection [4], and neuromorphic vision [5]. This article specifically focuses on scalable knowledge extraction, aiming to automate knowledge extraction given a problem statement.

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We propose a novel framework for inter-domain information pairing that combines the TRIZ methodology with the capabilities of Large Language Models (LLMs) [6]. The concept of inter-domain information pairing and knowledge transfer has been explored in prior research, such as keyword network-based morphology analysis for identifying technology opportunities [7]. However, this research extends this concept by integrating TRIZ and LLMs to accelerate problem-solving in emerging fields. This broader framework is unique compared to existing solutions, as it not only automates the knowledge extraction process but also facilitates cross-domain knowledge transfer, promoting breakthrough innovations (level 4 or 5 in Altshuller’s sense) [8,9].

This research aims to provide solutions to domain-specific problems by leveraging knowledge from other domains. This approach has the potential to promote breakthrough innovations by facilitating cross-domain knowledge transfer and expanding researchers’ problem-solving capabilities beyond their specific domains and enabling researchers to access a broader range of knowledge and perspectives.

2 Problem Definition, Challenges, and Solutions

2.1 The Inter-Domain Information Pairing Framework

The proposed methodology focuses on intrafield knowledge extraction, that is, the first stage of the framework presented in “Bridging Two Different Domains To Pair Their Inherent Problem-Solution Text Contents: Applications to Quantum Sensing and Biology” [2] at TFC 2022. The complete framework comprises three primary stages:

1. Extraction of knowledge within a specific scientific domain.
2. Inter-domain knowledge extraction.
3. Inter-domain problem-solution text content association.

This framework aims to address the key challenges of automating knowledge extraction and enabling cross-domain knowledge transfer.

2.2 Motivations for Utilizing Large Language Models

The proposed knowledge extraction methodology involves querying scientific literature providers and publishers using keywords to retrieve a large number of articles, which are then ranked based on semantic similarity to the research question. This enables to narrow down a large pool of candidates into a smaller set of articles deemed the most relevant. The abstract and specific sections of the full text are then analyzed using Large Language Models to generate or inspire answers to questions related to the research subject. The methodology strictly relies on the retrieved material and avoids using Large Language Models’ training data to answer questions.

Large Language Models offer several benefits over traditional methods for feature extraction, such as improved accuracy and the ability to generate more

insightful answers to research questions [10, 11]. By employing LLMs, the proposed methodology can better identify relevant knowledge and perspectives that can be applied to solve domain-specific problems. The use of LLMs in this methodology is grounded in their ability to understand complex patterns in textual data and generate human-like responses [12].

2.3 Proposed Knowledge Extraction Model

The intended implementation seeks to improve the effectiveness of knowledge extraction and problem-solving relative to conventional techniques [13, 14].

It consists of three steps:

- Literature lookup & ranking
- Feature extraction using Large Language Models
- Summarization & persistence

The three-step process operates sequentially to identify pertinent literature, harness LLMs to obtain essential features and solutions, and synthesize the extracted information. The user initiates the process by framing the research query as a TRIZ-based contradiction.

To frame a research query as a TRIZ contradiction, the user must identify a problem in their domain that involves two conflicting aspects or parameters. The rationale is that contradictions often spark innovation [15]. The three steps are described as following:

Step 1: Literature Lookup and Ranking. During this first step, the research question is stripped of stop words and prepositions, resulting in a collection of keywords for literature search across various sources. For this proof of concept, we utilize the Semantic Scholar API. The title, abstract, and metadata-comprising authors and full-text links when accessible-are acquired for up to 1,000 results, generating an initial pool of potential articles for further examination.

Dense text embeddings [16] are useful in various tasks, such as clustering, topic modeling, deduplication, paraphrase mining, and semantic search. To rank articles by relevance, semantic similarity is utilized by calculating embeddings for both the initial research question and the candidate abstracts, employing, for the purpose of our experiment, the models `text-search-babbage-doc-001` and `text-search-babbage-query-001`. An initial selection of the top 10 results, based on semantic similarity, is retained. The number of results can be increased iteratively if similarity is considered insufficient, expanding the depth of the search dynamically. This will be the object of future work. Figure 1 illustrates this process.

Step 2: Feature Extraction Using a Large Language Model. In this subsequent step, a Large Language Model is utilized to extract relevant attributes or features from the individual articles shortlisted earlier. These features of interest

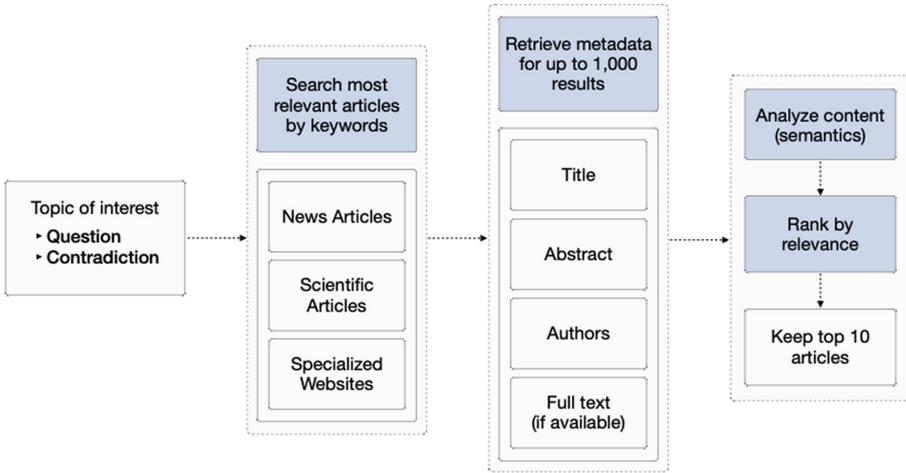


Fig. 1. Process to lookup and rank literature.

can be thought of as metadata associated with each article, encompassing both how the article may offer a solution to the overarching research question and any miscellaneous related questions, including information about contradictions within the article. For example:

- What are the tradeoffs in this work? Isolate contradicting parameters.
- What did they test?
- What outcomes did they measure?
- What solutions are proposed?

With this modular set of questions, the Large Language Model is prompted to answer each question using an excerpt from the research paper (either the abstract or, when available, sections of the full text). A single answer for each question is generated for every article. In our experiments, OpenAI’s GPT-3.5 `text-davinci-003` was employed to extract and summarize information. The process is described in Fig. 2.

Step 3: Summarization and Persistence. In this final step, individual answers generated in the previous step are summarized to provide a high-level overview of the spectrum of answers generated. The process is described in Fig. 3.

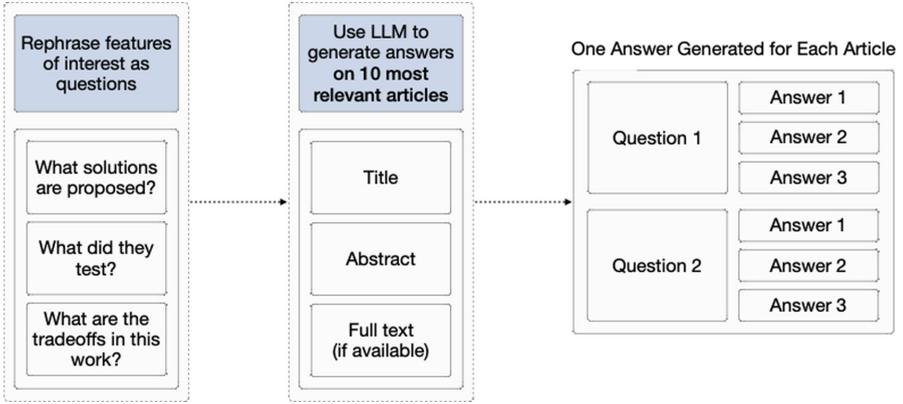


Fig. 2. Process to extract features using a Large Language Model.

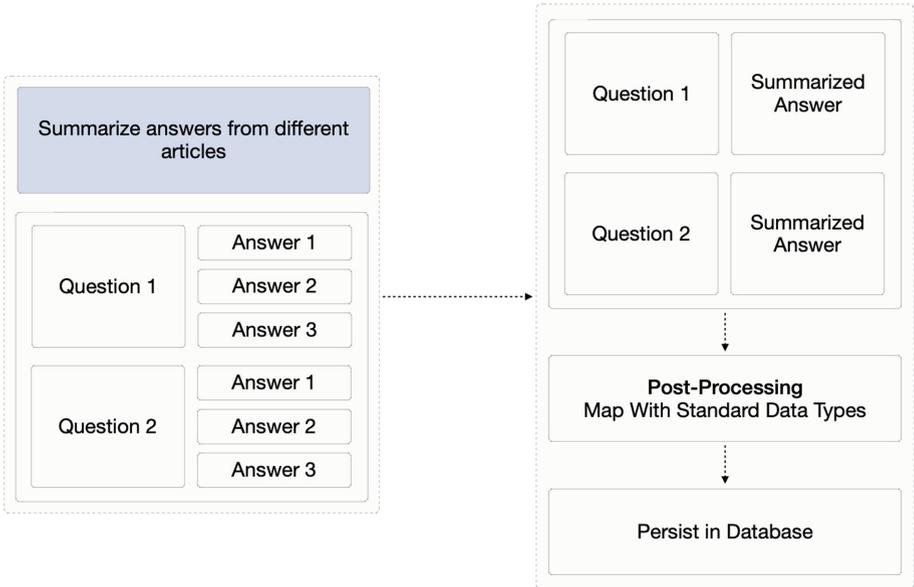


Fig. 3. Process to summarize & persist extracted information.

2.4 Quantum Hardware Case Study

Safeguarding qubits from noise is an essential challenge in developing functional quantum computing hardware. We consider the research question “How to protect Qubits from noise without degrading control?” to serve as input for the knowledge extraction model. The model’s output, consisting of the shortlisted selection of articles sorted according to their semantic similarity ranking, is depicted in Table 1.

Table 1. Example chart of semantic similarity scores

How to protect Qubits from noise without degrading control?		
Rk ^a	Article Title	Scr ^b
1	Entangling Transmons with Low-Frequency Protected Superconducting Qubits	0.45
2	State protection by quantum control before and after noise processes	0.45
3	Experimental protection of two-qubit quantum gates against environmental noise [...]	0.44
4	Overcoming noise-driven instability of entangling logic in silicon with bias control	0.44
5	Fast, high-fidelity readout of multiple qubits	0.44
6	Quantum Error Mitigation via Matrix Product Operators	0.44
7	Quantum state protection from finite-temperature thermal noise via quantum gates	0.44
8	Dephasing-Insensitive Quantum Information Storage and Processing [...]	0.44
9	Overcoming noise-driven degradation in fidelity of silicon-based entangling gates [...]	0.44
10	Quantum governor: Automatic quantum control and reduction of the influence of noise [...]	0.44

^aRelevance Ranking^bSemantic Similarity Score

Subsequently, by employing a large language model for feature extraction and summarization, per the method introduced in 2.3., we obtain concise summaries that highlight the connections between the articles, as shown below.

“How to Protect Qubits from Noise without Degrading Control?” (i.e., the research question as is) Various methods can be used to protect qubits from noise without degrading control, such as employing non-computational states to mediate a two-qubit entangling gate, using do nothing or discriminate and reprepare protocols, dynamical decoupling, device engineering, a matrix product operator (MPO) representation of a quantum circuit, weak measurement and feedforward control, a weak continuous and resonant driving field, and distillation followed by a recovering step.

“What are the Tradeoffs in this Work? Isolate Contradicting Parameters.” The tradeoffs discussed in this work involve noise-robustness, speed, control freedom, fidelity, accuracy of modeling noise, and success probability. These contradicting parameters have implications for device engineering, coupling quantum systems to external instruments, the strength of noise, the type of noise, and the magnitude of charge noise.

2.5 Towards Inter-Domain Information Search

The proposed knowledge extraction methodology is a first step towards enabling inter-domain information search, which can further enhance cross-domain knowledge transfer. We aim to employ further natural language processing techniques to discern semantic similarities between pairs of sentences or paragraphs. Utilizing the WordNet corpus [17], a comprehensive lexical database of English words and their semantic relationships, we tokenize each sentence or paragraph into individual words and map these words to their corresponding sets of synonyms (synsets) in WordNet, where each word in a sentence or paragraph can be associated with multiple synsets.

We then calculate the maximum path similarity between all pairs of synsets for each word in the two sentences being compared. This is done to account for cases where different words in the sentences have multiple possible meanings, and to identify the most similar pair of synsets. The resulting similarity score represents the overall similarity between the two sentences or paragraphs, and a threshold score is used to determine whether the pair is considered “sufficiently similar” to be included in the analysis. The utilization of WordNet is supported by its widespread application in natural language processing tasks, such as word sense disambiguation, information retrieval, and semantic similarity computation [18] and further enhances the potential for cross-domain knowledge transfer [7].

The presented methodology has the potential to be generalized and applied to various other domains, facilitating knowledge transfer and problem-solving across different fields [19,20]. This generalizability would enable researchers to find innovative solutions to domain-specific problems by leveraging knowledge from other disciplines.

3 Conclusion

This research presents a methodology that employs generative AI to acquire pertinent scientific articles for engineering problems, along with associated features and summaries for facilitated knowledge exploration. Situated within a high-level inter-domain information pairing framework, the study strives to harness both the TRIZ methodology and Large Language Models to streamline problem-solving in emerging fields. This approach fosters the growth of innovative knowledge domains and strengthens TRIZ’s contribution to expediting innovation. As part of future studies, we plan to investigate solutions for inter-domain information searching.

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Enhancing Creativity in Deep Learning Models with SAVE-Inspired Activation Functions

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Abstract. Deep Learning models, a type of artificial intelligence (AI), generate new outputs based on their training data. Examples include Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Large Language Models (LLMs) like ChatGPT. However, these models lack human-like creativity, imagination, and original thought. Activation functions play a significant role in these models, determining a neuron's output by mapping inputs to non-linear outputs. This paper aims to explore new activation functions inspired by inventive principles to increase these models' creative potential. The research methodology involves studying each inventive principle of the Structured Activation Vertex Entropy (SAVE) method and identifying associated mathematical models inspired by physics or other natural science areas. These models can be turned into activation functions, which, based on the SAVE algorithm, can be proposed for the type and order of activation functions in a neuronal network. A novel model architecture investigates input-output transformations, leading to recommendations for deep learning model architecture and input formulation. The study's main findings are that human-behavior inspired activation functions might increase the inventive capacity of deep learning models, and there are practical ways to formulate inputs in deep learning models for handling complex and abstract concepts. However, this paper is limited to a narrow aspect of designing deep learning models for inventive design, and further research is needed to investigate various hyperparameters, network architecture, training data quality, and optimization algorithms in combination with the proposed activation functions.

Keywords: Deep Learning · Activation Functions · SAVE Method · Inventive Principles · Neural Networks · Creative Design

1 Introduction

1.1 Generative Artificial Intelligence

The rapid growth of artificial intelligence (AI) and its applications has led to a surge in interest in deep learning models. These models, such as Generative Adversarial Networks (GANs) [1], Variational Autoencoders (VAEs) [2], and Large Language Models

(LLMs) [3] like chatGPT [4], are designed to generate new outputs based on their training data. They have been used in various domains, such as image synthesis, natural language processing, and even music generation, enabling innovations and breakthroughs in numerous industries.

Despite their remarkable successes, these models often lack human-like creativity, imagination, and original thought, which are essential for addressing complex and abstract problems. To advance the capabilities of deep learning models, it is crucial to enhance their creative potential, allowing them to generate novel, inventive, and high-quality solutions. This would help AI systems become more effective in tackling real-world challenges and offer a competitive advantage in various fields, from scientific discovery to arts and entertainment.

1.2 The Problem with Current Deep Learning Models

A key aspect of deep learning models is the use of activation functions [5], which play a significant role in determining a neuron's output by mapping inputs to non-linear outputs. Common activation functions, such as ReLU [6], sigmoid [7], and tanh [8], have been used to drive the success of deep learning models. However, they may not be optimal for promoting creativity and originality in AI-generated outputs.

Current deep learning models can be limited in their ability to explore and generate novel solutions, often producing outputs that closely resemble their training data [9]. This lack of creativity is partly due to the limitations of conventional activation functions, which may not be best suited for fostering inventive capabilities in deep learning models. As a result, current models may struggle to tackle complex and abstract problems that demand creative and innovative solutions.

Even the recently launched model, GPT-4 [10], with an amazing 100 trillion parameters (500 times more than chatGPT, which has 175 billion parameters) is not capable of comparing with human creativity. This is argued by the reply of GPT-4 to the following question: Are you creative in the sense of imagining completely, out-of-the-box solutions? Where is your limit in creativity?

GPT-4's replies was *"As an AI language model, my creativity is derived from the patterns and knowledge that I have learned from the vast amount of data I have been trained on. While I can generate seemingly creative and out-of-the-box solutions based on this knowledge, my creativity is fundamentally constrained by the data and patterns I have encountered. There are a few limitations to my creativity: (a) Knowledge cutoff: Since my training data only goes up until September 2021, any new information after that date are not reflected in my responses; (b) Absence of true original thought: My creativity is based on analyzing and synthesizing existing information, not on generating truly original ideas. While I can produce novel combinations of ideas and concepts, these combinations are still based on patterns I have observed in the data I have been trained on; (c) Lack of personal experience and emotions: As an AI model, I do not have personal experiences, emotions, or a sense of self. This limits my ability to draw from subjective experiences, which can be an essential aspect of human creativity; (d) Context and understanding: My understanding of context and nuances in language may not be perfect, leading to potential misunderstandings or misinterpretations. This can impact my ability to provide relevant and creative solutions to certain problems"*.

1.3 The Research Purpose

The primary objective of this research is to explore new activation functions inspired by inventive principles to enhance the creative potential of deep learning models. In this paper the focus is on the inventive principles promoted by the Structured Activation Vertex Entropy (SAVE) method [11].

By investigating each SAVE inventive principle and identifying associated mathematical models inspired by physics or other natural science areas, the aim is to develop novel activation functions that can be incorporated into neuronal networks, capable to answer to this research question: Can the creation and application of innovative activation functions, drawing from inventive principles, improve the creative capabilities of deep learning models?

2 Background and Related Work

2.1 Deep Learning Models and Activation Functions

Deep learning models are a subset of machine learning techniques that rely on artificial neural networks to process and learn from large datasets [12]. These models have gained significant attention in recent years due to their ability to achieve high performance in various tasks, such as image recognition, natural language processing, and game playing. Deep learning models employ intricate architectures consisting of multiple layers of interconnected neurons, which allow them to capture complex, hierarchical patterns and relationships within the input data, ultimately leading to highly accurate and sophisticated predictions or classifications [13]. Activation functions, biases, and weights work together in a neural network by applying non-linear transformations to the weighted sum of inputs and biases at each node, allowing the network to learn and model complex relationships between input features and target outputs [14].

A crucial component of deep learning models is the activation function, which determines the output of a neuron within the artificial neural network. Activation functions introduce non-linearity into the network based on a mathematical relationship between inputs and outputs from the network's nodes, allowing it to learn complex, non-linear relationships between input and output data [15]. Without activation functions, neural networks would be limited to modeling linear relationships, severely restricting their learning capabilities [16]. There are several commonly used activation functions in deep learning models:

- Sigmoid: The sigmoid function maps input values to a range between 0 and 1, making it particularly useful for binary classification problems. However, it suffers from issues like vanishing gradients, where the gradients become very small during backpropagation, leading to slower learning or convergence (Fig. 1) [17].
- Hyperbolic Tangent (tanh): The tanh function is similar to the sigmoid function, but maps input values to a range between -1 and 1 . It also suffers from vanishing gradients, but its output range can provide better learning dynamics compared to sigmoid (Fig. 1) [18].

- **Rectified Linear Unit (ReLU):** ReLU is a popular activation function that maps input values below 0 to 0 and retains positive input values. It addresses the vanishing gradient problem to some extent and is computationally efficient. However, it can suffer from dead neurons, where neurons stop learning due to consistently negative inputs (see Fig. 1) [19].
- **Leaky ReLU:** This is a variation of ReLU that allows a small, non-zero output for negative input values, mitigating the dead neuron issue. It maintains most of the benefits of ReLU while addressing its primary drawback (see Fig. 1) [20].
- **Exponential Linear Unit (ELU):** ELU is another variation of ReLU that smoothly approximates the output for negative input values, providing a differentiable function. It can help mitigate the vanishing gradient problem while maintaining computational efficiency [21].

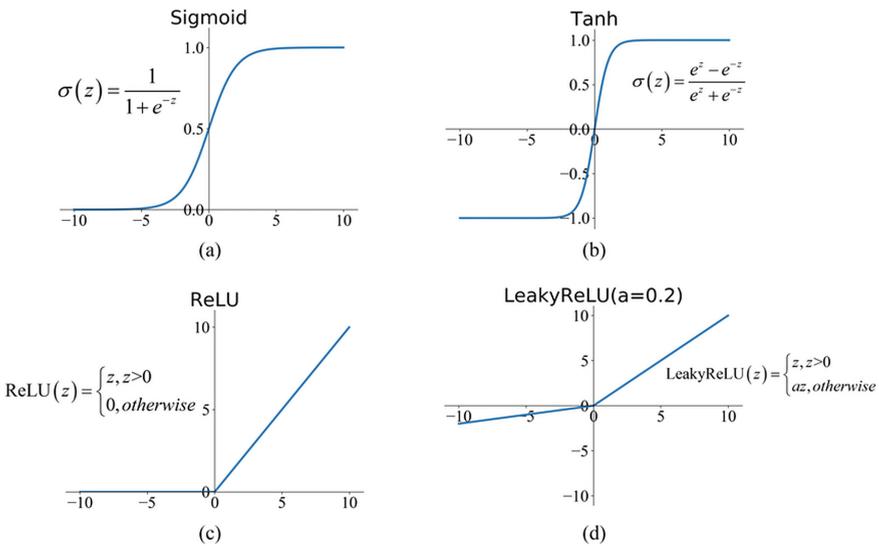


Fig. 1. Graphical and mathematical description of some of the most popular activation functions: Sigmoid, Tanh, ReLU, and Leaky ReLU (courtesy: [22]).

Each activation function has its advantages and drawbacks, making them more or less suitable for specific tasks or network architectures. However, one common limitation among conventional activation functions is their potential inability to promote creativity and originality in AI-generated outputs. Some arguments that support this statement are introduced below:

- **Non-linearity:** Activation functions introduce non-linear transformations, which allow deep learning models to learn complex patterns in the data. However, these non-linearities are typically based on predefined mathematical functions (e.g., sigmoid, ReLU, tanh) that may not be specifically designed to encourage creativity or exploration of novel solutions.

- **Optimization focus:** The training of deep learning models typically focuses on minimizing a loss function, which represents the difference between the model's predictions and the ground truth. This optimization process emphasizes the replication of known patterns and relationships present in the training data, potentially limiting the ability of the model to generate truly original outputs.
- **Gradient-based learning:** Conventional activation functions work well with gradient-based optimization algorithms, such as stochastic gradient descent, which update the model's weights based on the gradients of the loss function. While this approach is effective for learning accurate predictions, it may not necessarily promote the generation of creative or novel outputs, as the model's primary goal is to minimize the loss function.
- **Local optima and overfitting:** Activation functions, along with the optimization process, can sometimes lead models to become stuck in local optima or overfit the training data. In these situations, the model may become too specialized in reproducing the patterns present in the training data, thus limiting its ability to generate original and creative outputs that deviate from those patterns.

To address these limitations, it makes sense to explore novel activation functions inspired by inventive principles, which could potentially encourage the generation of more creative and original outputs in deep learning models. These new activation functions may be better suited to promote exploration and innovation, rather than merely optimizing predictive accuracy.

2.2 Current Achievements on Enhancing Creativity in Artificial Intelligence

The quest for enhancing creativity in AI continues to be a vibrant area of research, encompassing a variety of disciplines, including deep learning, optimization techniques, and problem-solving strategies. One research focus is on embedding divergent thinking and exploration in AI systems, a feat accomplished by incorporating mechanisms inspired by human creativity, such as intrinsic motivation, novelty search, and curiosity-driven learning [23]. However, curiosity-driven and exploration-based methods may face challenges in scaling to complex and high-dimensional environments. The performance of these methods also can vary greatly, depending on the task or domain, necessitating careful tuning of exploration parameters.

A separate field of investigation in creative AI involves the use of generative models like Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and transformer-based models [24–26]. These models synthesize creative outputs across various domains, including images, text, and music. However, training such models, particularly GANs, can be challenging due to issues with convergence, stability, and the limited range of generated outputs known as mode collapse.

There's also significant interest in employing evolutionary algorithms and genetic programming techniques to evolve AI models capable of generating creative solutions to complex problems [27, 28]. Nevertheless, these techniques can be computationally expensive, potentially converging prematurely to suboptimal solutions or being misled by the fitness landscape, a problem known as deception.

The use of multi-objective optimization techniques to balance conflicting objectives like accuracy and creativity in AI-generated outputs is another focus area [29, 30].

However, defining and optimizing trade-offs between these competing goals can be challenging, and scalability can become a problem when dealing with many objectives or high-dimensional search spaces.

The field of computational creativity, which seeks to develop AI systems that can produce creative artifacts or engage in creative problem-solving autonomously, is another key research domain [31, 32]. Challenges in this area include the difficulty of evaluating the creativity of AI-generated outputs and the reliance on domain-specific knowledge, limiting the general applicability of certain techniques.

In the realm of inventive design, efforts are being made to enhance the TRIZ framework using AI-driven algorithms [33–39]. This aims to strengthen structured inventive problem-solving and addresses the complexity inherent in traditional TRIZ learning. The use of deep learning to simulate TRIZ reasoning on a broad dataset of patents has shown promise, and the adoption of generative pre-trained transformers (GPT) for the generation of natural language design concepts has bridged the gap between abstract and detailed design in early-phase exploration. A method involving the identification, enhancement, categorization, and application of elementary TRIZ inventive principles has also been proposed for automated idea generation.

Finally, research into the development of novel activation functions inspired by human creativity is ongoing, and although these novel functions might not generalize across different tasks, network architectures, or data distributions, they hold promise for potentially enhancing the creative capacity of deep learning models [40, 41]. However, the introduction of alternative activation functions might increase computational complexity, thereby affecting the efficiency and scalability of these models.

3 Methodology

The major challenge with neural network (NN) models is that there isn't a universally applicable scientific approach to designing their architecture. The existing models have largely been developed through trial-and-error and empirical approaches. Observations related to accuracy and convergence have guided the selection and refinement of these architectures.

Therefore, it is an opportunity to explore the potential of TRIZ, the Theory of Inventive Problem Solving [42], for defining better guidelines to create the methodology and design the NN model. TRIZ is a systematic approach to finding innovative solutions by identifying and resolving contradictions. In the context of designing a neural network model to investigate the impact of novel activation functions on creativity, some possible contradictions might be considered:

1. Complexity vs. Interpretability: A more complex neural network model may potentially better capture the impact of novel activation functions on creativity, but it may also make the model more difficult to understand and interpret.
2. Exploration vs. Exploitation: Encouraging creativity in the model may require exploring a wide range of possible outputs, but this can also lead to reduced performance in terms of accuracy or convergence, as the model may focus more on generating diverse solutions than finding the best ones.

3. **Flexibility vs. Overfitting:** A flexible model that can adapt to different activation functions and problem domains may be more likely to uncover creative solutions. However, increased flexibility may also make the model more prone to overfitting the training data, which can harm generalization performance.
4. **Computational Efficiency vs. Creativity:** Encouraging creativity in the model may require additional computational resources, such as incorporating more layers, nodes, or additional terms in the loss function. This can increase the computational cost of training and inference, potentially making the model less practical for real-world applications.
5. **Novelty vs. Realism:** Encouraging the generation of novel outputs may sometimes lead to unrealistic or nonsensical results, creating a contradiction between the desire for creativity and the need for outputs to be plausible or coherent.

Applying TRIZ to the set of contradictions identified previously can provide insights into designing a neural network model that effectively investigates the impact of novel activation functions on creativity while minimizing potential drawbacks or limitations. Below there are TRIZ-inspired suggestions for each contradiction:

1. **Complexity vs. Interpretability:**

- **Principle of Segmentation:** Divide the model into simpler sub-modules, making it easier to interpret the impact of novel activation functions on creativity at each level.
- **Principle of Local Quality:** Use different levels of complexity in different parts of the model, focusing on the areas where the impact of activation functions is most significant.

2. **Exploration vs. Exploitation:**

- **Principle of Dynamics:** Adaptively balance exploration and exploitation during training, e.g., by using techniques like curriculum learning or adjusting the learning rate.
- **Principle of Self-Service:** Use auxiliary tasks or additional loss terms that encourage exploration without compromising the main objective.

3. **Flexibility vs. Overfitting:**

- **Principle of Parameter Changes:** Adjust the model's capacity or architectural complexity according to the problem at hand to prevent overfitting.
- **Principle of Composite Materials:** Combine different regularization techniques (e.g., dropout, L1/L2 regularization) to improve generalization while maintaining flexibility.

4. **Computational Efficiency vs. Creativity:**

- **Principle of Asymmetry:** Asymmetrically allocate computational resources, concentrating more on parts of the model that contribute most to creativity.
- **Principle of Universality:** Design a model that can efficiently handle different activation functions and problem domains without significant modifications or resource overhead.

5. Novelty vs. Realism:

- Principle of Feedback: Introduce feedback mechanisms to adjust the degree of novelty based on the realism of generated outputs, e.g., using a discriminator in a GAN-like setup.
- Principle of Prior Action: Preprocess input data or use domain-specific knowledge to guide the generation of novel but realistic outputs.

These TRIZ-inspired guidelines can help direct the design of a neural network model that effectively investigates the impact of novel activation functions on creativity while addressing the identified contradictions. Their application is highlighted in the next sections of this paper.

For studying the SAVE inventive principles and transforming them into activation functions, the following systematic research methodology was used:

1. Understand the inventive principles:

- Study the inventive principles and their underlying concepts, mechanisms, and intended effects on a system or process.

2. Identify relevant mathematical models:

- Based on the understanding of inventive principles, search for mathematical models or equations that capture the essence of each principle.
- These models can be found in areas such as physics, biology, or other natural sciences, or they can be based on abstract mathematical concepts that resonate with the inventive principles.
- Gather diverse perspectives on the inventive principles and potential mathematical interpretations.

3. Transform mathematical models into activation functions:

- Analyze the identified mathematical models to ensure they meet the basic requirements for activation functions, such as continuity, differentiability, and computationally efficient evaluation.
- Modify or adapt the mathematical models, if necessary, to comply with these requirements while still preserving the underlying inventive principle.
- Formulate activation functions based on the adapted mathematical models, ensuring they are suitable for integration into neural networks.

4. Validate and refine the activation functions:

- Validate the proposed activation functions using small-scale experiments, simulations, or theoretical analysis to ensure they exhibit the desired properties and behavior.
- Iterate on the activation function formulations, based on the validation results, refining their mathematics to better align with the inventive principles.

5. Integrate the activation functions into neural networks:

1. Incorporate the formulated activation functions into neural network models, as outlined in the previous step-by-step process for testing the model.

2. Evaluate the impact of these activation functions on creativity, novelty, and realism in the generated outputs, and compare their performance to conventional activation functions.

This approach ensures a rigorous and structured process for investigating the potential of inventive principles-based activation functions in enhancing creativity in artificial intelligence.

4 Theoretical Results

4.1 The Activation Functions

The Structured Activation of Vertex Entropy (SAVE) method is a problem-solving approach that utilizes ten principles, called “vertexes” in a specific and well-defined order [43]. The method is based on the idea that interactions between the different elements of a system can lead to distorted messages and that by applying external stimuli in a specific order, it is possible to guide the evolution of the system towards a desired outcome. The SAVE’s specific vertexes are activating resonance, introducing neutral elements, asymmetry etc., which are intended to help solve problems in a non-compromising way. These vertexes are based on real-life examples and are intended to be easy to understand and apply by people in various situations. The vertexes should be applied in a specific order, vertex 1 is applied first and the result is analyzed, then vertex 2 is applied on the result of vertex 1, and so on, until the tenth vertex is reached. Pursuant to the proposed methodology, the mathematical representations of the SAVE inventive principles are further introduced. To convert each formula into an activation function for a neural network, we need to ensure they meet certain performance indicators, such as speed of calculation, low computational complexity, relevance to the problem, differentiability, and monotonicity. Thus, some functions need to be modified when they are converted into activation functions.

Vertex 1: Activation of resonance:

$$y = A \cdot \sin(\omega \cdot x + \varphi). \quad (1)$$

This formula represents a sine wave, which is a common mathematical representation of resonance. ‘A’ represents amplitude, ‘ ω ’ is angular frequency, ‘x’ is the input, and ‘ φ ’ is phase. In this case we need to replace sin with tanh to ensure differentiability and bounded output. Thus, the related activation function will be:

$$y = A \cdot \tanh(\omega \cdot x + \varphi). \quad (2)$$

Vertex 2: Introduction of neutral elements:

$$y = x + k. \quad (3)$$

This linear equation adds a constant ‘k’ to the input ‘x’ to create a new path of evolution. This linear equation is already differentiable and computationally efficient.

Vertex 3: Action against the wolf-pack spirit:

$$y = a \cdot x^b. \quad (4)$$

This power-law equation represents a relationship between ‘ x ’ and ‘ y ’ where a small change in ‘ x ’ can lead to a significant change in ‘ y ’ without relying on external support. In this case we need to replace ‘ x ’ with $\text{ReLU}(x)$ to ensure non-negative outputs and differentiability. In this situation, the new formula is:

$$y = a \cdot [\text{ReLU}(x)]^b. \quad (5)$$

Vertex 4: Activation of centrifugal forces:

$$y = r \cdot e^{\theta \cdot x}. \quad (6)$$

This polar coordinate transformation represents the centrifugal forces that push elements away from the center as ‘ x ’ increases. To ensure bounded output and differentiability, we replace $e^{(\theta \cdot x)}$ with $(1 - e^{(-\theta \cdot x)})$. The new formula is:

$$y = r \cdot (1 - e^{-\theta \cdot x}). \quad (7)$$

Vertex 5: Application of multi-level connections:

$$y = c_1 \cdot f_1(x) + c_2 \cdot f_2(x) + \dots + c_n \cdot f_n(x). \quad (8)$$

This weighted sum of multiple functions (f_1, f_2, \dots, f_n) represents the synergy and alignment with other systems. In this case we apply ReLU to each function to ensure non-negative outputs and differentiability. The result is:

$$y = c_1 \cdot \text{ReLU}(f_1(x)) + c_2 \cdot \text{ReLU}(f_2(x)) + \dots + c_n \cdot \text{ReLU}(f_n(x)). \quad (9)$$

The number of functions ‘ n ’ in the activation function is a hyperparameter that needs to be chosen based on the complexity of the problem and the size and properties of the input data. There is no fixed rule for determining the optimal number of functions, as it depends on the specific problem being solved and the properties of the input data. However, in general, having more functions can increase the capacity of the network to learn complex patterns and relationships in the data, but can also lead to overfitting and slower training. A common approach to determining the number of functions is to use a trial-and-error process or a hyperparameter tuning method. This involves trying different numbers of functions and evaluating the performance of the network on a validation set. The goal is to find the smallest number of functions that result in good performance on the validation set, to avoid overfitting. A good starting point for the number of functions is often between two and ten, depending on the complexity of the problem and the size of the input data. The form of the functions can vary widely depending on the architecture of the neural network, the type of problem being solved, and the properties of the input data. To choose the form of the activation functions for the neurons in the hidden layer, you need to consider the properties of the problem and the input data. For creativity problems, we encourage others to explore a wide range of possible solutions, while still

being able to converge on promising solutions. We can use activation functions that are nonlinear and have a wide dynamic range, such as Gaussian activation functions, which have a smooth, bell-shaped curve and a wide dynamic range. The Gaussian function can be defined as:

$$f(x) = e(-x^2). \quad (10)$$

This function has a center at $x = 0$ and decays to zero as x moves away from the center. By using multiple Gaussian functions with different centers and widths, we can create a complex activation function that can capture a wide range of patterns and relationships in the input data. Another option could be to use a family of activation functions called “bump functions,” which are defined as:

$$f(x) = \left(1 - (x/a)^2\right)^b \text{ if } |x| < a, 0 \text{ otherwise,} \quad (11)$$

where a and b are constants that control the width and height of the bump function. This function has a sharp peak at $x = 0$ and decays to zero as x moves away from the center. By using multiple bump functions with different centers and widths, you can create a complex activation function that can capture a wide range of patterns and relationships in the input data.

Vertex 6: Application of asymmetry:

$$y = |x - a|. \quad (12)$$

This absolute value function represents the asymmetry between a system and a much bigger system by capturing the distance from a reference point ‘ a ’. Here, we replace absolute value with ReLU for differentiability and non-negative output.

$$y = \text{ReLU}(x - a). \quad (13)$$

Vertex 7: Harmonization of individual goals with collective goals:

$$y = w_1 \cdot x_1 + w_2 \cdot x_2 + \dots + w_n \cdot x_n. \quad (14)$$

This linear combination of variables (x_1, x_2, \dots, x_n) with weights (w_1, w_2, \dots, w_n) represents the alignment of individual goals with collective goals. In this case we apply ReLU to each variable for non-negative outputs and differentiability. The result is:

$$y = w_1 \cdot \text{ReLU}(x_1) + w_2 \cdot \text{ReLU}(x_2) + \dots + w_n \cdot \text{ReLU}(x_n). \quad (15)$$

For creative problems, the choice of the number of functions ‘ n ’ in the activation function depends on the specifics of the problem and the data. In general, creative problems may require more complex and diverse models that can explore a wide range of solutions and capture subtle patterns and relationships in the input data. Therefore, a larger number of functions may be necessary to achieve good performance. The choice of the number of functions is not a one-time decision and can be adjusted during the training process as needed. As the network learns more about the data and the problem being solved, the optimal number of functions may change, and it’s important to monitor

the performance of the network and adjust the hyperparameters accordingly. A good starting point for the number of functions in a creative problem is often between 10 and 20, depending on the specifics of the problem and the data. The input ‘ x ’ refers to the output of the previous layer that is fed.

Vertex 8: Transformation for value-added:

$$y = k \cdot x^{1-\alpha}. \quad (16)$$

This production function (Cobb-Douglas) represents increased outputs ‘ y ’ with the same inputs ‘ x ’ by adjusting the parameter ‘ α ’. The activation function for this vertex is adapted to meet the requirement for bounded output and differentiability. The result is shown below:

$$y = k \times (1 - e^{-\alpha \cdot x}). \quad (17)$$

Vertex 9: Application of prisoner paradox:

$$y = f(x) \cdot g(x). \quad (18)$$

This product of two functions (f and g) represents the intelligent rearrangement and utilization of existing local resources. Here we consider ReLU to ensure non-negative output and differentiability, resulting the following activation function:

$$y = \text{ReLU}(f(x) \times g(x)). \quad (19)$$

To determine appropriate forms for $f(x)$ and $g(x)$ in the context of creative problems, we can look at some common features of creativity and how they might be modeled mathematically. Creative problems often require divergent thinking, which involves generating multiple ideas or solutions from a single starting point. A function that models this behavior could be an exponential function. For example, $f(x) = e^x$, where ‘ x ’ represents the input, such as the level of creativity, and ‘ e ’ is the base of the natural logarithm. Solving creative problems also often involves convergent thinking, which is the process of combining ideas or concepts to find a single solution. A function that models this behavior could be a logistic function that saturates at higher values. For example, $g(x) = 1/(1 + e^{(-k \cdot x)})$, where ‘ k ’ is a positive constant that controls the steepness of the curve.

Together, these functions might represent the interaction between divergent and convergent thinking in solving creative problems. The product of the two functions, $f(x) \times g(x)$, would then model the balance between generating ideas and refining them. Finally, the ReLU function ensures that the output is non-negative and differentiable:

$$y = \text{ReLU}((e^x)/(1/(1 + e^{(-k \cdot x)}))). \quad (20)$$

This is just one possible interpretation of the functions f and g for creative problems. Different functions may be more appropriate depending on the specific context and desired properties of the activation function.

Vertex 10: Application of shipwrecked paradox:

$$y = (a \cdot x + b)/(c \cdot x + d). \quad (21)$$

This rational function represents the transformation of local negative factors into positive factors by finding hidden value networks through the ratio of two linear functions. Also, here we consider ReLU to ensure non-negative output and differentiability. The result is:

$$y = \text{ReLU}((a \cdot x + b)/(c \cdot x + d)). \quad (22)$$

4.2 The Neuronal Network Model

The neural network model consists of a generator model and a discriminator model. The generator model uses a sequential architecture with layers such as Embedding, LSTM, Dropout, and Dense. It takes the input sequences and aims to generate creative outputs by applying novel activation functions. The discriminator model, on the other hand, has a simpler architecture with Dense layers and aims to distinguish between real and fake outputs generated by the generator. In the followings we describe how this model aligns with the TRIZ-inspired suggestions:

Complexity vs. Interpretability: (a) Principle of Segmentation: The model incorporates LSTM layers to segment the input sequences into simpler sub-modules, facilitating the interpretation of the impact of novel activation functions on creativity at each level. (b) Principle of Local Quality: The model introduces different levels of complexity in different parts, focusing on areas where the activation functions have the most significant impact on creativity.

Exploration vs. Exploitation: (a) Principle of Dynamics: The model applies techniques like dropout and curriculum learning to adaptively balance exploration and exploitation during training, allowing for a gradual increase in the difficulty of the training data. (b) Principle of Self-Service: Auxiliary tasks, such as unsupervised learning, can be incorporated to encourage exploration without compromising the main objective of creativity.

Flexibility vs. Overfitting: (a) Principle of Parameter Changes: The model adjusts its capacity and architectural complexity according to the problem at hand to prevent overfitting. (b) Principle of Composite Materials: By combining different regularization techniques like dropout and L1/L2 regularization, the model enhances generalization while maintaining flexibility.

Computational Efficiency vs. Creativity: (a) Principle of Asymmetry: The model asymmetrically allocates computational resources by focusing more on the layers with novel activation functions that contribute most to creativity. (b) Principle of Universality: The model is designed to efficiently handle different activation functions and problem domains without requiring significant modifications or additional resource overhead.

Novelty vs. Realism: (a) Principle of Feedback: The model incorporates a feedback mechanism in the form of a discriminator, which helps adjust the degree of novelty based on the realism of the generated outputs. (b) Principle of Prior Action: The model pre-processes input data or incorporates domain-specific knowledge to guide the generation of novel yet realistic outputs.

By incorporating these TRIZ-inspired suggestions, the neural network model aims to effectively investigate the impact of novel activation functions on creativity while

addressing the identified contradictions. It balances complexity and interpretability, encourages exploration and exploitation, prevents overfitting while maintaining flexibility, efficiently utilizes computational resources, and seeks a balance between novelty and realism in the generated outputs.

A simpler model can also be investigated. This simpler model could be a sequential neural network model that incorporates various TRIZ-inspired suggestions to investigate the impact of novel activation functions on creativity. Its relation to the TRIZ indications are shown below:

Complexity vs. Interpretability: (a) Principle of Segmentation: The model divides the input data into simpler sub-modules by using LSTM layers, allowing for better interpretation of the impact of novel activation functions on creativity at different levels. (b) Principle of Local Quality: Different complexity levels are introduced in different parts of the model, focusing on the areas where the activation functions have the most significant impact.

Exploration vs. Exploitation: (a) Principle of Dynamics: The model utilizes techniques such as dropout regularization and the usage of novel activation functions to adaptively balance exploration and exploitation during training. (b) Principle of Self-Service: By incorporating auxiliary tasks and dropout layers, the model encourages exploration without compromising the main objective of creativity.

Flexibility vs. Overfitting: (a) Principle of Parameter Changes: The model adjusts its capacity and architectural complexity using different activation functions to prevent overfitting and increase flexibility. (b) Principle of Composite Materials: By combining different activation functions and regularization techniques, such as dropout, the model enhances generalization while maintaining flexibility.

Computational Efficiency vs. Creativity: (a) Principle of Asymmetry: The model allocates computational resources asymmetrically, focusing more on layers with novel activation functions that contribute most to creativity. (b) Principle of Universality: The model is designed to efficiently handle different activation functions and problem domains without requiring significant modifications or resource overhead.

Novelty vs. Realism: (a) Principle of Feedback: The model does not explicitly incorporate a feedback mechanism like a discriminator to balance novelty and realism. However, the novel activation functions can contribute to generating outputs with a balance between novelty and realism.

The simpler model leverages TRIZ-inspired ideas to design a neural network architecture that effectively explores the impact of novel activation functions on creativity.

5 Practical Applications

5.1 Use Case

The two neural models have been transformed into Python code and evaluated in a Jupyter Notebook. Due to limited resources, the tests were conducted specifically on one product: the hammer. For this purpose, a file was created containing descriptions of existing hammers, along with some other objects that could potentially serve as hammers

in critical situations. In total, the file includes 124 objects. Table 1 provides an overview of how these objects were described.

Table 1. Data sets for hammer-like objects.

#	Description	Label
1	A tool used for striking a chisel, punch or other similar tools	Sledgehammer
2	A tool used for bending or shaping metal, usually consisting of a head and a pair of handles	Blacksmith hammer
3	A tool used for drilling into hard surfaces, such as concrete, stone or brick	Masonry hammer
...
122	A weapon consisting of metal finger rings with attached metal plates or spikes, typically made of brass or other hard materials, used for hand-to-hand combat	Brass knuckles
123	A type of clamp consisting of a frame shaped like the letter “C”, with a threaded screw mechanism to adjust the opening width, commonly used in woodworking or metalworking	C-clamp
124	A hammer with a flat striking surface on one side and a curved, forked end on the other side, commonly used for driving nails or removing them with the claw end	Claw hammer

5.2 The Model

One of the critical factors in model design is the selection of hyperparameters. This includes the coefficients in the activation functions, the arrangement of the model’s layers, the number of nodes, the dropouts in various layers, and the sequence of activation functions. A significant challenge in model design is ensuring compatibility between raw and transformed data, which falls within the realm of data engineering expertise. Additionally, the architecture is influenced by the types of layers used and their arrangement. The code for the two models, which employ a non-traditional neural network architecture, are too long to be included in the paper.

5.3 Tests and Results

Both models were trained and tested using the dataset outlined in Table 1. Due to limited resources, rather than employing more advanced NLP-specific models such as Transformers (e.g., BERT, GPT, RoBERTa, T5, XLNet), LSTM algorithms were utilized in the initial layers following the input layer of the models [44]. This was deemed sufficient for evaluating the significance of the activation functions from a scientific perspective. While the outputs might not form perfectly coherent sentences, they do provide essential keywords to inspire designers. These keywords can be further integrated into tools that

already have pre-trained transformers, such as chatGPT, for more fluent sentence formulation. It should be noted, however, that the generation of fluid sentences extends beyond the capacity of the training dataset used for this model. But this limitation falls outside the scope of the scientific research conducted in this paper. However, the research will be expanded in the future by including transformers in the models instead of LSTM.

In continuation there are illustrated results from the application of the two models. Four ideas, generated by each model, will be shown. First, they will be shown as they have been released by the models, and after that converted into fluent sentences. Results after 4 running times (each time for a new idea) of the simpler model:

- Idea 1: “This tool as used but soil striking handle a woodworking another used mechanism striking peas a a as construction a other to face tool two correct end apart species by often as in symbol or or on a including in a other long cutting metal in of tasks the for or”
- Idea 2: “This tool a species to striking like for correct used a used hammer to as used heavy geologists mining used designed the used and axe designed commonly chisel a hammer the or chipping a small a other a printed tool or a firefighters chisel or side used striking for surface used the”
- Idea 3: “This tool a used or used breaking like and for hammer situations materials for a the object hammer labor in by used the tool in tasks tool hammer with used a designed and held like hammer a heavy featuring peen communication and with hammer of hammer in on featuring broom hammer of”
- Idea 4: “This tool commonly as metal of or commonly that and staples and commonly for large a typically chisel other tool or handle or frames symbol or texturing as used or by a specifically a lifting x pair be as edge hammering the a short striking hammer as a used concrete hammering commonly”

Following the restructuring of keyword clusters into coherent narratives, we derived the following concept descriptions:

- Idea 1: “Woodsoil Strikehammer: this tool combines the elements of woodworking and soil striking. It features a handle for striking soil, similar to a traditional hammer, but with a specialized mechanism for woodworking tasks. The tool has two striking faces, one designed for soil-related tasks and the other for woodworking purposes. It can be used in construction or other tasks that require striking or cutting various materials, including metal. The tool’s versatility makes it suitable for a wide range of applications”.
- Idea 2: “GeoStrike Heavy-Duty Hammer: an innovative tool designed for professionals in geology, mining, and firefighting. This versatile hammer combines the functionalities of a hammer, chisel, and axe to deliver exceptional performance in heavy-duty applications. With a well-balanced design for striking precision, it ensures correct and powerful blows. The robust construction withstands rigorous use, while the multi-functional versatility allows for chipping, chiseling, cutting, and splitting tasks. Printed tool indications provide valuable information, enhancing usability and safety. Specifically designed for firefighters, it aids in forcible entry and striking surfaces during emergency situations. The GeoStrike Heavy-Duty Hammer embodies

power, versatility, and durability, empowering professionals in demanding fields to tackle tasks with unmatched efficiency and effectiveness”.

- Idea 3: “CommuniStrike Heavy-Breaker: a revolutionary hammer-like tool that redefines the concept of communication in labor-intensive tasks. This innovative tool combines the strength and functionality of a traditional hammer with advanced features designed to enhance performance. Built to withstand tough materials and demanding situations, the CommuniStrike Heavy-Breaker excels in breaking and hammering tasks across various industries. Its object-oriented design focuses on optimizing efficiency and user comfort, reducing fatigue during prolonged use. Embracing the power of communication, this tool integrates unique features that promote seamless teamwork and collaboration, enabling real-time data transmission for improved task coordination. With its specialized peen-shaped striking surface, precise and efficient strikes are achieved, while the broom-like functionality keeps the work area clean and minimizes interruptions. The CommuniStrike Heavy-Breaker is the epitome of strength, innovation, and effective communication, revolutionizing labor-intensive tasks with unparalleled performance and functionality”.
- Idea 4: “MightyForge Concrete ChiselHammer: a novel hammer-type tool that defies conventions and redefines the realm of versatility and strength. Crafted with precision and innovation, this extraordinary tool combines an array of remarkable features to deliver unmatched performance. From its dominant metal composition, ensuring durability and resilience, to its expertise in removing staples effortlessly, the MightyForge Concrete ChiselHammer excels in large-scale projects and upholstery work. Its specialized chisel head empowers users to tackle diverse chiseling tasks with ease, while the reinforced handle provides maximum control and minimizes hand fatigue during extended use. Imprinted with a symbolic frame, this tool exudes distinction and craftsmanship. With texturing capabilities and lifting power, the MightyForge Concrete ChiselHammer effortlessly enhances surfaces and aids in maneuvering heavy objects, simplifying construction projects. Its cutting-edge design enables precise and forceful hammering, while its compact agility allows for effortless maneuvering in tight spaces. Specializing in concrete-related tasks, this tool displays unrivaled strength and efficiency. The MightyForge Concrete ChiselHammer stands as a testament to innovation, setting a new standard for hammer-type tools. Experience the transformation of your projects into masterpieces with the unmatched power and versatility of the MightyForge Concrete ChiselHammer”.

Results after 4 running times of the model, which includes feedback with GAN, are shown in the next paragraphs:

- Idea 5: “The hammer plumbing finger their require posts allows has softer water eyes”
- Idea 6: “The hammer mirror yachtsmen fish rubber tightened masonry or turning sturdy species”
- Idea 7: “The hammer lifting narrow rock chisels horseshoes content binding glass combination tip”
- Idea 8: “The hammer square featuring sending be light jaw feet cover fastening serve”.

Results are reformulated in clear descriptions by the team of designers, and the final form of the description is shown below. Also, AI models such as chatGPT or ELI5 can be used to help in this process. It helps for automatic image generation:

- Idea 5: “AquaGrip Water Hammer”, a groundbreaking tool that redefines the plumbing category. This innovative hammer-type tool combines precision, comfort, and versatility to provide unparalleled performance. With its finger-friendly grip and post compatibility, it ensures optimal control and seamless integration with various plumbing fixtures. The AquaGrip Water Hammer’s softening power minimizes impact force, safeguarding delicate plumbing components. Embracing the power of water, it incorporates a water flow control system for precise adjustments. With its built-in visual indicator, it offers real-time feedback on water pressure and flow. The AquaGrip Water Hammer sets a new standard for plumbing tools, empowering professionals and DIY enthusiasts alike with its unmatched accuracy, comfort, and efficiency”.
- Idea 6: “FlexMirror Masonry Hammer: a groundbreaking hammer-type tool that seamlessly merges the worlds of yachting and masonry. This extraordinary tool embraces innovation and versatility, offering a range of unique features. The mirror reflection integrated into the hammer’s head provides a practical solution for yachtsmen, allowing them to check their appearance or surroundings on board. For avid fishermen, a built-in fishhook remover enhances their fishing experience. The rubberized grip ensures a secure and comfortable hold, while the specialized tightening mechanism enables users to tighten various fixtures effortlessly. With its robust construction and expertise in masonry tasks, the FlexMirror Masonry Hammer excels in brickwork, stonework, and other sturdy applications. Celebrating the diversity of nature, symbolic representations of species adorn the hammer, adding an artistic touch. Experience the exceptional capabilities of the FlexMirror Masonry Hammer, where innovation meets functionality, and elevate your hammering tasks to new levels of efficiency and craftsmanship”.
- Idea 7: “FlexiGrip ChiselHammer: a visionary marvel that revolutionizes the world of hammers. With its novel and innovative design, this remarkable tool transcends conventional boundaries and embraces a new era of functionality. The FlexiGrip ChiselHammer showcases an array of extraordinary features meticulously crafted to empower users in every task they undertake. Firstly, its lifting capability sets it apart from ordinary hammers, as a unique lifting mechanism is integrated, enabling effortless handling of heavy objects during construction or renovation endeavors. Precise and controlled strikes in confined spaces become effortless with the hammer’s narrow design, effortlessly navigating corners and narrow crevices with absolute finesse. But the FlexiGrip ChiselHammer doesn’t stop there—it combines the power of a hammer with the finesse of a chisel. A built-in rock chisel makes breaking and shaping rocks or hard materials encountered in masonry or geological tasks a seamless endeavor. Additionally, the handle boasts a specialized holder for horseshoes, catering to equestrian enthusiasts or professionals who demand a versatile tool for both hammering and horseshoe maintenance. This extraordinary tool doesn’t cease to amaze; it features an innovative content binding mechanism, allowing users to securely bind various materials together, be it wood, metal, or fabric, with unparalleled precision and ease. Furthermore, a specialized glass combination tip sets the FlexiGrip ChiselHammer

as the go-to tool for glassworkers and craftsmen in the glazing industry, proficient in glass cutting, shaping, and removal. The FlexiGrip ChiselHammer embodies versatility, functionality, and innovation, seamlessly blending the tried-and-true elements of a traditional hammer with groundbreaking features. It ushers in a new era of efficiency, empowering users across an extensive range of applications. With the FlexiGrip ChiselHammer in hand, craftsmanship reaches new heights, and possibilities become boundless”.

- Idea 8: “SquareGrip Light-Hold Hammer: a cutting-edge hammer-like tool that combines innovative design elements to redefine hammering and fastening tasks. With its square-shaped head, the SquareGrip Light-Hold Hammer maximizes contact area for precise strikes, ensuring accurate and controlled hammering. Weighing significantly less than traditional hammers, this featherweight tool offers effortless handling, reducing user fatigue during extended use. The jaw-style grip mechanism provides a secure hold on various objects, transforming the SquareGrip Light-Hold Hammer into a versatile fastening tool. With its protective cover, it safeguards the hammer’s head when not in use, prolonging its lifespan. Engineered for speedy fastening, this tool combines convenience and efficiency for quick and seamless project completion. The SquareGrip Light-Hold Hammer revolutionizes hammer-like tools, delivering superior functionality and user-friendly features that cater to professionals and DIY enthusiasts alike. Experience a new level of precision, convenience, and efficiency with the SquareGrip Light-Hold Hammer, setting a new standard in the realm of hammering and fastening tasks”.

Utilizing advanced text-to-image AI systems like MidJourney, DALL-E2, or Stable Diffusion, product ideas can be visually explored during the initial stages of the design process. These AI systems provide a means to generate visual representations based on the descriptive texts, serving as inspirational references. In the upcoming section, we present a collection of visual representations created with MidJourney.



Fig. 2. GeoStrike Heavy-Duty Hammer – versions generated with MidJourney based on the description from Idea 2.

Figures 2, 3, 4 and 5 depict basic concepts of four distinct tools possessing hammering features. It’s important to note that these AI-generated concepts should not be viewed as final, perfect solutions, as they may not faithfully represent the engineering aspects in certain cases. However, they enhance productivity of the design process by fostering the conceptualization phase in designing innovative products. Of course, there is no need to use AI-image generation systems to visually conceptualize the product, as long as the



Fig. 3. MightyForge Concrete ChiselHammer – versions generated with MidJourney based on the description from Idea 4.



Fig. 4. FlexiGrip ChiselHammer – versions generated with MidJourney based on the description from Idea 7.



Fig. 5. SquareGrip Light-Hold Hammer – versions generated with MidJourney based on the description from Idea 8.

description in the AI-text generation systems provide sufficient information for helping designer to workout innovative solutions.

The results from this experiment are promising. However, this paper doesn't delve into the process of hyperparameter optimization for the AI models used in the study. This subject involves the investigation of both activation function coefficients and the architecture of the deep learning models, and generally requires an empirical, trial-and-error approach. Data quality and quantity also significantly influence AI model performance. In our case, we utilized a relatively small dataset of 124 data points. Ideally, a more robust model would incorporate thousands or even tens of thousands of data points.

Even without the benefit of model optimization or a comprehensive dataset, the proposed models performed beyond expectations. This suggests that activation functions,

inspired by human thought patterns, can generate capacity for divergence and diversification. Consequently, these become powerful tools in fostering creativity in artificial intelligence.

6 Conclusions

We can see that the potential of AI tools in accelerating the process of inventive design is immense and multifaceted. They have the ability to transform the landscape of product creation, providing new and powerful means of ideation, design, and optimization. By automating and enhancing tasks such as data analysis, pattern recognition, and concept generation, AI tools can significantly expedite the innovation process. Furthermore, AI can enable continuous, real-time iteration of designs, considering multiple factors and constraints to ensure optimal outcomes. This enhances not only the speed but also the quality of innovation. AI tools can explore vast design spaces and generate a multitude of options in a fraction of the time taken by traditional methods, thereby promoting creativity and diversity in product development.

Our results demonstrate how these AI systems, despite being subject to the constraints of small datasets and without extensive hyperparameter optimization, can still facilitate impressive results in concept generation and design ideation. This is a testament to the inherent potential of AI to revolutionize the product development landscape, reshaping it into a canvas of immense creative diversity and efficiency. Operating with a small data set presents a limitation in this research. However, in the practical world of product design, access to large-scale data for a particular type of product is not always possible. Consequently, developing a method that can efficiently utilize and learn from small datasets becomes not only necessary but also advantageous. This is precisely one of the key strengths of the proposed model. The model's ability to extrapolate and generate valuable insights from smaller datasets mitigates the limitation of the small sample size. This capability is particularly beneficial for cases where data is sparse, such as niche design areas, new fields, or confidential domains where data is proprietary and limited.

This study opens the door for future research to build upon these findings and delve deeper into the optimization process for AI models. Such research can explore different architectures, activation functions, and data augmentation techniques to maximize the performance of AI models. In particular, studies could investigate how different combinations of hyperparameters impact the performance of AI in design generation, providing further insights into the way AI can foster creativity and innovation. AI-driven conceptual design brings numerous benefits, including efficiency and speed, as it can analyze and generate concepts from vast data volumes more rapidly than human designers. Additionally, AI models provide objectivity, bypassing the cognitive biases that humans may possess, and thus facilitating the exploration of overlooked or discounted concepts. Moreover, AI, particularly generative models, excels at generating novel and creative concepts by exploring extensive design spaces. When compared with classical TRIZ and brainstorming activities, the advantages of AI-driven design become more prominent. TRIZ, a problem-solving methodology, relies heavily on the user's knowledge and skills, and may not always lead to novel solutions, contrasting with AI models that can independently generate novel designs. Meanwhile, brainstorming, though fostering diverse potential solutions, is often constrained by group dynamics, individual

knowledge and experiences, and can be time-consuming. In contrast, AI-driven design can rapidly produce a wide range of novel concepts, independent of these limitations. Future research comparing AI-driven conceptual design with TRIZ, and brainstorming would provide a comprehensive understanding of AI's strengths and potential in design innovation, not only emphasizing the advantages but also highlighting areas for enhancement and integration with existing design methodologies.

Our research does center on a specific case study, and we acknowledge that this approach inherently carries some limitations regarding the broad generalizability of our findings. The nature of our study is exploratory, aiming to shed light on a complex issue and stimulate discussion and further research in this area. We believe the example we provide is a compelling illustration of the potential AI-based innovation has to offer, even though it represents a single point in a vast space of possibilities.

Additionally, future work could extend the dataset size to further enhance the performance and the generalizability of the AI models. The inclusion of thousands or tens of thousands of data points could allow AI systems to understand deeper patterns and relationships, leading to an explosion of creative and innovative design concepts. The integration of AI with large, diverse datasets would further empower the democratization of design and innovation, allowing more people to contribute to and benefit from the process.

The role of AI in product design and innovation is just beginning to be realized. As AI continues to evolve and improve, it is expected that it will play an increasingly central role in the ideation, creation, and optimization of products. It's exciting to imagine a future where AI is seamlessly integrated into our creative process, capable of generating and iterating upon millions of concepts in the time it takes a human to sketch a single idea. This could usher in a new era of innovation, marked by unprecedented levels of creativity, efficiency, and democratization.

Moreover, AI tools can contribute to the democratization of innovation by making advanced design and optimization capabilities accessible to a wider audience. This can lead to the emergence of novel, user-centric products that disrupt existing markets and create new ones.

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Sustainable Development



Sustainability, TRIZ and Packaging

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Abstract. There is a great need to increase sustainability in general and specifically of products and packaging. The paper aims at supporting efforts to improve future developments by identifying examples in the packaging industry and mapping these to existing trends.

A new general trend line to the existing TRIZ trend systematic is proposed and possible sub trends are presented. Furthermore, a classification to already existing trends are shown.

The analysis is limited to parts of the packaging industry and the found changes in this area but a transfer to other industries and the service sector seems possible without adding substantiating proof. The application of the proposed trends and sub trends could help to increase and measure product and packaging sustainability.

Keywords: Sustainability · TRIZ · Trends · Packaging · Need

1 Introduction

The need to take care of the environment and to leave future generations a place worth living in has created a trend to increased sustainability in different areas. Looking at the packaging industry the change to greater sustainability could be perceived accordingly.

The term sustainability is defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1, p. 41]”.

Packaging is a material which “is used for the containment, protection, handling, delivery, presentation, promotion and use of products” [2, p. 44] with the possible functionality of protection, information, convenience and handling.

Trends are heuristic development directions which have been derived by analysis of past and present products and services. In [3] the notion of trends of engineering systems are described in more detail.

The paper presents examples of changes that have already been taken place in the packaging industry and proposes an addition the TRIZ trend tree.

Several sub trends are outlined, and specific guidelines are shown and explained. Furthermore, the paper tries to answer the research question if the found changes could be transferred to other industries and services.

In [4, p. 682] sustainability has three aspects (see Fig. 1). These aspects are:

- social,
- environmental and
- economic.

Important social factors are changing legislation and people's needs. The dynamics of those changes are slow but should be observed because a changing legal situation could be a threat to company objectives. Environmental factors could be divided into the areas land, sea, air and beyond earth. Economic factors are cost, e.g., for manufacturers and customers, or needed efforts like human resources.

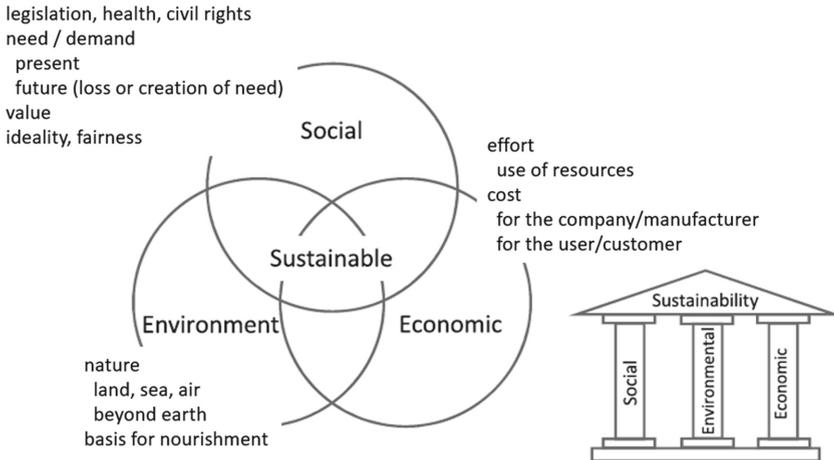


Fig. 1. Three aspects of sustainability [4, p. 682], combined with [5, p. 8] and edited by the author.

The creation and consumption of energy and material resources might be assignable either to the field of the environment or the economy. According to [5, p. 47] sustainable packaging must address the following four needs:

- effective – fulfil the required functionality (e.g., protect, limit access, ensure originality, ...)
- efficient – amount of resource consumption (e.g., raw and natural materials, energy, space, ...)
- cyclic – re-use, renew, recover essential material and energy
- safe – for people and the environment.

After these general outlines examples of packaging industry are presented.

2 Analysis of Packaging Products and the Way of Packing

The functionality and needs stated in the previous paragraph result either in requirements a packaging must meet or in requests. To get more insight 5 questions could be asked (see Fig. 2). What is the ideal packaging for the product? For whom (client) is the packaging intended, why does the customer need it together with the question where and when is

it needed. The where and when are greatly influenced by legislation, either of a specific country or an economic area, e.g., the EU. It does not only cover the actual time of usage but includes the procurement of raw materials, the production of pre-stage parts or structures and the time after the use as well. Especially the raw material and energy consumption during the time after use have a great impact on nature and the population.

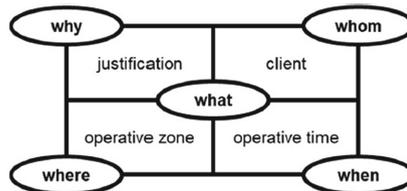


Fig. 2. $5 \times W$ to question the impact of packaging [6].

2.1 Packaging Products

Below some examples of food packaging are revealed. They depict different levels of ideality and different strategies to achieve an increased sustainability.



Fig. 3. Packaging in nature (left), packaging for transport (middle) and sale (right).

On the left-hand side of Fig. 3 a natural packaging of an orange is presented. For shipping and sale additional packaging like cardboard boxes and paper inserts are required (Fig 3 (middle and right)). The following figures show another example of the food industry (cream cup), one example of the clothing industry (milk and shoe box) and an example of a packaging for a packaging product (clingfilm packaging).

An analysis of the different packaging reveal certain characteristics:

- reduction of plastic material, transfer of the stabilising function to a different, less harmful material, segmentation into homogeneous materials with the drawback of the gluing point (removing the glue would result in the next step to a more ideal packaging), instructions for recycling (Fig. 4)
- avoiding (refusing) of a gluing process (trimming the glue and a likely thermal process), homogeneous material, use of present processes to create the shoe box (Fig. 5)



Fig. 4. Disassembled packaging of cream (cup, paper cover, aluminium lid).



Fig. 5. Transport and storage packaging for milk packs (left) and shoe packaging (middle and right).



Fig. 6. Packaging and integrated cutting aid for clingfilm.

- use of present resources to increase the customer involved functionality (integration of the cutting geometry in the paper cover, guidance of the paper cylinder holding the clingfilm with paper cover cut outs), homogeneous material (avoiding a metal cutter which was previously present) (Fig. 6)

The described changes imply that they not only increased the sustainability of the packaging but also increased the company profit assuming that the selling price remained the same. In the first example the amount of plastic material was reduced, in the second a thermal process and an additional material has been trimmed and in the last example existing resources were used to a maximum positive effect. Therefore, an increase in sustainability may also lead to positive economic effects for the manufacturer including the chance to promote the new design in advertising and improve the reputation.

2.2 Trends of Technical System Evolution and Proposal of a New General TRIZ Concerning the Respect and Care for Nature

Figure 7 presents an improved version of the TRIZ Trends of Engineering System Evolution. Together with the classical TRIZ trends and the trend of increased addressing of the senses [7, p. 21–22] the proposed new trend of increased care and respect for nature is shown.

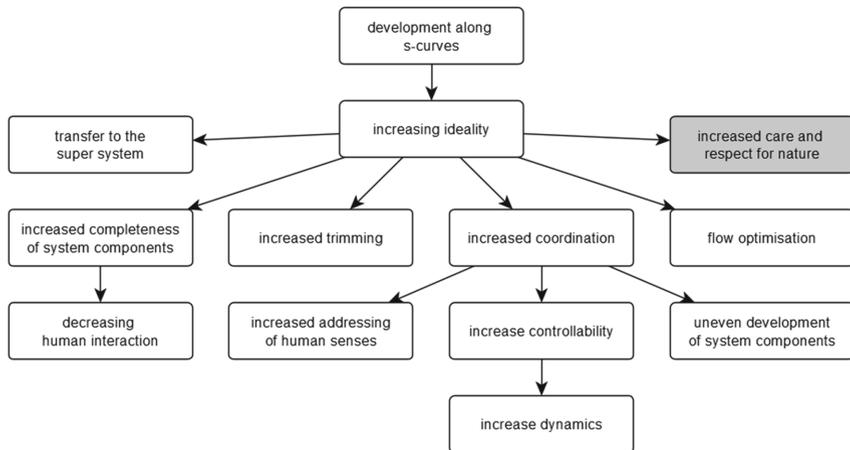


Fig. 7. Classical TRIZ tree of Trends of Engineering System Evolution [3, p.6; 8, p. 318] with the addition of the Trend of “Increased addressing of the senses” by O. Mayer and the proposed Trend of “Increased care and respect for nature”.

The proposed new branch begins at the increase of ideality and adds the item “increased care and respect for nature”. From there three steps are introduced:

- remove harm from the environment
- zero harm to the environment
- reduce harm to the environment.

Removing harm include developments like air carbon capturing or removing plastic waste from the sea. Zero waste aims at a cyclic process from the cradle to the grave and the reduction of harm at least limits the impact of products and processes. The order was derived from the different levels of circularity depicted in Fig. 8 [9, p. 16] and the priority is thought to be coinciding with the level of ideality.

The trend of increased sustainability is thought to be a sub-trend of reduced and zero harm to the environment (Fig. 9). Sub-trends of those are represented by the different levels of circularity (10 R’s). The mapping of the 10 R’s, which give exact directions of actions, to the sub-trend (see Fig. 10) create a hierarchical order that helps to implement and evaluate the level of sustainability. This schematic could support the packaging industry and its players to come up with ideas how to make required packaging more sustainable and allows for an evaluation of different actions which has been carried out.

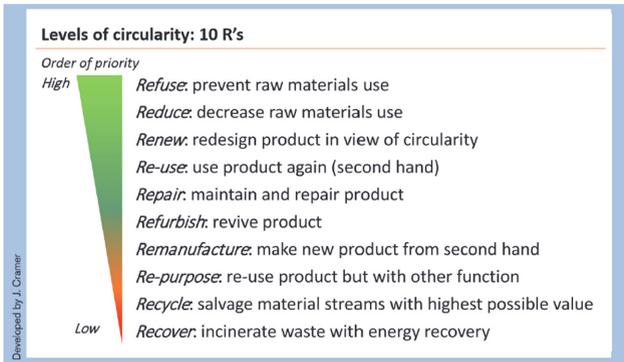


Fig. 8. Levels of circularity: 10 R's [9, p.16].

The indicated examples could be mapped to third level of increasing ideality, i.e., the reduction of harm. The sustainability is increased with measures like a decrease in plastic material consumption also having the positive effect of reducing the amount of energy needed. The possibility to dismantle items made from different materials helps to recover raw material in a pre-sorted way thus supporting a recycling process. This is further supported by making parts of the packaging from homogeneous materials and using existing production processes.

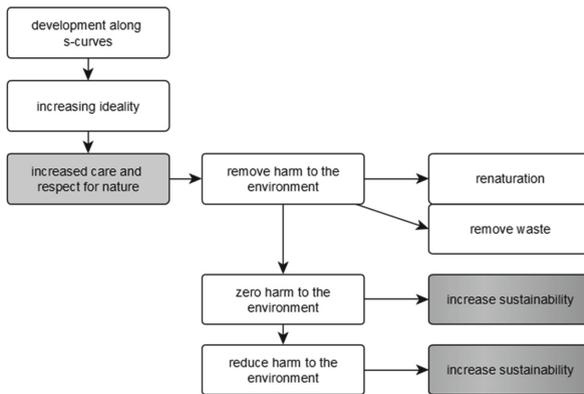


Fig. 9. Proposed new branch “increased care and respect for nature” to the TRIZ trend tree systematic.

Earlier certain inventive principles are hinted. These 40 inventive principles, together with separation principles for solving the physical contradiction [10, 11, p. 339–340] and already existing classical TRIZ trends [11, p. 148–183] could be combined to improve the efficiency and reliability during the process. Figures 11 and 12 give an impression on how these are connected. See [11, p. 114] for a more detailed description of the principles and their connection to separation principles.

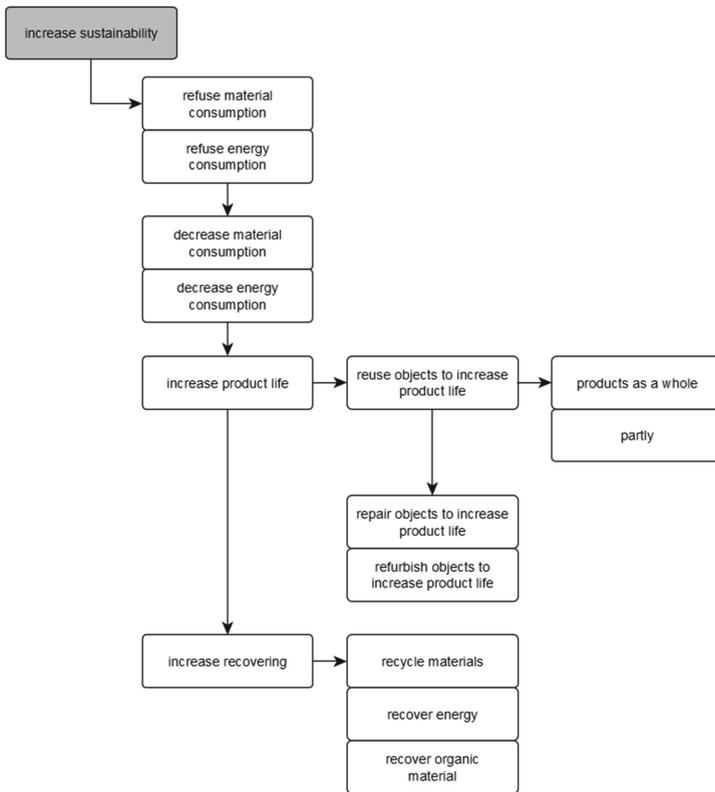


Fig. 10. More detailed schematic of the trend “increase sustainability”.

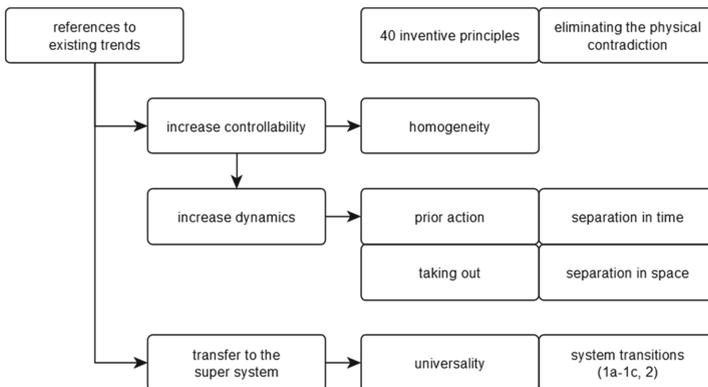


Fig. 11. References to inventive principles, separation principles and existing trends.

The author’s assignment of the inventive principles is based on the analysis of examples, either the ones presented in the paper or additional ones which are not specifically

The trendlines and the connection with inventive and separation principles allow a good overview and act as a working aid: These support tools are derived from a limited number of samples from the packaging industry. The conclusion seems to be consistent since certain changes could be mapped to already existing trend lines. The fact that products and services could be mapped to the proposed trend lines as well imply a general applicability

Figure 13 gives some examples for services and parts, e.g., the evolution of a map for spare time activities in a certain holiday region. The size of the map was reduced significantly from the year 2022 to 2023 (reduced amount of needed material) and it could be used for winter and summertime spare activities (increased universality, manufacture with greater batch size). The inventive principle of universality is also used for the improvement of timetables. Displays always show the most recent information, increase the user interaction, allow for giving the information in different languages and unite multiple types of information in one area. Thus, the amount of available information is increased, and the large paper timetable can be removed leaving space for the people. Ball pen designs made of paper or wood would be another example (see Fig. 14). The presented T-shirt is made from recovered ocean plastics which is considered a further step to increased sustainability.

The implementation and work with the process is supposed to be straightforward, but the current level of practicability/usability should be improved by further work. This includes the search and integration of more examples to the diagram presented in Fig. 12. Computer and AI support could be gained by setting up a database with possible examples and associated images for the different boxes of the trend hierarchy with special reference to care and respect for nature (sustainability).

This database could be browsed, or an AI could provide proposals based on a user interaction, e.g., questions raised by the AI application and answers of the user. Herzig proposed this kind of expert system for evaluating results of an examination and determining a suitable treatment [12, p. 34; 13, p. 84; 14, p. 6–61].

Entering images of designs, problem sketches or part lists followed by automated, AI supported image processing and providing suggestions based on development trends for increased sustainability could also help to improve products, processes and services.

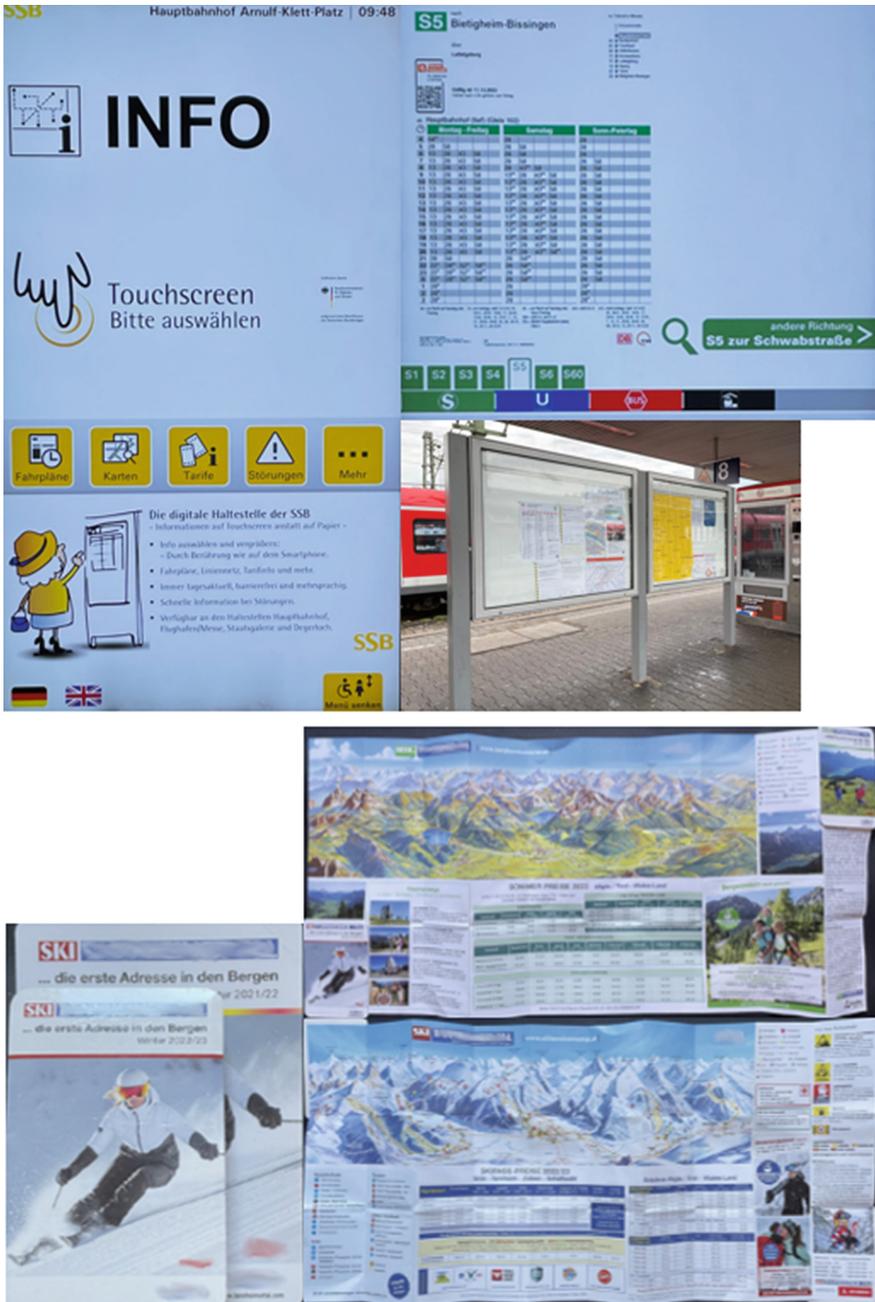


Fig. 13. Examples of services (timetables, top) and parts (tourist information, below)



Fig. 14. products made of recovered plastic waste (T-shirt) and recycled (paper and plastic, left ball pen) or sustainable material (wood, right ball pen)

4 Summary and Conclusions

The analysis of packaging example led to the proposal of an additional trendline to the TRIZ trends hierarchy of Technical Engineering System Evolution. The proposal must be further validated with more examples and with different industries. Nevertheless, the systematic structure seems to be logic, sensible, useful, and fitting common sense because it was derived from the analysis of changes which already have taken place for packaging products. The drivers of these changes could not be identified with one hundred percent certainty since some super effects like getting rid of thermal process (drying glues) and additional materials (the glue) are present as well. These super effects reduce cost and increases profit therefore helping the producer in two ways (more sustainable and cost reduction). The increased sustainability is used for marketing and improving the company reputation as well. The inventive principles used to increase the sustainability of packaging are present in other products and services as well. Therefore, it could be assumed that the transfer of the found trendlines and the associated action directions with them is possible and feasible in other areas as well.

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Function-Oriented Search, TRIZ and the Sustainable Use of Information Resources

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Abstract. Finding leading areas and industries is currently not supported within Function-Oriented search. The proposed workflow aims at a systematic approach to help finding possible leading areas together with the implementation of existing resources. This increases the sustainability because the amount of used human resources is decreased and the utilisation of present information resources is increased. Thus, the effort within development is improved which increases the efficiency. The application and value of Function-Oriented Search is simplified, and the level of subjectiveness is reduced.

The proposed workflow was tested with an example. Therefore, it should be substantiated with additional example problems in different fields of industry. Furthermore, during the work a change of the resources were perceived. This could lead to further research if those changes could be predicted. Expert systems and AI could enhance the process by automated analysis of search results or suggestions where to perform additional searches.

Keywords: Function-Oriented Search · TRIZ · Sustainability · Information · Resources

1 Introduction

In older versions of Altshuller's ARIZ (Algorithm of Inventive Problem Solving) [1, p. 108, 109] and in the newer TRIZ tool Function-Oriented Search (FOS) it is required to find a leading industry. A leading industry is defined as an industry in which the fulfilment of a defined function is vitally important.

Both TRIZ tools, a part of ARIZ and FOS aim at finding solutions to a functional analogous problem and transfer the solution to the specific problem at hand. In case secondary problems turn up during the implementation of the found solution additional TRIZ tools could be applied. The problem now is that neither the ARIZ versions nor Function-Oriented Search give hints of how to proceed to find this leading area or industry. The paper aims at supporting this search in a systematic and less subjective way. A workflow is proposed which starts at the step 4 of FOS and returns to FOS with suggestions of possible leading industries at step 6.

To support the efficiency and to use already present resources the workflow implies using present internet or patent database search engines. The use of present information resources and search tools save time and resources and is therefore thought to be sustainable as well.

2 Function-Oriented Search

A literature and internet research for the TRIZ tool Function-Oriented Search shows that Function-Oriented Search (FOS) could date back to 1973 [2]. The basis for FOS, a problem solving TRIZ tool without stating a contradiction, is the analogy of a specific problem situation at hand to a problem situation in another area in which the problem has been solved. The analogy is formulated on a functional level and might be done with a verb only (e.g., to stabilise) or with a verb and an object (e.g., to stabilise a rod – using a verb and an object could increase a possible fit to the specific problem to be solved). The term Function-Oriented Search was coined by Simon Litvin in 2004. In [3, p. 505–508] Simon Litvin proposed an FOS algorithm with 12 steps (see Table 1).

Table 1. Process steps of the first version of Function Oriented Search by Simon Litvin [3].

Step 1	Identify the Key Problem that prevents the Product/Process from solving the Initial Problem
Step 2	Formulate necessary function(s) for Key Problem solving
Step 3	Formulate required functional parameters
Step 4	Formulate a generalised function
Step 5	Identify a leading area(s) of industry where such types of functions are vitally important
Step 6	Find the best experts in the identified leading area
Step 7	Using professional databases and experts' knowledge, identify candidate technologies
Step 8	Select the Technology(ies) closest to required functional parameters
Step 9	Formulate a Secondary Problem(s) that would potentially prevent the selected technology from being immediately implemented to solve the Initial Problem
Step 10	Solve that Secondary Problem(s)
Step 11	Describe a slightly modified existing technology as the solution to the Initial Problem
Step 12	Submit necessary data to substantiate the effectiveness of the identified technology and suggest a practical plan for its implementation

The major drawback of this first algorithm is the fact that experts in certain fields are needed to identify a leading area. In the current form of the algorithm the steps where experts are needed are omitted (see Table 2 [4]). FOS is not a classical TRIZ tool and the current algorithm or workflow to follow with its 8 steps is presented in Table 2. After

the definition of the key problem, the required parameters and the generalisation of the identified function it is necessary to identify a leading area or industry.

The tool and how to carry out the process is also described in various other publications [5, pp. 219–220; 6, p. 199]. In [7–9] Hill relates the idea of working with functions to bionics and shows a workflow called Nature Oriented Innovation Strategy together with a catalogue of functions realised by nature. An improvement of the original version of Function-Oriented Search was proposed by Savelli and Feygenson in [10].

Table 2. Process steps of the current version of Function Oriented Search [4].

Step 1	Identify the key problem to be solved
Step 2	Identify the specific function of the system that needs to be improved
Step 3	Formulate the required parameters
Step 4	Generalise the identified function
Step 5	Identify the leading areas or industries in which a similar function is vitally important
Step 6	Select the technology that is most suitable to perform the desired function based on your requirements and constraints
Step 7	Identify secondary problems required to adapt and implement the selected technology
Step 8	Solve the secondary problems

The one drawback already stated remains. How to find the leading areas or industries? Furthermore, it could be noted that the algorithm not only asks for one industry but for a multitude of possible industries and for areas which would include nature or nature inspired problem solutions as well.

The following chapter proposes a workflow with which this could be done in a systematic and objective way.

3 Workflow to Derive a Leading Area and Obtain Results

The workflow to derive a leading area or industry starts after the first 4 steps of FOS have been carried out, i.e., the key problem is identified [11], a specific function of the system that needs to be improved is stated, required parameters are named and the function is generalised.

It is recommended to go back to step 2 and diversify the function by finding analogue formulations for the specific function of the same initial problem. This could be done in two possible ways. One path uses images or sketches of the problem situation to find the leading area and the other path uses terms to carry out this task. The image must represent the key problem and its parameters in a generalised way. With this image a picture search is carried out with suitable internet search engine to find images with analogous content. Using the generalised function to perform an internet or patent database search could lead to problems if the function is very generic, e.g., move solid or stop liquid. In these cases, it is needed to move one step back from the generalised function and try to find specific

terms, for example by looking at important parameters, which represent the function in the best possible way. Thesaurus programs could be applied to find analogous terms, synonyms or even antonyms. The result of this search is added to the results of the image search. The order what to do first it not defined. In [12] the path applying images is described in more details and in [13] the path using terms is outlined. Both papers aim at the individual application of using either one or the other process to directly find possible solutions which could be transferred to the problem situation. The proposed workflow in the current paper aims at combining the two processes and use the results for an additional search with patent database search engines or a combination with additional TRIZ tools like the operator “size, time, cost”.

The search results are analysed by comparing the identified key solution hints to previously defined parameters and constraints.

Possible constraints and associated area could be:

- cost – toys or cheap consumer goods (solutions must be easy to implement, cheap and easy to get materials, short product lifetime)
- reliability – aerospace, medicine (solutions must work to avoid fatal accidents)
- sustainability – recycling industry, nature (solutions with a chance of longer lifetime).

Having found a leading area a deeper search is carried out there to find further solutions with an increased fit the problem. If the first search already yielded good results which lead to solution concepts this step could be skipped.

Figure 1 shows a problem situation, i.e., the prevention of the bending of the rod which is described in [13, pp. 114–115].

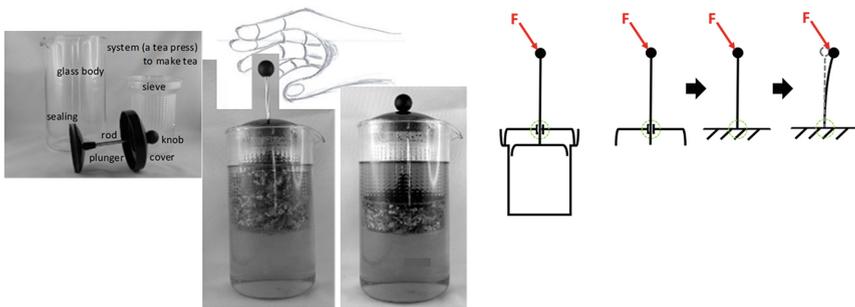


Fig. 1. Problem of a bending rod during the pressing down process of a tea press.

Figure 2 displays the workflow for the search to find a leading area for this problem together with some of the used sketches and terms. Figure 3 shows the general workflow starting from step 4 in Function-Oriented Search and returning to the Function-Oriented Search at step 6 with an identified leading area and first solution ideas.

In case a deeper search is carried out additional sources could be queried like:

- internet (text, pictures, videos, podcasts)
- research databases (Scopus, ResearchGate)

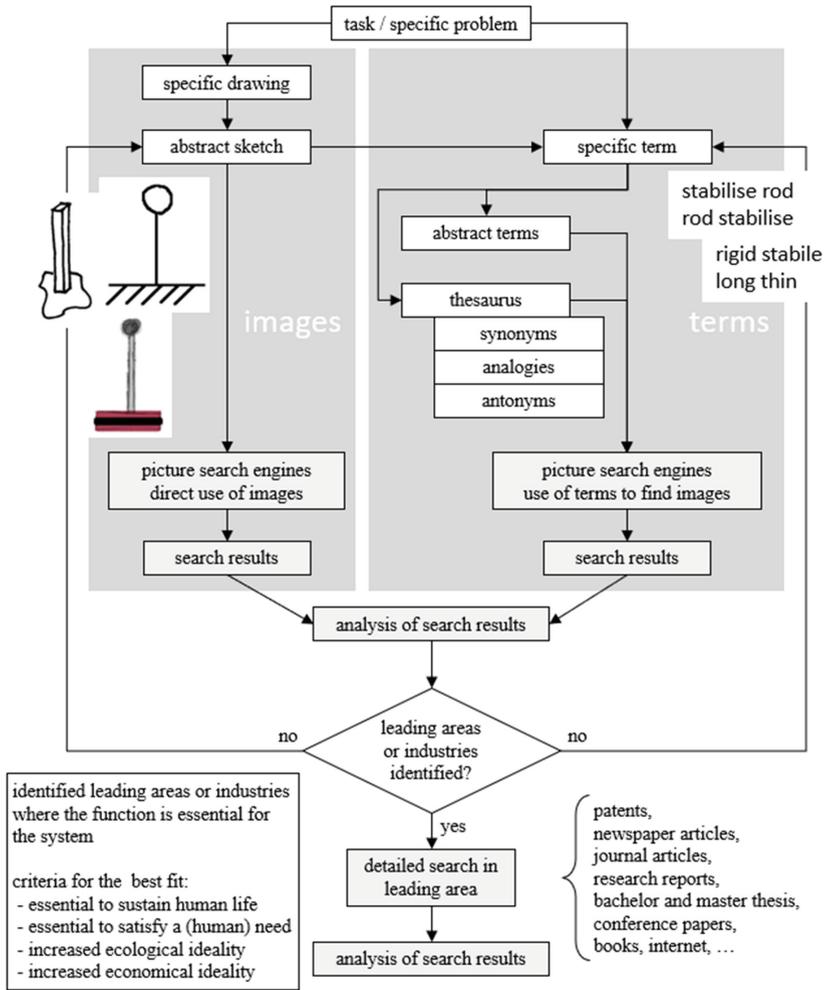


Fig. 2. Proposed workflow to support the search for a leading area of a problem situation.

- literature (books, journals, bachelor and master thesis, dissertations, newspaper articles, ...)
- patent databases.

As mentioned before, the aim is to look for solutions. The easier to implement, the more fitting to present resources of the systems, the greater the analogy to the problem to be solved the better. All the criteria stated usually reduce additional effort to solve secondary problems that could arise during the implementation.

To make the most of the solution Inverse Function-Oriented Search could be carried out. With this TRIZ tool other sectors could be found where the solution might be implemented as well.

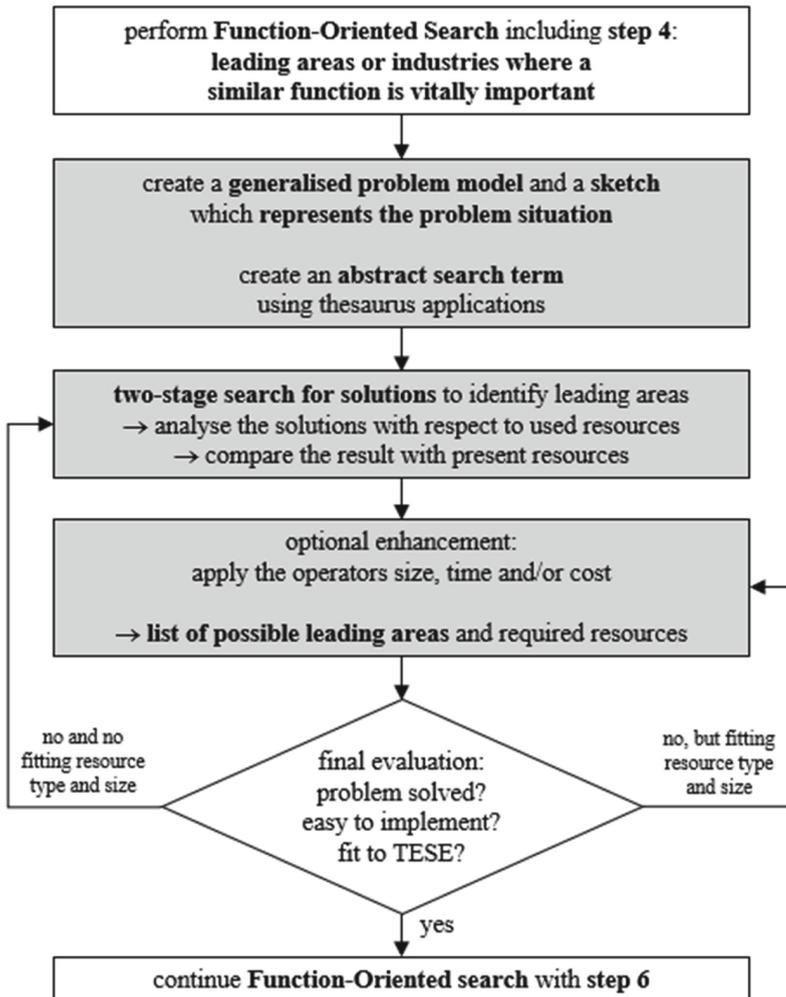


Fig. 3. Outline of the proposed workflow to support (detail) step 5 of FOS

The workflow is tested with the tea press example described in [11]. The results of a text and an image search are taken from [12, 13] and presented below.

The text search yielded (results already analysed, raw data see [12, p. 29]):

- Bing: Tool handle, bone, tube, multi-layered part, higher dimension, syringe
- Gettyimages: Glass tube
- Google: Tool handle, multi-layered part, tube, bone, glass,
- Nyp1: No matching result.
- Picsearch: Tube, glass, support
- Shutterstock: Flask
- TinEye: Search with image input only.
- Yahoo: multi-layered part, bone, higher dimension, syringe, pencil, tool handle

- Yandex: Tube

The image search yielded (results already analysed, raw data see [13, p. 118]):

- Chandelier – use multiple rods in parallel (increase the number of rods while possibly decreasing the diameter of the individual rod)
- Rail for sliding gate, spoon – higher dimension (moving material to a greater diameter and introduction of hollow centre)
- Test tube, lighthouse and tower – moving the material to the outside without changing the mass of the rod (see above)
- Stub, tree – local quality (rigid close to the surface and ductile in the near the centre) (heat treatment)
- Cactus, pop-up stopper, fence top – higher dimension (star shaped cross-section)
- Damper – nested doll (rod with multiple sections, telescope)
- Funnel – higher dimension, hollow (change of outer diameter)
- Buoy – the other way round (could the plunger be pulled with a rope rather than pushed)

Figure 4 shows the solution concept which could be derived from the search result data. The associated area was nature and the design of a cactus. The solution concept seems feasible; therefore, an additional search was omitted.

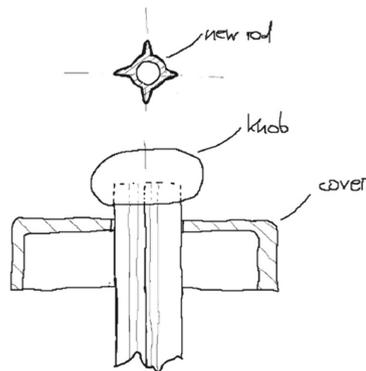


Fig. 4. Solution concept to improve the design of the tea press rod.

For the current conference paper, the search for analogous images was repeated with the search engine that yielded the best results for a previous search. It must be noted that this time the results returned by the browser proved to be very poor. The layout of the result display was completely changed, and the quality of the results was bad (see Fig. 5).

This should not lead to the conclusion that the workflow itself is not suitable. Nevertheless, the comparison of the two searches at different times gives the insight that using free, publicly available tools and present resources one should be aware of the dynamic character of these resources. Something useful and good could be inappropriate some days later or the other way round. The fact that an older search yielded good

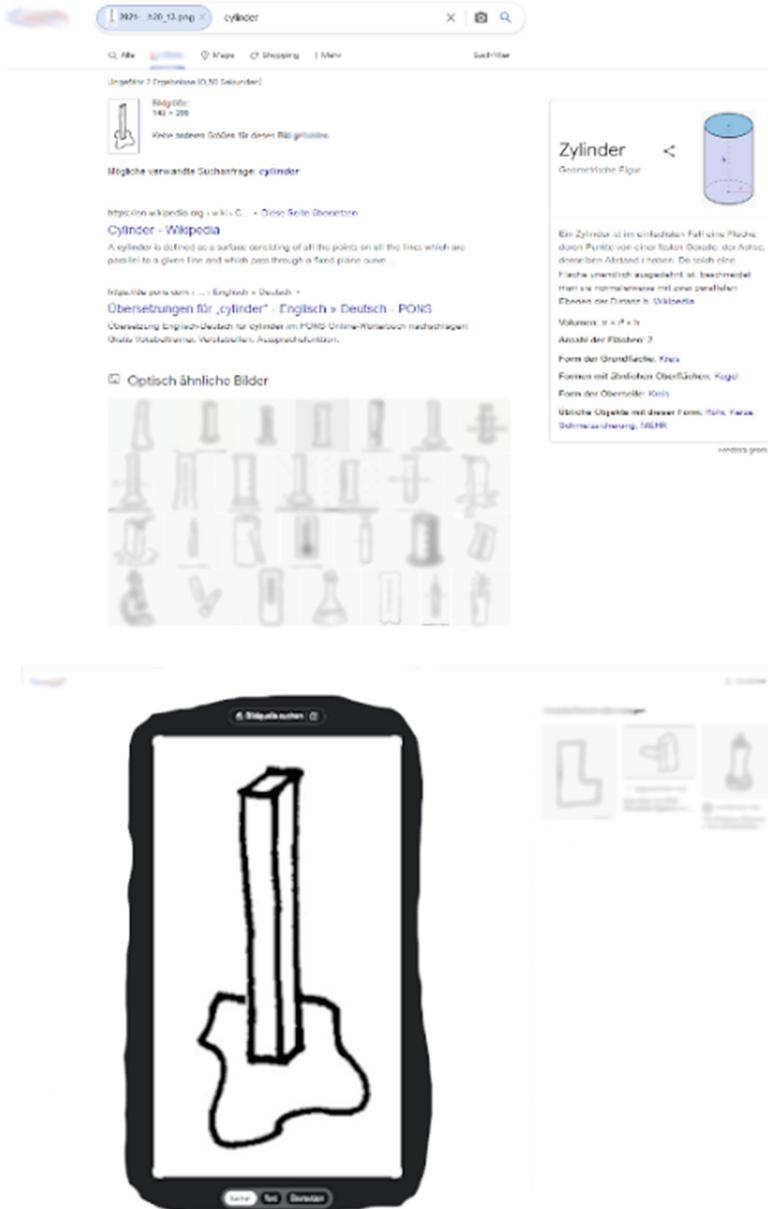


Fig. 5. Comparison of an older internet image search (above) and a new one (below) carried out with the same browser (intentionally blurred to focus on the change in layout and results).

results might lead to the creation of a special, self-developed search tool to increase the control on what happens and focus on certain key features which are deemed important. A question based expert system or AI software would further improve the situation. A trained AI image processing tool combined with a database of carried out searches and their results might lead to a very effective development support tool. Automated search image generation based on photographs or technical drawings seems to be a good help as well. This effort is thought to be sustainable because with good results the software application saves development time and cost, i.e., the reduction of human resources and interaction could create sustainable and quality products and a shorter time.

AI could also support the process of finding a leading area and industry. An automatic classification of the results might provide suggestion, e.g., a large number of test tubes, measuring cylinders or syringes leads to medicine as a leading field. If the focus of the product at hand is reliability this area is of special interest.

The term-based search is suitable for browsing patent databases. The keywords are entered in the search form and various result display options can be chosen. If a leading area has already been identified and the search should be limited to this area the search can be narrowed by specifying associated International Patent Classifications (IPCs) or Cooperative Patent Classification (CPCs), for example A63H for a search in the field of toys.

The application of the operator “size, time and cost” might yield additional analogies. Applying this TRIZ tool the system parameters size, time and cost (for possible improvements) are mentally changed close to zero and close to infinity. The impact on the system is noted to create additional solution ideas and overcome mental inertia. Figure 6 illustrates the procedure for the operator size. The reference size is drawn in the middle and has the rough dimension of a human being. The left-hand image shows an increasing of size to the dimensions of a telecommunication tower. The right-hand picture reduces the size to length of a human finger. Each individual sketch could provoke different associations of possible leading areas, i.e., the building sector if size is drastically increased (towers or pipelines), medical appliances if size is reduced to a great extent (test tubes, syringes, endoscopes) or household products.

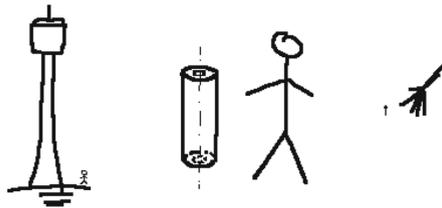


Fig. 6. Application of the operator size for a long, thin and rigid part.

4 Summary and Conclusions

Finding leading areas and industries is currently not supported within Function-Oriented search. The proposed workflow aims at a systematic approach to help finding possible leading areas together with the implementation of existing resources. This increases the sustainability because the amount of used human resources is decreased and the utilisation of present information resources is increased. Thus, the effort within development is improved which increases the efficiency and leads to a greater sustainability. The dynamic character of present information resources implies that one should be prepared for changes of those at any time. The application and value of Function-Oriented Search is simplified, and the level of subjectiveness is reduced.

The proposed workflow was tested with an example. Therefore, it should be substantiated with additional example problems in different fields of industry. Furthermore, during the work a change of the resources were perceived. This could lead to further research if those changes could be predicted. Expert systems and AI could enhance the process by automated analysis of search results or suggestions where to perform additional searches.

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Unified Eco-Innovation Methodology Based on TRIZ and C-K

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Abstract. This article presents a methodological contribution for eco-innovation in order to assist design teams in the development of eco-innovative products. We propose a unified methodology that allow users to self-guide in order to create eco-innovative product concepts through the application of C-K theory combined with the TRIZ method while integrating the principles of the ASIT method. Understanding the links between the different sources of knowledge in relation to the birth of eco-innovative concepts allows us to design one or more generic solutions. A simplified and adapted application of TRIZ will lead us to an eco-innovative solution.

Keywords: Eco-design · Eco-innovation · TRIZ · ASIT · C-K · AI

1 Introduction

Our planet is now facing a degradation of its natural environment, which is mainly due to human activities and the massive production of goods that impact the environment. According to scientists, a warming of 1.8 °C to 2 °C between 1990 and 2050 could lead to the elimination of a quarter of living species [1]. All of our activities emit carbon dioxide. The earth is a living organism that has its own properties. And any living organism, if it does not live in harmony with its own laws of balance and evolution, deteriorates. Also, the planet has a fragile balance, so our current life choices determine the ecological behavior of the planet in the future. Faced with this environmental and societal emergency, it is necessary to rethink our production system as a whole, but also our way of designing and consuming.

Moreover, our modes of production and consumption have also generated numerous social inequalities with strong consequences on human health [2]. By taking up the “all technological” challenge in optimizing energy consumption and combating climate change, our civilization is increasingly resorting to metals that we do not know how to recycle. The depletion of these resources could become a global issue in the same way as the depletion of oil [1]. One of the main industrial responses has been to set up eco-design approaches based on environmental analysis tools such as Life Cycle Analysis (LCA). These tools have made it possible to come up with proposals or avenues for

improvement aimed at redesigning the product by integrating the environmental criterion into the specifications.

However, the tools quickly reached their limit, in particular by their complexity of implementation and by being limited to “technical” solutions [3]. In addition, few tools focus on the generation of ideas with support for parameters related to the user and the designer or the company, as an actor in the implementation of Eco-design [4]. However, design teams need to be more efficient in their process of generating, evaluating and selecting the most promising ideas [5].

Indeed, the evolution of systemic innovation has given rise to guides for simpler eco-design and creativity-innovation tools integrating ideation as well as the user dimension. However, drawing on the most efficient tools, a proposal for a unified eco-innovation methodology based on the TRIZ and C-K (C-K theory is based on the interaction between a Concept space and a Knowledge space) methods remains the main objective of this article.

2 State of the Art

2.1 Eco-Design

Eco-design is defined by the ISO 14062 standard as a global and multi-criteria approach to the environment, which is based on taking into account all stages of the product life cycle. Thus this standard proposes to integrate the environmental criterion from design planning to product design review [6].

Indeed, the designer, being the first consumer, has projected himself into the environment of the product because the main purpose of a product or service is the use made of it by the user. A product must be able to fulfill its initial function in order to find its audience. And the product, which not respect this principle, can be eco-designed but does not have much interest. Also, taking into account the social dimension of the product is the key to sustainable development, because the user refers to society, relationships, behaviors, beliefs, lifestyles. So what determines buying behavior and consumer behavior when in contact with the product of their choice?

Eco-design is then lived every day in a continuous way through small daily gestures. The latter will promote small regular improvements to existing goods encouraging incremental type innovations [7]. However, only an integrated consumer, that is to say one who has knowledge and understanding of the product, can have a global vision of the product as well as of the environment. This eco-consumer has an integral vision of the purchase and after purchase of the product. Because, it would be necessary to be able to take into account the entire product, criteria and design constraints at the same time [8].

To limit the risk of impact transfer, the environmental relevance of ideas must be assessed using a multi-criteria approach throughout the life cycle [5]. Therefore, the product designer is a key player in the operationalization of sustainable development. Indeed, the analysis of the product life cycle product must be able to integrate all these factors in order to have an optimal result.

2.2 Product Life Cycle Analysis (LCA)

LCA deals with environmental aspects and potential environmental impacts throughout the life of a product, from the acquisition of raw materials to its production, use, end-of-life treatment, recycling and disposal rebus (i.e., from the cradle to the grave) [9]. Thus, an LCA approach consists of 3 main stages which are:

- The first step consists of an orientation phase of the study. During this stage, it is requested, for example, to specify and justify the scope of the study, the functional unit of the system, the types of environmental impacts studied and the methods used to obtain them. This step is essential because it makes it possible to justify the entire study by the repercussions it generates.
- The second step corresponds to the inventory of the life cycle. It is above all a question of collecting all the data necessary for the realization of the study. For this, all incoming and outgoing flows (energy, materials, water, etc.) are identified and quantified. This step is often associated with the notion of completeness and representativeness of the data: what is the percentage of considered data? The question to answer at this step is: Are the data representative of reality or are they approximations?
- The third step aims to translate these flows into environmental impacts or damage. This translation is carried out using different calculation methods [6]. For example, evaluating the ton of paper produced in relation to the number of trees and the liters of water used for their production.

Thus, the multi-stage dynamic makes it possible to avoid pollution transfers throughout the chain. It is making a product robust while making the environment robust. Environmental labeling allows manufacturers or distributors to communicate their environmental impacts and offers consumers a new criterion of choice. Therefore, the analysis of all the steps of the product's life cycle must be completed by the quantification of the incoming and outgoing flows of the system studied, in terms of raw materials and energy consumption in particular [3].

Indeed, the designer can therefore determine the behavior of future users and thus influence the evolution of society because it is up to him to design and develop products which are often the subject of specific requests from clients. While knowing that the product supposed to reach the end of its life, continues to live. Only its properties change.

The use of LCA generally responds to strategic concerns on the part of companies. From an environmental point of view, the tool effectively reduces waste at source and the consumption of resources, but in doing so, it contributes to improve the environmental performance of the companies that use it.

However, we note some limitations because the reliability of an LCA depends in particular on the inventory carried out and the reliability of the data collected. This inventory step can be complex and time-consuming.

Moreover, the results obtained are difficult to understand by an untrained group, and are widely subject to interpretation. Indeed, the lack of consensus on the environmental products assessment and a scarcity of global approach can be corrected by having a societal and cultural vision, and an optimal assessment of the user approach in the current practice of Eco-design.

Minimizing impacts often results in degraded performance and/or increased cost. The solution to overcome this problem is to use optimization techniques that are able to find a set of compromises between these conflicting objectives, while guaranteeing the same or better performance [3].

3 Creativity-Innovation Tools (TRIZ, ASIT, C-K, etc.)

Creativity is required to enable the organization to capture and articulate valuable new ideas, while the field of innovation is to capture the benefit of those ideas. To achieve this goal, the innovation process will therefore need creativity, not only to create an initial idea, but also throughout the innovation process to be able to derive the expected benefits [10]. And while designing or inventing may be an individual activity, innovation is a collective achievement [11].

Indeed, teamwork in engineering and design facilitates precision. Whether in the design of megastructures or nanostructures. Design teams must work in synergy to join forces for a common goal. This collaboration, anticipating future risks that may arise in the design process as well as in the product life cycle, promotes creativity and innovation.

Indeed, in order to animate the group of participants, the hybridization of creativity methods is favored to allow us to benefit from the advantages of intuitive methods while structuring the session by more systematic methods [12]. It is in this context that a creativity session is above all a group work in order to lead to creative ideas relating to the problem to be solved, the confrontation between the points of view aiming to make the generation of proposals even more productive [13].

Any innovative design process requires the implementation of a project group. There is a need to step out of the box, or rather existing cognitive frames, to embrace complex thinking, to demonstrate creativity and the ability to challenge and deconstruct mental representations, ideas, thoughts, beliefs, and more. Usually the cognitive processes produced [2].

However, when we go beyond the limiting effects of psychological inertia on a cartography of solutions covering multiple scientific and technological disciplines, we notice that the ideal solution can be found outside the prospective domain of the inventor. It is then ignored or sometimes even invisible [14].

It is also the concrete and natural illustration of the idea that the hand is the indispensable extension of the human brain [15]. Therefore, creativity seems “commonly” inseparable from innovation [16].

However, we can define innovation as a process whose outcome is an original achievement that includes value-creating attributes. It is the original and progressive implementation of a discovery, an invention or simply a concept. An invention, or a new idea for a product or process, that is not commercialized is not an innovation [16]. Also, the inventive approach is based on the ability to develop an idea into an intermediate object. Thus, we can go from an idea to a drawing, from a plan to a prototype. We are talking about the ideation phase upstream of the design phase of a good or service [17].

According to Udo Lindemann, without a detailed understanding of creative processes, there will be no effective creativity techniques to apply in design. Mastering the innovation process therefore requires mastering the design process and the creativity

process [18]. Thus, it is important to combine and hybridize eco-design with innovation and creativity through an approach called: eco-innovation [16]. However, psychological inertia is the main obstacle to individual creativity [14]. It is in this context that the TRIZ method offers tools for unblocking mental passivity in order to promote creativity. However, while stimulating the search for innovative concepts, this method has evolved (ASIT Method). Thus, we will present these methods to arrive at the C-K theory.

3.1 The TRIZ Method

TRIZ is a creativity method whose Russian acronym stands for “Theory for Inventive Problem Solving”. It was developed by the Soviet Guenrich ALTSHELLER [19]. Associates abstract solutions [20]. It is a creative approach that allows us to get out of the random processes of Brainstorming. This method fights against psychological inertia and fixation which are truly major brakes on the imagination. In fact, becoming aware of this fixation will help us step aside. For this reason, TRIZ will allow us to have a critical look and to put our finger on new lines of thought. Based on the analysis of the existing situation, this approach will tell us how to transform it.

The purpose of this method is to rationalize and extend the areas investigated to enable engineers to exploit, as efficiently as possible, the principles of solutions already proven in other innovative applications. The main contribution of TRIZ is therefore to promote creativity applied to the resolution of technical problems. The proposed tools fulfill two distinct functions.

The former makes it possible to model, to abstract the specific problem into a standard problem. Reaching a certain level of abstraction makes it possible to free oneself from the particularities of the problem dealt with and more broadly from the usual way of approaching it specific to a discipline.

The latter are resolution tools and systematically offer standard solutions [16].

Indeed, because contradiction plays a central role in understanding the problem, the development of the TRIZ focuses on a coherent and robust method allowing to extract the contradiction(s) from the problematic situation [21]. Thus, with this type of approach, the main design resource is the designer.

Regarding the limits of TRIZ, some research on the use of this method and the associated tools point to the difficulty of formulating a specific problem into a standard problem expressed in terms specific to TRIZ, but also and above all the difficulty of interpreting the solutions. Generic to adapt them into specific solutions. Indeed, no specific tool is offered to perform this operation, which aims to deduce specific solutions from the proposed standard solutions [16].

Also, many tools are available but little used by companies and the community, due to the level of mastery required at the expert level [4]. However, simplified or more “generic” approaches were proposed in particular in the 1980s by Roni Horowitz, including the ASIT method (Advanced Systematic Inventive Thinking) [22].

3.2 The ASIT Method: From Eco-Design to Eco-Innovation

Looking at different solutions, particularly the most “elegant”, Roni Horowitz noticed that the “solution world” does not introduce any new type of objects compared to the

“problem world”: creative solutions are very close in their “genealogy” to conventional solutions. This constitutes the first condition of the ASIT method, called the “Closed World” condition, and joins certain principles of TRIZ and in particular the notions of ideality and resources. The second condition, that of “qualitative change”, can be explained by the use or cancellation of the cause of the problem [16].

The ASIT method therefore offers only two conditions and five tools that promote creativity. These tools, although inspired by the 40 principles of the TRIZ matrix, are simple to use and not related to engineering problems. Thus, the ASIT method makes it possible to treat all types of problems provided that there is an identified aggravating factor. It is inexpensive in time and its use is relatively simple thanks to its refined formalism. This is why we believe that the ASIT method is efficient in an industrial context, when there is a specific need for creative resolution. It should be noted however that there are two variants of ASIT: “ASIT resolution”, which is the best known version and which is therefore oriented towards problem solving and “ASIT Design” which is oriented towards the generation of new concepts. But which still remains little disseminated mainly by some methodological and theoretical limitations [16].

Indeed, even if the nature of these objects is relatively multifaceted and open in ASIT, because it is possible to use physical objects, of the human actor or organization type, it is important to rework the formulation of the problem, in particular by adapting the size of “problem world” objects, to encourage users to work at high systemic levels. In addition, the need to orient the reflection towards life cycle approaches, but also social and behavioral ones, was previously underlined. But if ASIT does not block these approaches, this tool does not encourage it. It is therefore necessary to encourage users to focus their creative thinking on all the pillars of sustainable development, which are all entry points into eco-innovation [6]. It is also interesting to note that eco-innovation is part of a more global concept of “sustainable innovation”. The latter is defined as a refinement of the concept of eco-design and eco-innovation, because it integrates the social and ethical pole of sustainable development. The concept also encompasses aesthetic considerations related to time, emotional connection and the lifespan of objects. It is therefore a broader approach that aims to make designers accountable by raising awareness of the impacts of their actions [16].

However, eco-innovation should not be analyzed according to the same principles as innovation. It should be considered as exploratory work which aims to express, educate and communicate eco-design and the principles of sustainable development to the various stakeholders [6]. Yet, ASIT encourages solving the problem by using these objects in the state in which they occur at the time of the problem. For example, the “Unification” tool seeks a new use for an existing object. However, the eco-innovation approach requires introducing the notion of the life cycle of these objects and therefore a temporal approach that promotes the construction of new scenarios and the generation of new concepts. This approach involves working on the interdependence between the different stages of the life cycle and on new combinations between the different “states” of these objects. In addition, the analysis of examples of eco-innovation (industrial ecology, the notion of Product-Service System, etc.) shows that many solutions come from relations between the objects of the problem and those of the environment (in the sense of ASIT).

Indeed, the relationships between the different objects of the problem (product, environment, user, etc.) result in changes to the environment and society, hence the importance of designing these relationships. However, a study of ASIT operators does not make it possible to highlight these recombinations, which will lead us to the establishment of an additional mechanism to promote this logic [6].

However, innovation can be defined as the creation of new knowledge which, once incorporated into new products, services, processes or organizations, becomes productive, and whose commercialization generates value [23]. We can therefore wonder, at first, about the benefits of innovation, always very oriented on technical performance, so much so that the public tends to.

3.3 The C–K Theory

In 1996, teaching design theories to students in the Design Engineering option that he had just created with Benoit Weil, Armand Hatchuel proposed a first formulation of what was then called the unified theory of design and which was to become the C-K theory [24] (Fig. 1).

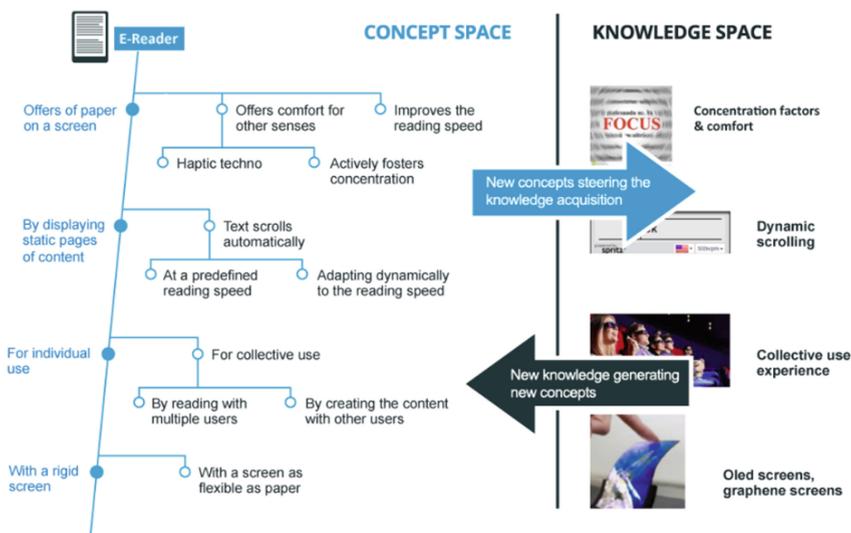


Fig. 1. C-K Model (Source: www.ck-theory.org).

Hatchuel and Weil, the authors of the C-K theory then recommend the comparison of the universe of C (for concept) and that of K (for Knowledge = knowledge) to allow the representation of the richness of the design process, and to account for both the declination of a concept and the production of associated knowledge. Considering design as a co-evolution of knowledge and concepts, as an interaction between a progressive specification of concepts and the creation of knowledge, allows them to take into consideration the notion of “expansion” [16]. Thus, these properties explain our

choice of the C-K theory. These make it possible to obtain an adequate framework for thinking about a design phenomenon that includes creativity and ideation in relation to knowledge generation mechanisms [25].

Also, C-K theory makes it possible to analyze existing methods and processes, revealing and clarifying some implicit assumptions concerning the level of the unknown to which these methods are adapted: assumptions on the knowledge available, on the capacities of the users, on the generative power that can be expected from a method or process. By functioning as an analyzer of the unknown, C-K theory makes it possible to integrate this “unknown” as a new contingency variable in innovation studies [24].

Then, the objective of a design reasoning is to obtain one or more feasible proposals, but also to structure and enrich the knowledge space and to explore the space of concepts [26].

With this new, more generic description, it is ultimately the whole diversity of design forms that is taken into account, including those that are part of a logic of innovation, that is to say those that are not based on a fixed identity of the objects to be designed [16].

Indeed, the first strength of C-K is to model design reasoning in order to see which moments of this reasoning have a chance of producing innovative things. What particularly interests us is that the person skilled in the art finds himself here “included” entirely in the design process modeled by C-K and it then becomes only an allegory of restrictive partition operations based on existing knowledge [25].

4 Methodology: Unified Meta-Model of Eco-Innovation

Researching the approaches that exist to understand them is a good thing. Taking them separately as the tool of choice is no longer relevant. We have reached a phase where the unification of the most efficient creativity-innovation tools is becoming a necessity. In other words, it is no longer enough to have a fragmentary approach, but on the contrary a global approach emanating from a direct vision. The latter allows us to understand that diversity breeds harmony.

Indeed, this unity in diversity is wealth. Its understanding, being the basis of a research-intervention approach which “can be described as a method forming part of the research-action approaches which “claim a double objective of concrete change in the social system and production of knowledge about it [27], allows us to be. A society of being, a real society where it is now a question of shining through its qualities instead of being colonized by its faults.

Thus, the designer is the craftsman, he is in the object, in the design. He is in the work he produced as an artisan. The opposite case is alienation, fragmentation, when in the design process you no longer find yourself at the end, you can be alienated in the process.

In the same vein, Papanek proposes in his book “Design for a Real World” a real manifesto for a design that is responsible and concerned with what he considers to be the authentic needs of humanity: “Recent design has, in general, satisfied with satisfying ephemeral demands and desires, while the genuine needs of man were neglected”. A chapter of this book deals with the role of the designer in the face of environmental

problems. “The designer is primarily concerned”, the author tells us. His training in systems analysis should indeed enable him to make some “inspired conjectures” [27].

For example, the notion of profitability must be redefined and integrated, it is no longer “what brings a benefit” but a real benefit which is the well-being and human health. Also, it is more responsible to adopt fair exchange as an economic model and mother of social justice.

However, the point of view depends on the purpose of the design and the knowledge of the designer. Thus design is the transition from a need to the identification of a concept, oriented by objectives to be achieved and limited by the knowledge available, in order to recognize, in this concept, a solution [28].

Being the user, the responsibility of the consumer is engaged. In other words, the consumer, when making his product choices, must think globally to preserve his own health. He must know when to walk instead of taking a taxi, when to take a bicycle instead of using a polluting means of transport. When you have to take public transport and leave your car. Also, the choice of diet has a great impact, for example choosing chicken meat instead of beef because the exploitation of the latter generates a lot of methane. The carbon tax will also have an effect on the choice of products, and will guide the consumer on his purchasing behavior, an incentive to go in the right direction. Indeed, the transition from consumer to eco-consumer must necessarily go through this transition which is a sign of his awakening. It’s all very well to multiply the performances, but they have to have a meaning. It is to give meaning to progress. Thus, the consumer and the designer become eco-consumer and eco-designer.

However, some more or less obvious links between the various sources of knowledge are not made explicit in the TRIZ literature [29]. Produced during its evolution. The more we advance, the more the product becomes infallible, clean. Thus, understanding the interactions of the product with its environment allows us to position it well on the market.

Then, several sources of knowledge then make it possible to design one or more generic solutions to the problem. It then remains to validate, specialize, this generic solution, called “concept of solution”, in the application field [29]. Indeed, the domain of application is in itself a source of knowledge.

Indeed, non-toxic emissions depend to a large extent on the health of the central, motor entity, which ensures the proper flow of energy in the system. Thus, an efficient, natural and balanced transmission of energy in the system only takes place with the motor health which is intimately linked to the source entity which feeds it. So, the more the system evolves, the more complex it becomes. And this complexity, given the capitalized knowledge, supposes a more intelligent, not to say complex, source of energy. However, if speed most often rhymes with heat, how can we combine speed and coldness? As the speed increases, the system cools proportionally to protect components and ensure reliability. This is how a good distribution of density and weight in a moving vehicle is a source of energy savings.

Indeed, the resolution of design problems requires a very good specific knowledge of the domain in question [30]. In addition, the Laws of Evolution concern the knowledge necessary for the correct formulation of the problem [20]. But this knowledge is not enough. It is necessary, however, to understand the laws of nature because the laws of

evolution of the technical system are in close symmetry with the laws of nature. Then, the birth of concepts is strongly linked to capitalized knowledge that is extensible. The loop, in a spiral, does not stop. As we feed on knowledge, concepts appear.

It is in this context that the C-K theory makes it possible to think about the renewal and regeneration of the initial data of design situations. A double expansion because design leads both to the creation of new knowledge and to the creation of new concepts [24] (Fig. 2).

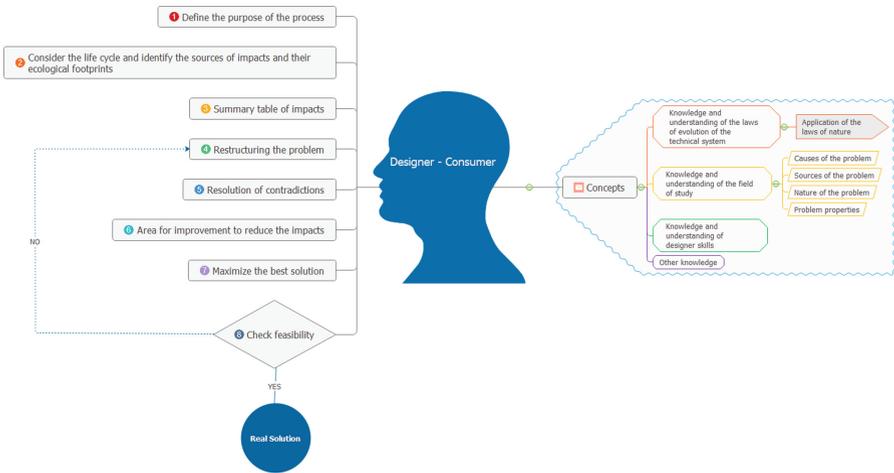


Fig. 2. Unified Meta-model of Eco-innovation.

4.1 Define the Purpose of the Process

Defining the object of the approach means specifying the scope of the study and the functional unit. In other words, if we intend to improve an existing product or eco-design a new product.

4.2 Consider the Life Cycle and Identify the Sources of Impacts and Their Ecological Footprints

It's back to taking inventory. That is to say the collection of all information relating to incoming flows (raw materials used, energy consumed, etc.) and outgoing flows (emissions into the air, soil, water or even the production of recycled).

Indeed, the durability of the product depends on its inner balance relating to the state of its components and the quality of the energy that connects them and ensures its viability. This energy must be purified as it evolves. Indeed, consumer and designer choices inevitably influence future releases. Therefore, the ease of use and the modularity of the product depend on the knowledge and understanding of the designer and become extensible for the consumer who must demand transparency in relation to the processes (from the extraction of raw materials to the end of life of the product).

4.3 Summary Table of Impacts

It is a question of listing, categorizing and classifying the different impacts, putting them in a table (data sources) in order to facilitate its reuse.

4.4 Restructuring the Problem

Since if there is a problem, there is necessarily one or more contradictions. The restructuring phase of the problem consists in analyzing the system as well as its resources in order to formulate the contradictions.

4.5 Resolution of Contradictions (Effects, Principles, Standard)

Instead of focusing on compromises that do not stimulate innovation, TRIZ is interested in the contradictions that appear in the impossibility of uniting the parameters of the system considered incompatible. These contradictions (technical, physical, etc.) are not always visible and can generate innovation:

- Technical discrepancy. It is a type of contradiction where the improvement of a useful characteristic A leads to the degradation of another characteristic, also useful, B (and vice versa). Technical contradictions are resolved using two TRIZ-tools: “the Resolution Matrix” and “the 40 Inventive Principles” [20].
- Physical contradiction. It is a type of contradiction where an element characteristic of a system must present two contradictory values at the same time strong and weak, hard and soft, smooth and rough... Physical contradictions are resolved using other TRIZ tools such as “the 11 Separation Methods” or the “76 Standard Solutions” [20].

4.6 Area for Improvement to Reduce the Impacts

This involves listing the parameters on which the main impacts depend in order to suggest ways of improving them to reduce them.

4.7 Maximize the Best Solution

Here, we choose the solution that is the cleanest, that is to say less impacting and to optimize it.

4.8 Check Feasibility

Finally, it must be checked whether the solution is realistic and acceptable. We must also be able to evaluate it over time. And if it can't be done, there's a problem. And the latter implies contradiction, so we return to the phase of restructuring the problem in order to remedy it.

5 Conclusion

While proving its worth, the appropriation of the TRIZ method has evolved thanks to the contributions of the ASIT method. Thus, the contribution of C-K theory in the generation of knowledge-related concepts influences ideation. Indeed, from these tools, we succeeded in proposing a methodology integrating their principle and approach.

Ultimately, the implementation of this unified meta-model of eco-innovation allows while proving its worth, the appropriation of the TRIZ method has evolved thanks to the contributions of the ASIT method. Thus, the contribution of C-K theory in the generation of knowledge-related concepts influences ideation. Indeed, from these tools, we succeeded in proposing a methodology integrating their principle and approach.

Ultimately, the implementation of this unified meta-model of eco-innovation allows us to lay the groundwork for the integration of artificial intelligence in engineering in order to achieve responsible eco-innovation. AI is set to take an increasing part in business processes, including in the product design phases. In other words, the arrival of AI techniques will make it possible to automate a number of design-related activities and tasks. This, at all stages of the design process. Thus, from the upstream phases of a project, AI can help the designer to formalize the problem and promote innovation by proposing solutions and pointing out any inconsistencies.

Indeed, as an iterative process, AI should be used to make key business processes more productive. Then, the value of a business model lies in the quality of the data it collects, yes, but above all in the way it will be sorted, disseminated and transformed. The role of the designer therefore becomes central.

It also makes it possible to offer designers effective assistance with a view to better integrating the axes of sustainable development. Thus, this approach describes the links and relationships that exist between the different sources of knowledge for the generation of eco-innovative concepts. Thus, allowing us to find solutions without making compromises, the TRIZ method allows us to resolve contradictions in order to find real eco-innovative solutions. So, the ideation and then the generation of concepts in relation to knowledge referring to the C-K theory, thus marrying the principles of the ASIT method, the unification of creativity-innovation tools remains a complex activity where several stakeholders must interact to a common objective: a unified meta-model in the diversity of creativity-innovation tools.

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Classification of Nature-Inspired Inventive Principles for Eco-innovation and Their Assignment to Environmental Problems in Chemical Industry

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Abstract. Eco-innovations in chemical processes should be designed to use raw materials, energy and water as efficiently and economically as possible to avoid the generation of hazardous waste and to conserve raw material reserves. Applying inventive principles identified in natural systems to chemical process design can help avoid secondary problems. However, the selection of nature-inspired principles to improve technological or environmental problems is very time-consuming. In addition, it is necessary to match the strongest principles with the problems to be solved. Therefore, the research paper proposes a classification and assignment of nature-inspired inventive principles to eco-parameters, eco-engineering contradictions and eco-innovation domains, taking into account environmental, technological and economic requirements. This classification will help to identify suitable principles quickly and also to realize rapid innovation. In addition, to validate the proposed classification approach, the study is illustrated with the application of nature-inspired invention principles for the development of a sustainable process design for the extraction of high-purity silicon dioxide from pyrophyllite ores. Finally, the paper defines a future research agenda in the field of nature-inspired eco-engineering in the context of AI-assisted invention and innovation.

Keywords: Eco-inventive Principles · Eco-innovation · Chemical Engineering · Process Design · AI-Aided Innovation

1 Introduction

Climate change caused by greenhouse gas emissions has become a global concern. The scarcity of fossil resources remains an unsolved problem. If no action is taken, economic growth accompanied by high material and energy consumption will lead to environmental degradation. The chemical industry, the source of our material well-being and most of the products we use every day, has a leading role to play in addressing these challenges. Improving and intensifying existing processes towards more efficient and sustainable production is a top priority today. Eco-innovation is needed to transform

and shape the future of today's chemical industry and enable sustainable development. Sustainability-driven innovation (SDI) is often an integral part of a company's vision and overall strategy for long-term success [1]. From a sustainability perspective, chemical processes should be designed to use raw materials, energy and water as efficiently and sparingly as possible to avoid the generation of hazardous waste and to conserve raw material reserves [2].

Instead of imposing our industrial system on nature, let nature influence our industrial and innovation system. Lessons from nature have the potential to lead the way to sustainability. Moreover, ecosystems, including a wide variety of species, have already solved complex problems similar to those we face today. Not surprisingly, many of the technologies we rely on today are inspired by solutions found in nature. Nature has always been an inspiration for innovation, bringing different scientific approaches to design. Nature-inspired innovation (NII) approaches [3], such as biomimicry [4], biomimetics [5], cradle-to-cradle design [6] and industrial ecology [7], are those SDI methodologies that specifically use ecological systems as a guiding framework. The concept of biomimicry, popularized by Benyus [4], is an innovative approach based on the inspiration, learning, and imitation strategies found in nature to solve human design challenges to create a healthier, greener, and more sustainable future. Another popular methodology that adapts nature-inspired solutions to chemical processes is Nature-Inspired Chemical Engineering (NICE). Coppens and co-workers [2, 8] developed the NICE methodology to solve chemical engineering problems based on nature-inspired fundamental mechanisms. Unlike biomimicry, NICE uses nature as a guide for innovation, but does not imitate nature. However, finding the most appropriate bioresources to solve engineering problems is still a major limitation due to the lack of proper guidance for engineers to conduct biological research.

Similar to the NICE methodology, the implementation of eco-inventive principles identified in natural systems for process intensification in our recent studies [9–11] can improve the environmental problems of current technology. It has also been shown that working with nature leads to sustainable solutions with lower secondary environmental impacts. However, finding the most appropriate nature-inspired principles and adapting them to the problem to be solved can be very time-consuming. Furthermore, misapplication of these principles to the problems to be solved can lead to further negative side effects and secondary problems, resulting in engineering contradictions [12, 13], as shown in Fig. 1.

According to VDI 4521 [14], an engineering contradiction can be defined as a situation where the improvement of one parameter in a system implies the deterioration of another parameter. In the context of eco-innovation, two types of eco-engineering contradictions can be defined - primary and secondary contradictions [9]. A primary eco-engineering contradiction occurs when improvements in non-ecological engineering parameters (e.g. process yield) lead to a deterioration of environmental properties (e.g. water pollution) or vice versa. A secondary eco-engineering contradiction is a situation where an improvement in one ecological parameter (e.g. air pollution) causes a deterioration in another (e.g. water pollution). Therefore, the study proposes a classification and assignment of nature-inspired inventive principles to eco-parameters, eco-engineering

contradictions, and eco-innovation domains, taking into account environmental, technological, and economic requirements. The classification method summarizes and evaluates the recent studies of the authors [9–11] on the further development of nature-inspired principles for eco-innovation.

Based on the experimental results of intensification of chemical processes the method analyzes and compares the abstract innovation principles extracted from biological solutions in bio-inspired designs and natural ecosystems. This classification will help to identify suitable principles quickly and also to realize rapid innovation. In addition, to validate the proposed classification approach, the study is illustrated with the application of nature-inspired invention principles for the development of a sustainable process design for the extraction of high-purity silicon dioxide from pyrophyllite ores.

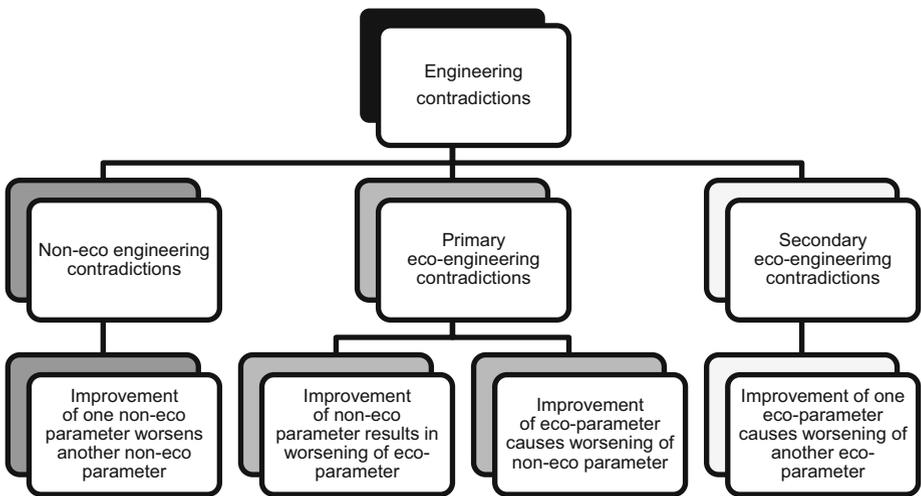


Fig. 1. Types of engineering contradictions [12].

2 Classification of Nature-Inspired Inventive Principles

Our recent studies on learning eco-innovation from nature [9–11] identified eco-inventive principles in natural systems for solving eco-engineering contradictions, as shown in Table 1. The identification of natural principles was carried out by combining different complementary approaches: first, by identifying the abstract natural solution principles in the existing bio-inspired eco-friendly technologies, for example in the AskNature database of the Biomimicry Institute [15]. Second, it was done by using problem-driven bio-inspired design approach, searching for biological solutions to existing environmental problems using various algorithms such as Function-Oriented Search for bio-inspired design [16] or the Unified Problem-Driven Process of Biomimetics [17]. Finally, it was carried out based on the modified solution-driven bio-inspired design approach proposed

Table 1. Nature-inspired inventive principles for eco-innovation [11].

Natural eco-inventive principle		Corresponding TRIZ inventive principle	
1.	Use in parallel different technologies or processes, for example to block harmful effect	5.	Combining
2.	Simultaneous absorption of substances from gas and fluid	5. 29.	Combining Pneumatic or hydraulic constructions
3.	Use different sides or parts of an object for (competing) operations	3.	Local quality, Separation in space
4.	Use natural materials	25.	Self-service / Use of resources
5.	Utilize waste resources	25.	Self-service / Use of resources
6.	Use microorganisms	25.	Self-service / Use of resources
7.	Attract and use bio-resources	25.	Self-service / Use of resources
8.	Apply biodegradable waste to remove harmful substances	25. 22.	Self-service / Use of resource Converting harm into benefit
9.	Isolate sensitive processes from hostile environment	3.	Local quality, Separation in time and space
10.	Use non-regular 3D reinforcement structures	4. 17.	Asymmetry Shift to another dimension
11.	Dynamic equilibrium [19] and force balancing [1]	15.	Dynamism and adaptability
12.	Dynamic self-organization and self-adaptability [2]	15. 25.	Dynamism and adaptability; Self-service
13.	Performing critical process phase in advance (under more favourable conditions)	10.	Prior useful action
14.	Accumulation of energy or substances in advance,	10.	Prior useful action
15.	Energy harvesting and micro-harvesting	25.	Self-service / Use of resources

(continued)

Table 1. (continued)

Natural eco-inventive principle		Corresponding TRIZ inventive principle	
16.	Substance or material harvesting	25.	Self-service / Use of resources
17.	Use of chemically diverse multi-structure	40.	Composite materials
18.	Use a variety of alternative resources: rapid, flexible, and reversible resources management	25.	Self-service / Use of resources
19.	Use the same system to collect and store substance or energy	6.	Universality
20.	Use large surface with short distance to desirable substance or object	3.	Local quality

by the authors [9], which includes the identification and extraction of biological solutions in the ecosystem existing in unfavorable environment or under temporary environmental stress.

As shown in Table 1, a comparison of the identified natural eco-inventive principles with the classical inventive principles from the theory of inventive problem solving TRIZ [18] outlines that some natural eco-inventive principles provide a more specific suggestion on how to design sustainable products or processes [11]. Based on the experimental results of the author's previous studies [9–11], these identified natural principles can be classified and assigned to eco-parameters, eco-engineering contradictions, and eco-innovation domains.

2.1 Nature-Inspired Inventive Principles for Eco-Parameters

Table 2 summarizes the recommended applied nature-inspired inventive principles for 13 key eco-parameters obtained from the analysis of bio-inspired eco-design solutions from the biomimetic AskNature database [15] and the experimental results of case studies solving environmental problems in the chemical industry [10, 11]. These principles provide solutions with high ecological feasibility (eco-feasibility), combining a high degree of fulfillment of the required ecological improvements with low to very low negative secondary ecological impacts and their minimal necessary mitigation.

The recommended nature-inspired inventive principles listed in Table 2 can be used in process intensification independently or in combination other nature-inspired inventive principles in response to eco-innovation needs.

Table 2. Recommended nature-inspired inventive principles with high eco-feasibility.

Eco-parameters	Nature-inspired inventive principles	
• Energy consumption	1.	Use in parallel different technologies, for example to block harmful effect
	5.	Utilize waste resources
	7.	Attract and use bio-resources
	14.	Accumulation of energy or substances in advance
	15.	Energy harvesting and micro-harvesting
	18.	Use a variety of resources: rapid, flexible, and reversible resources management
	19.	Use the same system to collect and store substance or energy
• Air pollution	2.	Simultaneous absorption of substances from gas/fluid
	4.	Use natural materials
	5.	Utilize waste resources
	7.	Attract and use bio-resources
	8.	Apply biodegradable waste to remove harmful substances
• Acidification	2.	Simultaneous absorption of substances from gas/fluid
	5.	Utilize waste resources
	8.	Apply biodegradable waste to remove harmful substances
• Safety risks	1.	Use in parallel different technologies, for example to block harmful effect
	2.	Simultaneous absorption of substances from gas/fluid
	13.	Performing critical process phase in advance (under more favorable conditions)
• Chemical waste disposal	4.	Use natural materials
	5.	Utilize waste resources
	6.	Use microorganisms
	7.	Attract and use bio-resources
• Depletion of abiotic resources	3.	Use different sides or parts of an object for (competing) operations
	5.	Utilize waste resources
	6.	Use microorganisms
• Toxicity	2.	Simultaneous absorption of substances from gas/fluid
	4.	Use natural materials
	5.	Utilize waste resources
	6.	Use microorganisms
	7.	Attract and use bio-resources
	9.	Isolate sensitive processes from hostile environment

(continued)

Table 2. (continued)

Eco-parameters	Nature-inspired inventive principles	
• Eutrophication	5.	Utilize waste resources
	8.	Apply biodegradable waste to remove harmful substances
	13.	Performing critical process phase in advance (under more favorable conditions)
• Photochemical oxidation	2.	Simultaneous absorption of substances from gas/fluid
	4.	Use natural materials
	6.	Use microorganisms
	7.	Attract and use bio-resources
• Ozone layer depletion	2.	Simultaneous absorption of substances from gas/fluid
	4.	Use natural materials
	6.	Use microorganisms
	7.	Attract and use bio-resources
• Water pollution	2.	Simultaneous absorption of substances from gas/fluid
	4.	Use natural materials
	5.	Utilize waste resources
	6.	Use microorganisms
	7.	Attract and use bio-resources
	20.	Use large surface with short distance to desirable substance or object
• Raw material intensity	4.	Use natural materials
	6.	Use microorganisms
	16.	Use large surface with short distance to desirable substance or object
• Solid waste	5.	Utilize waste resources
	8.	Apply biodegradable waste to remove harmful substances
	16.	Substance or material harvesting

2.2 Nature-Inspired Inventive Principles for Eco-Engineering Contradictions

The 13×13 correlation matrix of eco-parameters, conceptualized in our recent work [11], represents interactions between 13 key eco-parameters and contains the most relevant combinations of natural eco-inventive principles to solve primary and secondary eco-problems in chemical and process engineering. This matrix can be used to determine which combinations of nature-inspired inventive principles address the relevant environmental problems. Table 3 shows examples of such recommended combinations of nature-inspired inventive principles for eco-engineering contradictions. The evaluation of the correlation matrix focuses on those inventive principles that not only address environmental problems, but also avoid or minimize secondary environmental and technological problems.

As can be seen in Table 3, there are several combinations of four nature-inspired invention principles proposed for the solution of the primary eco-contradictions. These

combinations can improve at least 2 ecological parameters without worsening the non-ecological engineering parameters or causing technical problems. Regarding the secondary eco-contradictions, Table 3 suggests several combinations of three inventive principles. These combinations will help to fulfill at least 2 ecological requirements without creating other secondary environmental problems.

Table 3. Recommended combinations of nature-inspired principles for eco-contradictions.

Eco-engineering contradictions	Combinations of nature-inspired inventive principles
<ul style="list-style-type: none"> • Primary eco-contradictions: Improvement of eco-parameters leads to deterioration of technical non-eco-parameters, or vice versa 	<ul style="list-style-type: none"> • 2. Simultaneous absorption of substances from gas and fluid; 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 5. Utilize waste resources • 2. Simultaneous absorption of substances from gas and fluid; 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 6. Use microorganisms • 2. Simultaneous absorption of substances from gas and fluid; 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 7. Attract and use bio-resources • 2. Simultaneous absorption of substances from gas and fluid; 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 9. Isolate sensitive processes from hostile environment • 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 5. Utilize waste resources; 11. Dynamic equilibrium and force balancing • 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 5. Utilize waste resources; 12. Dynamic self-organization and self-adaptability • 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials; 5. Utilize waste resources; 18. Use a variety of resources: rapid, flexible, and reversible resources management • 4. Use natural materials; 5. Utilize waste resources; 11. Dynamic equilibrium and force balancing; 12. Dynamic self-organization and self-adaptability • 4. Use natural materials; 5. Utilize waste resources; 11. Dynamic equilibrium and force balancing; 18. Use a variety of resources: rapid, flexible, and reversible resources management
<ul style="list-style-type: none"> • Secondary eco-contradictions: Improvement of one eco-parameter leads to deterioration of another eco-parameter 	<ul style="list-style-type: none"> • 1. Use in parallel different technologies, for example to block harmful effect; 4. Use natural materials; 5. Utilize waste • 1. Use in parallel different technologies, for example to block harmful effect; 4. Use natural materials; 6. Use microorganisms • 2. Simultaneous absorption of substances from gas and fluid; 3. Use different sides or parts of an object for (competing) operations; 4. Use natural materials • 2. Simultaneous absorption of substances from gas and fluid; 4. Use natural materials; 5. Utilize waste resources • 2. Simultaneous absorption of substances from gas and fluid; 4. Use natural materials; 6. Use microorganisms • 4. Use natural materials; 5. Utilize waste resources; 6. Use microorganisms

2.3 Nature-Inspired Inventive Principles for Eco-innovation Domains

Table 4 provides recommended sets of natural principles for three general eco-innovation domains, such as Environment, Technology and Economy. This assignment has been done using a modified solution-oriented bioinspired design approach [9] by identifying and selecting biological solutions that are primarily applicable to address environmental, technical, and economic requirements. Although all 20 principles presented in Table 1 can solve environmental problems, in this section the authors empirically rank the principles that are best suited to solve problems from a technical and economic perspective.

Table 4. Recommended sets of nature-inspired inventive principles for eco-innovation domains under consideration of environmental, technological, and economic requirements.

Eco-innovation domain	Nature-inspired inventive principles
<ul style="list-style-type: none"> • Environment (environmental requirements consideration) 	<ol style="list-style-type: none"> 2. Simultaneous absorption of substances from gas / fluid 4. Use natural materials 5. Utilize waste resources 6. Use microorganisms 7. Attract and use bio-resources 8. Apply biodegradable waste to remove harmful substances 13. Performing critical process phase in advance 14. Accumulation of energy or substances in advance
<ul style="list-style-type: none"> • Technology (technological requirements consideration) 	<ol style="list-style-type: none"> 1. Use in parallel different technologies, for example to block harmful effect 2. Simultaneous absorption of substances from gas/fluid 3. Use different sides or parts of an object for (competing) operations 9. Isolate sensitive processes from hostile environment 10. Use non-regular 3D reinforcement structures 11. Dynamic equilibrium and force balancing 12. Dynamic self-organization and self-adaptability 15. Energy harvesting and micro-harvesting 16. Substance or material harvesting 17. Use of chemically diverse multi-structure 18. Use a variety of resources: rapid, flexible, and reversible resources management 19. Use the same system to collect and store substance or energy 20. Use large surface with short distance to desirable substance or object
<ul style="list-style-type: none"> • Economy (economic requirements consideration) 	<ol style="list-style-type: none"> 1. Use in parallel different technologies, for example to block harmful effect 4. Use natural materials 5. Utilize waste resources 6. Use microorganisms 8. Apply biodegradable waste to remove harmful substances 10. Use non-regular 3D reinforcement structures 11. Dynamic equilibrium and force balancing 12. Dynamic self-organization and self-adaptability 18. Use a variety of resources: rapid, flexible, and reversible resources management 19. Use the same system to collect and store substance or energy 20. Use large surface with short distance to desirable substance or object

3 A Case Study – Assignment of Nature-Inspired Inventive Principles to Environmental Problems in Chemical Industry

A case study of process intensification in the chemical process industry is presented to illustrate the viability of the proposed classification of nature-inspired inventive principles. The case study was conducted to improve environmental issues in chemical processes that recover high-purity nano silica powder from pyrophyllite ores. Nano silica powder also known as silicon dioxide (SiO_2) is used in many industrial applications such as cement production, ceramics, chromatography, catalytic applications, and wastewater treatment [20]. Nano silica is produced by various methods such as the sol-gel method [21] and the precipitation method [22]. These processes use high-purity chemicals to obtain high-purity silicon dioxide. The main problems of these synthetic methods are the use of hazardous chemicals and high synthesis temperatures, which subsequently consume large amounts of energy. In addition, there is often a primary environmental contradiction in dealing with this problem. For example, trying to minimize the problem of high energy consumption tends to reduce product quality.

In this case, the classification of the 20 principles presented in Tables 2, 3 and 4 can help the engineer to efficiently determine the most appropriate solution to the contradiction in the existing process technology. To do this, the engineers need to know which ecological issues need to be addressed. The problem analysis and selection of appropriate nature-inspired inventive principles in this case study was carried out based on a modified problem-driven bio-inspired design process, as shown in Table 5. The proposed classification of inventive principles has shortened the time to find an eco-design solution with low technological and ecological negative secondary impacts. In addition, the design, optimization, and implementation of a novel, environmentally friendly process for recovering high-purity nano silica powder from pyrophyllite ores and achieving maximum efficiency at minimum cost can be carried out using the Advanced Innovation Design Approach (AIDA) for process engineering [23], a holistic innovation method that also applies analytical and problem-solving tools from the theory of inventive problem solving, TRIZ.

Table 6 shows the experimental results of the implemented nature-inspired inventive principles for the production of high-purity nano silica. It can be seen that the recommended combination of the inventive principles from Table 3 resulted in very low negative ecological impact (no impact mitigation was required). In addition, as shown in Fig. 2, the use of hazardous chemicals such as HCl to extract SiO_2 from pyrophyllite can be improved by applying the inventive principle (#4) *Use natural materials*. In this experiment, the authors used NaOH instead of HCl, a more environmentally friendly material. The authors also applied the inventive principle (#5) *Utilize waste resources* by reusing the remaining NaOH solution from the extraction process to reduce chemical waste. Furthermore, the high energy consumption due to the use of high temperatures in the prior process can be overcome by applying the inventive principle (#11) *Dynamic equilibrium and force balancing* by performing the extraction process at room temperature without heating. In order to achieve the same high product quality as before, one can also apply the inventive principle (#18) *Use a variety of resources: rapid, flexible, and reversible resources management* by adding mixing at a certain speed. Thus, the combination of these 4 nature-inspired inventive principles (#4, #5, #11, #18) can solve two

Table 5. Modified problem-driven bio-inspired design process with recommended analytical and problem-solving tools and methods.

Phase	Description	Tools
I. Problem analysis	<ul style="list-style-type: none"> Analysis of the eco problems and identification of primary and secondary eco-contradictions 	Function analysis & process mapping [23], Root conflict analysis RCA+
	<ul style="list-style-type: none"> Translation into environmental impact categories 	Correlation matrix of ecological requirements [11, 24]
II. Selection and application of relevant nature-inspired inventive principles and complimentary tools	<ul style="list-style-type: none"> Search for engineering domains and problems for application of natural inventive principles 	Correlation matrix of ecological requirements [11, 24];
	<ul style="list-style-type: none"> Creative and systematic idea generation 	Classification of nature-inspired inventive principles; Elementary TRIZ principles for eco-innovation [24]
	<ul style="list-style-type: none"> Creation and optimization eco-innovation concepts 	Advanced Innovation Design Approach (AIDA) concept design and optimization method [23], Process Intensification innovation strategies [25]

Table 6. Results of applying nature-inspired inventive principles for silica recovery.

Critical eco-parameters	Applied nature-inspired inventive principles	Experimental realization	Experimental results
<ul style="list-style-type: none"> - Chemical waste disposal - Energy consumption 	#4 Use natural materials #5 Utilize waste resources #11 Dynamic balance #18 Use a variety of resources	<ul style="list-style-type: none"> - Use organic material instead of hazardous chemicals - Reuse chemical waste - Use low temperature - Replace heating with rapid mixing 	Very low negative ecological impact (no eco-impact mitigation required)

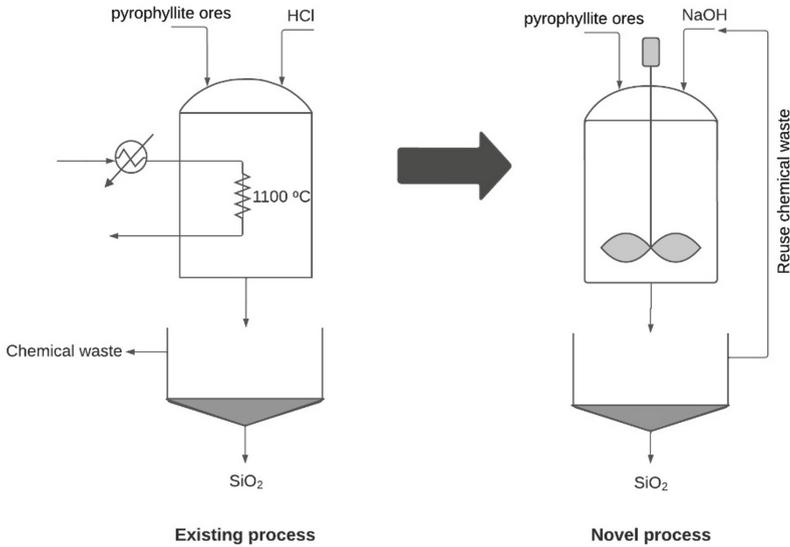


Fig. 2. Illustration of SiO₂ extraction from pyrophyllite ores in prior and novel processes.

ecological problems (*chemical waste disposal* and *energy consumption*) without creating new secondary problems. In addition, as shown in Tables 2 and 4, the combination of these 4 principles will also help to overcome other ecological and technological problems such as toxicity, water pollution, depletion of abiotic resources and high production costs.

4 Concluding Remarks and Outlook Towards AI-Aided Eco-innovation

Nature-inspired Eco-Innovation is a hypothesis-driven approach since natural systems show a lower environmental impact than human-made products or technologies. The evolution of natural systems and their ancestry dates back millions of years. The basis of the study is to understand the natural systems and their abstract problem-solving mechanisms, nature-inspired designs, evolution of flora and fauna, living in complex and extreme environments, and more. The research aims to extract innovative characteristics from natural systems evolved, in a way that natural system takes care of their eco-problems without secondary impacts. The major steps involved in the development of the natural eco-inventive operators comprise identification of natural biological systems evolving in hostile environment, analysis of the natural strategies, extraction of abstract natural solution principles, and reframing natural/biological solution principles in universally applicable engineering terms.

In this paper, the authors have for the first time combined and presented their previous separate publications within the framework of nature-inspired eco-innovation. While the implementation of inventive principles identified in natural systems allows

avoiding secondary problems in chemical process design, finding the most appropriate nature-inspired principles and adapting them to the problem to be solved can be very time-consuming. Therefore, the study proposes a classification of nature-inspired inventive principles according to eco-parameters, eco-engineering contradictions and eco-innovation domains.

The classification method summarizes and evaluates the authors' recent studies on the evolution of nature-inspired inventive principles for eco-innovation and shows that different principles can be used in different settings to address both environmental and technological problems. Furthermore, the strongest inventive principles can be used repeatedly to solve different eco-problems. The feasibility and advantages of the proposed method for classification and selection of inventive principles have been demonstrated by a case study in the chemical process industry dealing with the recovery of high-purity nano silica powder from pyrophyllite ores. In the experiments, the novel environmentally friendly process based on the combination of four nature-inspired invention principles demonstrated high output product quality with very low negative secondary environmental impact.

The research on nature-inspired eco-innovation continues. While only 20 nature-inspired inventive principles are presented in this paper, the preliminary evaluation of the new studies conducted at the Offenburg University helped to identify up to 100 nature-inspired inventive principles and sub-principles. For this purpose, more than 50 biological systems and 50 eco-innovative engineering solutions based on biological prototypes were analyzed in a very time-consuming manner. Further empirical analysis aims at building an application ontology for sharing and reusing eco-innovation knowledge.

The increasing diffusion of rapidly evolving AI technologies is an emerging interdisciplinary research area that aims to transform innovation research, design, application and assessment of systematic approaches to invention and innovation in general and eco-innovation in particular. For example, the Generative Pre-trained Transformers can significantly increase the productivity of problem analysis or automated ideation by processing a larger number of applied inventive principles, as confirmed by the authors' first experiments. Therefore, the authors suggest that innovation researchers, engineers and engineering educators should consider incorporating AI technologies into their professional activities to improve their performance in developing and applying interdisciplinary tools for systematic eco-innovation and inventive problem solving. In the context of the presented research, AI technologies can accelerate ontology building, identify, and structure nature-inspired inventive principles faster, and refine and strengthen the proposed classification recommendations or correlation matrix.

The new nature-inspired invention principles, as well as the proposed methods of their targeted selection and application, can help practitioners solve complex interdisciplinary problems and eco-engineering contradictions. Thus, engineers can efficiently and effectively predict the solutions for eco-innovation by focusing on more appropriate principles that can be applied to a given problem. The results will also contribute to the enrichment of the TRIZ body of knowledge with complementary bio-inspired approaches for systematic eco-innovation.

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Integrating TRIZ and MCDM for Innovative and Sustainable Decision-Making: A Case Study in the Life Cycle of Olive Oil

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Abstract. The combination of the Theory of Inventive Problem Solving (TRIZ) and Multi-criteria decision-making methods (MCDM) has the ability to support decision-making and make innovative solutions in different fields. One such field is the production of olive oil, which has a complex life cycle involving multiple phases. This study involved the evaluation and selection of different scenarios for improving the sustainability of olive oil production, using multiple criteria such as environmental impact, cost, and social acceptance. Then TRIZ approach was used to identify innovative solutions that meet the criteria and offer additional benefits such as reduced waste generation and increased efficiency. The results of the case study demonstrate the effectiveness of the integrated TRIZ-MCDM approach in generating innovative solutions that meet multiple criteria and address conflicting objectives in the life cycle of olive oil. The approach enabled decision-makers to identify solutions that not only met the criteria but also provided additional benefits such as reduce water consumption, reduce greenhouse gas emissions, and increase social acceptance.

Keywords: TRIZ · MCDM · Olive Oil · Life Cycle · Inventive Scenario

1 Introduction

Innovative design approaches are essential for achieving sustainability goals, as they can help reduce resource consumption, minimize waste and emissions, and promote equitable and ethical practices. In agriculture, sustainable design practices are particularly critical, as this sector is one of the largest contributors to global greenhouse gas emissions and other environmental problems [1]. That's why sustainable design approaches in agriculture can help improve the efficiency and effectiveness of farming practices, reduce the negative impacts of agriculture on the environment, and promote more sustainable and equitable food systems. There is a growing need for tools and frameworks that can support sustainable design in agriculture, such as life-cycle assessment, eco-design, and biomimicry [2].

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These tools can help designers and farmers identify opportunities for improvement, assess the environmental and social impacts of their design choices, and optimize their designs for sustainability [3]. By embracing innovative design approaches and leveraging the power of design thinking, we can create more sustainable and resilient agricultural life cycle that can meet the needs of the present generation without decrease the ability of future generations to meet their own requirements [2]. However, by combining MCDM with inventive design thinking, designers and farmers can identify both incremental improvements and inventive solution that lead to more sustainable and resilient agricultural practices.

2 Literature Review

According to TRIZ, any problem that designers encounter may have already been resolved by other designers, and the fundamental idea of TRIZ is to provide access to a wide range of solutions proposed by former inventors [4, 5]. This theory provides tools and techniques that help designers develop new ideas without numerous trials and errors. To solve a problem within this theory, the problem-solver must transform the real problem into a conceptual one and search for abstract solutions, which helps to diverge thinking and generate practical solutions [6].

In recent years, TRIZ has been increasingly used in sustainability-related contexts to develop more environmentally friendly products, processes, and systems [7]. TRIZ's ability to identify contradictions and resolve them creatively makes it a powerful tool for sustainable innovation. This tool has been used to reduce waste, energy consumption, and material use, as well as to extend product life and optimize resource use. Several studies have investigated the use of TRIZ in eco-design, and they have found it to be effective in identifying more focused and conscious solutions compared to traditional approaches [7].

Designers face the critical demand for sustainability, which has been emphasized by legal standards, regulations, and the growing environmental consciousness of consumers. To address this challenge, several techniques have been developed to assist designers in evaluating the product's life cycle and providing recommendations for designing sustainably. TRIZ methodology, in particular, offers concepts and tools that can be employed to evaluate and innovate a technical system that meets sustainability requirements. A recent study [2] explores the potential of TRIZ in ecological design by reorganizing TRIZ tools, such as Ideality, Resources, and the Laws of technical systems evolution, as eco-design guidelines for product innovation. These guidelines were tested on household appliances, and their effectiveness was evaluated by proposing them to experts without any prior experience in TRIZ. The positive outcomes of the study have encouraged the authors to further develop this method [3].

Based on the literature reviewed, it can be concluded that TRIZ is a powerful methodology that has proven to be effective in addressing sustainability challenges by fostering innovative and sustainable solutions. However, there is a need to combine TRIZ with other tools and techniques to enhance its potential and achieve greater sustainability outcomes.

MCDM is one such approach that can complement TRIZ by providing a structured decision-making process that considers multiple contradicted criteria, including economic, social, and environmental factors.

Combining TRIZ and MCDM can potentially lead to more sustainable solutions that consider a broader range of factors and stakeholders. Therefore, this research based mainly on the integration of TRIZ and MCDA, this can be valuable for advancing sustainability efforts in various domains.

3 Proposed Methodology

The methodology proposed in this study aims to provide a sustainable and innovative life cycle for products by defining the problem area and providing a step-by-step guide to finding a sustainable solution, (Fig. 1).

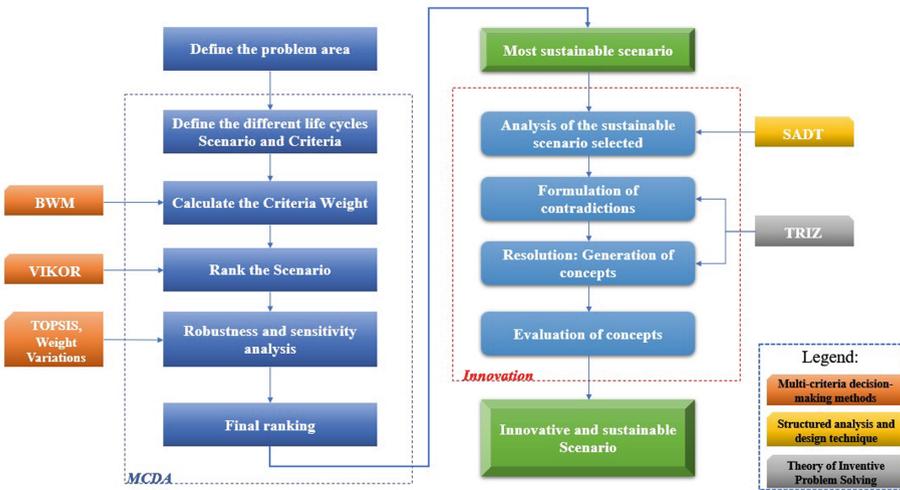


Fig. 1. Methodological framework.

The methodology consists different steps that will be explained in detail below:

- **Step 1:** The objective of this step is to define the problem area. This involves identifying the specific problem that needs to be addressed. For example, the problem could be reducing the environmental impact of a product or improving its durability.
- **Step 2:** The objective of this step is to define the different life cycles of the product that needs to be studied, and criteria to construct decision matrix. The life cycles could include manufacturing, transportation, use and disposal. Criteria to construct the decision matrix can include factors such as environmental impact, cost and usability. These criteria will be used in later steps to evaluate the sustainability of alternatives.
- **Step 3:** To ensure a comprehensive multicriteria analysis, several steps need to be considered. Firstly, the Best Worst Method (BWM) is employed to calculate the criteria

weights [8]. Once the criteria weights are determined, the VIKOR method is utilized to rank various product life cycles based on three indices: the S_j index (group utility values), the R_j index (individual regrets), and the synthetic VIKOR index represented by the calculation of Q_j [9]. The lowest value of Q_j corresponds to the scenario closest to the ideal value, indicating the most favorable outcome. Additionally, it is important to conduct sensitivity analysis to assess the impact of changes in criteria or weights on the ranking of alternatives. Furthermore, the robustness analysis evaluates the ability of alternatives to withstand variations in criteria and weights. In our methodology, the TOPSIS method is employed to examine the robustness of the VIKOR calculation results and analyze the consistency of the obtained outcomes.

- **Step 4:** The analysis of the sustainable scenario involves systematically describing the problem using modeling tools and identifying stakeholders, environmental conditions, resources, goals, and constraints. Our contribution is integrating Structured Analysis and Design Technique (SADT) to comprehensively analyze loops in the initial situation. This helps identify materials flow and return loops in the sustainable scenario. We propose new processes, including a waste recovery management phase, to optimize the utilization of return loops and valorize waste throughout the life cycle. This step enhances our understanding of loops and contradictions within the sustainable scenario [10].
- **Step 5:** Formulation of contradictions: Here, we have identified the TRIZ parameters that represent the contradictions within any product's life cycle. By pinpointing these contradictions, we can start generating ideas to resolve the issue.
- **Step 6:** Resolution: generation of concepts: This step involves applying TRIZ principles and tools to generate innovative solutions to identified contradictions.
- **Step 7:** Evaluation of solution concepts: This step involves evaluating the ideas generated in the previous phase using criteria such as technical feasibility, cost, safety, sustainability, and environmental impact, [11].

The inclusion of the proposed seven-step process provides a clear and concise guide for addressing sustainability concerns in product design and development, enhancing the practicality and effectiveness of the methodology.

4 Case Study

To illustrate our decision-making methodology presented in Fig. 1, for selecting the best sustainable and innovated scenario, we provide a concrete case study.

- **Step 1:** We choose to present a case study of olive oil supply chain in the region of Sfax-Tunisia. This case concerns agricultural practices, processing methods, and waste management practices in the olive oil industry [12].
- **Step 2:** Through field studies involving stakeholders such as farmers, mills, and government officials, eight scenarios have been identified. These scenarios were proposed by experts from the Olive Institutes in Sfax and represent the most commonly used agricultural practices in the city. Each scenario encompasses a complete life cycle of olive oil (Table 1).

Table 1. Description of scenarios.

	S1	S2	S3	S4	S5	S6	S7	S8
Agr. Practices	Conventional				Organic			
Irrigation	Dried		With irrigation		With irrigation		Dried	
Soil management	Mechanics with use of machines							
Pruning	Manual with saws							
Harvest	Manual with workers							
Fertilization	Distribution of manure and waste water from mills with NPK and on the ground				manure and wet pomace(WP) compost	WP compost and wastewater	manure and WP compost	WP compost and waste water(WW)
Pesticides herbicides	Manual, twice a year, with insecticides				--			
Extraction method	Traditional system	3-phase	Traditional system	3-phase	2-phase system			
Pomace processing	Extraction of pomace oils				--			
Treatment of wet pomace	--				manure and WP compost	WP compost and WW from the mills	Manure, WP compost	WP compost, WW from the mills
Treatment of vegetable waters	Application of wastewater from the mills directly to the fields						Application wastewater on fields	
Treatment of pruning residues	Crushing, dispersing on the fields		Burning, ash scattering on the fields		Crushing and dispersing on the fields		Burning and ash scattering on the fields	

- **Step 3:** In Table 2, the weights of the criteria in our case study are presented. All the data in the table were derived from expert input, where they provided their point of view. Subsequently, we employed this data to calculate the weights of all the criteria using the BWM algorithm.

Table 2. Weight of criteria and sub criteria using BWM.

Criteria	Sub-Criteria	Weight of sub criteria	Weight of criteria
Environmental impacts	Global warm	0,323	0,711
	Eutrophication	0,194	
	Acidification	0,194	
Economic impacts	Operation cost (DT)	0,097	0,194
	Productivity (Kg)	0,097	
Social impacts	Workers	0,032	0,097
	Work conditions	0,065	

After obtaining the criteria weight, presented in Table 2, the VIKOR method can be applied to evaluate the ranking of the 8 scenarios in order to obtain the best compromise solution. The results of optimization phase are illustrated in Table 3 where it can be

observed that scenario 6 is ranked highest according to the Q_j value (i.e., the minimum value).

Table 3. VIKOR assessment results and sorting.

	S_j	R_j	Q_j	Ranking
S1	0,3297	0,1570	0,9631	6
S2	0,3324	0,1613	0,9856	7
S3	0,3242	0,1556	0,9457	5
S4	0,3391	0,1599	0,9944	8
S5	0,1583	0,0484	0,1672	2
S6	0,1064	0,0342	0,0000	1
S7	0,1995	0,0968	0,4461	4
S8	0,1584	0,0895	0,3292	3

Based on the results of the robustness (TOPSIS) and sensitivity analysis (Weight variation), it can be concluded that the proposed method for ranking alternatives is valid and reliable. The analysis showed that the method is robust, meaning it produces consistent results even when ranking method are changed, and sensitive, as it accurately captures changes in the ranking of alternatives when criteria or weights are modified. These findings validate the effectiveness of the proposed method and reinforce its suitability for identifying sustainable solutions in product life cycles [1].

- **Step 4:** Scenario 6 is comparatively better than the other scenarios, particularly in terms of environmental, economic, and social performance. In this case study, SADT was used to analyze all the loops of scenario and identify contradictions in scenario 6.
- **Step 5:** Many contradictions were identified as a result of using SADT in Scenario 6 compared to the other scenarios. Agriculturalists are faced with a difficult and contradictory choice when it comes to choosing a farming method. On one hand, the use of conventional agricultural practices involving pesticides and herbicides can increase productivity (2160 kg/hectare), but has a significant negative environmental impact. On the other hand, organic farming is more sustainable but productivity is often less reliable (850 kg/hectare). Therefore, it is important to examine the trade-offs for sustainable agriculture methods.

In the olive oil extraction phase, cleaning the olive trees is an important step in obtaining high-quality olive oil. For example, a three-phase extraction system requires 110 L of water to obtain 20 L of high-quality virgin olive oil. However, using such a large amount of water is not compatible with the concept of sustainability. Therefore, it is important to find olive oil extraction methods that reduce the amount of water used and are more sustainable. Research is needed to develop more sustainable technologies for the olive oil industry in order to preserve the environment and meet growing sustainability demands. These contradictions are summarized in the following tables:

- **Contradiction 1:** using water to clean olives during the extraction phase but not using it to satisfy sustainability, (Table 4).

Table 4. Contradiction 1.

	Cleaning olives	
	Clean (Va)	Unclean (Va -)
Use of water	☺	☹
Sustainability	☹	☺

- **Contradiction 2:** The pesticides and herbicides have to be used to satisfy productivity and not used to satisfy sustainability, (Table 5).

Table 5. Contradiction 2.

	Pesticides and herbicides	
	Using (Va)	Not using (Va -)
Productivity	☺	☹
Negative impact	☹	☺

- **Contradiction 3:** The Agricultural practice have to be Conventional to satisfy productivity and Organic to satisfy sustainability, (Table 6).

Table 6. Contradiction 3.

	Agricultural practice	
	Conventional (Va)	Organic (Va -)
Productivity	☺	☹
Negative impact	☹	☺

- **Step 6:** In this phase, the previously identified contradictions mentioned in step 5 will be resolved by generating inventive solutions:
 - **The possible inventive solution to the first contradiction:** The first evaluation parameter, “Use of water” can be found in Parameter 26, “Amount of substance” in the TRIZ matrix. The second evaluation parameter, “Sustainability” can be found in Parameter 23, “Waste of substance” By combining these parameters in the TRIZ matrix, we arrived at four potential inventive principles: Local Quality (3), Universality (6), Prior Action (10) and Intermediary (24).

In our case study, two principles could be used to solve this contradiction:

The inventive principle 10, “Prior Action”, the waste water that was used to cleaning action could be used to irrigate the olive trees, this system called “The closed-loop water system”

The inventive principle 3, “Local Quality” could be interpreted by replacing water by other alternative such as steam and ultrasound....

In this case, the parameter that was changed was the use of water in the extraction process.

The closed-loop water system was inspired from the circular economy principle could be proposed as a solution of how the parameter of water usage was changed to achieve the desired effect of reducing water usage and minimizing environmental impact. By capturing and recirculating water within the process or using alternative cleaning methods, the overall water usage can be reduced and wastewater discharge can be prevented.

The second solution could be to use another cleaning methods that do not require water. For example, some expert use mechanical or dry-cleaning methods to clean objects instead of using water. These methods can be effective at removing debris and contaminants from the objects without using water.

In summary, by implementing closed-loop water systems or alternative cleaning methods, olive oil producers can reduce their water usage and minimize the environmental impact of the extraction process. This approach can help satisfy both the cleaning requirements of the olives and the sustainability requirements of the industry.

- **The possible innovative solution to the second contradiction:** The first evaluation parameter, “Productivity” is the Parameter 35, in the TRIZ matrix. The second evaluation parameter, “Negative impact” can be found in Parameter 30 “Harmful side effects”. By combining these parameters in the TRIZ matrix, we arrived at four potential inventive principles: Turn the Harm to One’s Good (22), Change of Physical and Chemical Parameters (35), Other Way Round (13) and Intermediary (24).

In our context, the most compatible inventive principle is 35, “Transformation of properties”, which could be interpreted as changing the Pesticides and herbicides with another substance that have less negative impact on the environment. This could be to shift to agroecological farming practices. Agroecology is a holistic approach to farming that focuses on using natural processes and ecological principles to promote soil health, biodiversity, and sustainability. By using agroecological methods, farmers can reduce their reliance on synthetic pesticides and herbicides while maintaining productivity. In our case study the Agroecological practices was inspired from Agroforestry approach. This solution is a beneficial approach where farm animals graze under trees for shelter and food, and their manure enriches the soil without the need to chemical Pesticides and herbicides. Agroforestry is a win-win and part of many agroecological methods.

- **Step 7:** The evaluation of proposed solution concepts is a critical step in the process of improving the sustainability of olive oil production. During this step, experts in the field of olive oil production assess the feasibility of proposed solutions based on criteria such as technical feasibility, cost, safety, and sustainability. Using a Likert scale to express their judgments, experts will evaluate proposed solutions via a

table (Row: criteria used and Column: Likert scale from 1 to 7). In our case expert appreciate the output of our study, as it ensures that proposed solutions are both effective and feasible in practice. Ultimately, the evaluation of proposed solutions will result in improvements to the sustainability of olive oil production, leading to a more sustainable and environmentally friendly process overall.

5 New Proposed Inventive Scenario

The new scenario incorporates the inventive solutions to the contradictions identified using TRIZ, (Fig. 2).

Olive oil Life cycle	Practices	Irrigation	Soil Management	Size	Harvest	Fertilization	Pesticides herbicides	Extraction Method	Olive waste management	Water management
Scenario 6	Organic	With Irrigation	Mechanics with use of machines	Manual with saws	Manual with workers	With manure and wet pomace compost	Nothing	2-phase system	Manure and wet pomace compost	Application of wastewater to fields
New proposed inventive scenario	Agroecological	Limited irrigation	Organic with agroecological practices	Manual with saws	Manual with workers	Compost made from olive waste and locally organic materials	using agroecological practices for pest and weed management	2-phase system	Composting and spreading on fields	Closed-loop water system for olive washing and irrigation, limited use of irrigation to conserve water resources

Fig. 2. Comparison between scenario 6 and the newly proposed inventive scenario.

To address the contradiction of using water for olive washing but not for sustainability, the scenario includes a closed-loop water system for olive washing and limited use of irrigation to conserve water resources, this solution was inspired from the Circular economy principle. So this system will reduce the overall water consumption and minimize the environmental impact of the process. Another solution could be proposed also by using mechanical or dry-cleaning methods to clean olives instead of using water. These methods can be effective at removing debris and contaminants from the olives without using water.

To address the contradiction of using pesticides and herbicides for productivity but not for sustainability, the scenario adopts agroecological farming practices. These practices prioritize soil health, biodiversity, and sustainability, while also maintaining productivity levels. This approach based on changing the use of chemical pesticides and herbicides, with using other substance (animal waste) and other practices (agroecological farming) that promoting soil health and biodiversity. Overall, the new scenario balances productivity and sustainability by incorporating innovative solutions to the contradictions identified using TRIZ.

6 Conclusion

In conclusion, this paper presents an innovative approach to improve decision-making processes using TRIZ methodology in combination MCDM, inventive design thinking and sustainability methods. Through a comprehensive literature review, it was evident that there are limited studies that have investigated the integration of TRIZ with MCDM and Life cycle sustainability assessment methods.

Therefore, this proposed methodology offers a novel and valuable contribution to the field of decision-making by identify where decider could invent to improve the optimal compromise found in optimization phase. The case study presented in this work demonstrated the effectiveness of the proposed approach in the olive oil industry, where it successfully improved the decision-making process and resulted in a more sustainable and environmentally friendly solution. Overall, this paper highlights the potential benefits of combining TRIZ with MCDM and Life cycle sustainability assessment methods, and its importance in addressing complex and challenging decision-making problems. Furthermore, it would be worthwhile to explore the effectiveness of other methods, such as multi-factor benefit analysis, in achieving similar outcomes as the proposed approach in this study, thereby enhancing our understanding of decision-making processes.

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How to Inspire Students for TRIZ – TRIZ as an Enabler for Product Development in a New Sustainable Study Programme

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Abstract. In a recently developed study programme at Reutlingen University, which focuses on practical orientations, an innovative product with solid company references is to be defined and realised by student teams. On the basis of this product, all subjects of the business engineering study programme “Sustainable Production and Business” are taught. By focusing on three main paths of future skills that have been developed by NextSkills to analyse upcoming social changes, global challenges and fields of work that are innovation-driven and agile, the new study programme aims to create responsible leaders who will shape global businesses respectfully. Thereby, different TRIZ tools help to support students in developing their own products with a focus on sustainability and pay off on the future skills enhancement. Further, students get to know TRIZ tools in an unbiased way, unburdened by too much theory, and are thus continuously supported in the progressing product development process that accompanies their studies. Hence, students perceive TRIZ on the one hand as a method to develop sustainable products and, on the other hand, to find sustainable solutions for everyday problems. The knowledge and positive experiences gained in this way should then arouse curiosity for the TRIZ class at the end of the study programme. The students can graduate with a TRIZ Level 1 certificate. Thereby, as many students as possible are introduced to the TRIZ methods, and the TRIZ tool is spread widely.

Keywords: TRIZ Tools · Future Skills · Study Programme

1 Introduction

Taking a look at the increasingly complex and dynamic global economy, it becomes apparent that higher education institutions must face these changes and adapt their curricula to the issues of the future. Therefore, it is inevitable to design future-proof degree programmes [1] in such a way that, above all, they contribute to the acquisition of competences the graduates will need to meet future job requirements.

Not only are the requirements for graduates becoming more and more various, but it is also the applicants' biographies that differ significantly from each other. Applicants are becoming increasingly diverse in terms of their education, expertise, and school careers.

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An example is the fast-growing number of first-year students in Germany without the German high school diploma “Abitur”, that are allowed to apply for higher education institutions. This number has more than doubled since 2011. Currently, more than 70,000 students have found their way to German universities via a vocational qualification rather than a school-based university entrance qualification [2].

This article focuses on a business engineering programme of the ESB Business School at Reutlingen University. The authors explain which future competencies are built up and strengthened by applying the TRIZ methodology to the study programme. In the literature there are already several approaches to integrating TRIZ into university’s courses or modules [3, 4] and how TRIZ is used in the overall learning and teaching context [5–7]. With the paper on hand the focus is on the overarching integration into a degree programme is discussed. A recent study by NextSkills, which is briefly explained in Sect. 2, serves as a basis to understand the overall concept of future competencies and how they pay off for the development of future-ready programmes [8]. One of the unique selling propositions (USP) of the business engineering programme SPB is that the students have to develop their own product. Section 3 illustrates the use of TRIZ on selected competence components that are needed for this product development. First experiences gained from previous semesters round up this paper.

2 Future Skills as a Basis for the Integration of TRIZ in a Study Programme

The challenges posed by significant changes in the requirements for a good university education are undergoing dramatic changes worldwide. The following aspect provides an idea of the changes that higher education institutions may face in the future: Industrialised countries are anticipated to dramatically increase the number of their first-year students by about 70% of all high school students applying for university over the next 15 years [9]. As a result, the number of students enrolled at both public and private universities will rise significantly by then. This trend will become even more pronounced globally as dramatic increases in demand for college graduates are also becoming evident in developing and emerging nations [10].

The demand on universities to prepare their graduates for the responsible shaping of the global and digitised world of tomorrow also brings with it a series of challenges that future-proof universities will have to face at an early stage. More over a report by Dell and the Institute for the Future predicts that 85% of jobs that will be available in 2030 haven’t been invented yet [11]. However, it is not just the sheer number of future students that will fundamentally change the higher education landscape there will be also lots of changes in the job specifications [3].

Focusing on the implementation of the Sustainable Development Goals (SDGs), Ehlers coined the phrase “drift to self-organisation” as the framework for the development of future skills. He focuses on system changes that are characterised by nonlinearity, speed, and complexity [9]. At this stage, the main forces driving change in the economy and society can be exemplified by the handling of issues triggered by megatrends. Megatrends include, among others, the ageing of society, growing connectedness, rising urbanisation, neo-ecology, increasing globalisation, features of new work, health, security, and gender shift [12].

Hence, future skills are to be understood as those abilities that enable graduates to master future challenges in the best possible way. Future skills are defined as “competencies that enable individuals to solve complex problems in a self-organised manner and to act successfully in highly demanding contexts. They are based on cognitive, motivational, and volitional as well as social resources, are value-based, and can be acquired in a learning process” [9].

The following explanations are taken from a study by Ehlers on future skills in Higher Education: The NextSkills Study. In this study, NextSkills evolves three relevant pathways for skills development that will best prepare students for the aforementioned challenges facing society [8]. Figure 1 provides an overview of these three pathways, which are defined as future skill profiles based on the assignment of 17 different future skills.

Future Skills Profiles

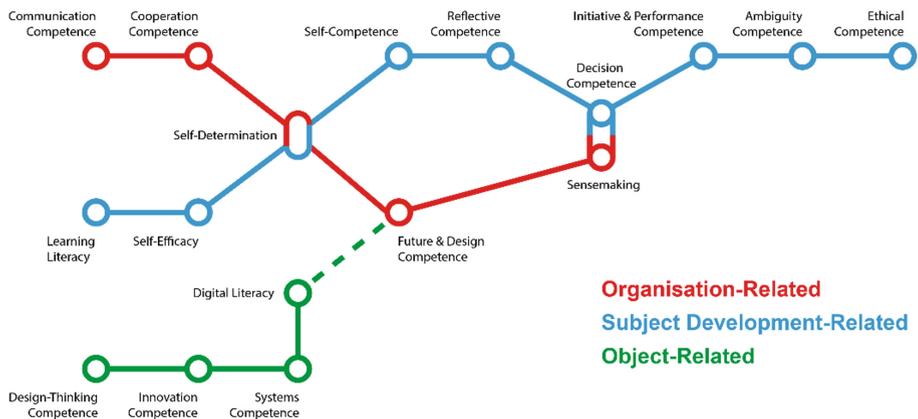


Fig. 1. Future Skills Profiles for higher education graduates. Source: Nextskills.org.

The following is a brief description of the three NextSkills dimensions that serve as a basis for integrating TRIZ into a study programme [8].

Subject Development-Related Dimension: This dimension, including seven future skill sub-profiles, relates to an individual’s subjective, personal abilities to learn, adapt, and develop in order to improve its opportunities to productively participate in tomorrow’s working world, actively shape it, and get involved with designing societies to cope with future challenges.

Object-Related Dimension: This dimension consists of three future skill profiles and relates to an individual’s ability to act in a self-organised way in relation to an object, a task, or a certain subject-related issue. It is emphasising a new understanding of knowledge, going beyond pure expertise and towards connecting knowledge with motivation, values, and the capacity to act in the concerned field of knowledge.

Organisational-Related Dimension: This dimension consists of five future skill profiles and relates to an individual’s ability to act self-organised in relation to its social

and organisational environment. It is emphasising the individual's role as the curator of its own social portfolio of membership in several organisational spheres, rethinking organisational spaces, and recreating organisational structures for the future.

Based on these future skills as a guideline for the development of student competencies, a new study programme with an emphasis on product creation at Reutlingen University was established. In the following sections it will be explained to what extent future skills can be manifested in this business engineering study programme with the help of TRIZ.

3 TRIZ as Part of the Sustainable Production and Business Study Programme

3.1 Basic Understanding of the Study Programme

The bachelor's degree programme *Sustainable Production and Business* (SPB) has been offered at Reutlingen University since October 2021. The aim of SPB as a bachelor of science (BSc.) is to educate industrial engineers who are prepared for future business requirements, as explained in Sect. 2 of this article.

In accordance with this, the structure of the business engineering programme replicates the product life cycle, from product development to the realisation and marketing of a sustainable product. The students are accompanied in teams of up to eight people from the first day of study onward. Starting with brainstorming to find an idea for a new product, students cooperate in teams throughout the entire study time at SPB. At the end of their studies, the teams will pitch their ideas to investors and discuss their possible implementation. At their best, all the study teams have a prototype of their sustainable product, including a business plan, ready for the graduation ceremony.

Not only is the content of a lot of lectures transferred to the team's product idea, but also the semester's chronological sequence is oriented towards product development planning. Hence, the SPB programme takes up the respective individual product ideas in class and thus fosters an intensive practical application of what has been heard theoretically. Figure 2 illustrates the structure of the study programme over the seven semesters of its standard study time.

In the *first semester*, SPB focuses on developing an idea for a physical and sustainable product. The students get to know each other and grow together as a team. The aim of this semester is to anchor their own product idea in the Sustainable Business Model Canvas and thus define the business model for the product. The contents of the accompanying lectures, such as marketing and cost accounting, support the development of one's own individual product idea and are therefore oriented in their structure to the business model. The *second semester* focuses on product design. The aim is to have the product ready in its design and to be able to present initial ideas about format, material, functionality, conception, etc. First models of the products can be printed with 3D printers to illustrate them. In the *third semester*, which has production planning as a central component, production plans are drawn up, product and process qualities are defined, and the required production resources for each team's product are determined. In addition, lectures on automation technology, electrical engineering, and production engineering take place

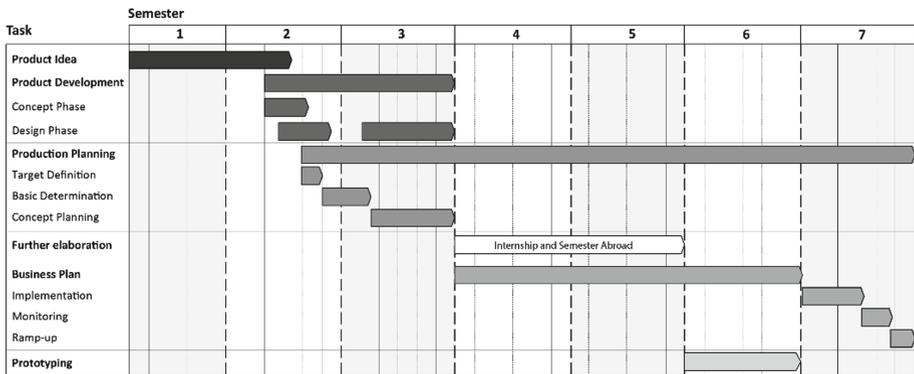


Fig. 2. Structure of the Study Programme Sustainable Production and Business. Own source.

in semester three. After the third semester, the students have two semesters to gain experience with practical projects and other cultures, both in a company and abroad. They are supposed to use this year to work through open points in their product development and to evolve the ideas even further. In the *sixth semester*—back on the Reutlingen campus—the student's task is to draw up an extensive business plan for their sustainable product, and in their last semester, the *seventh semester*, to finalise the idea by building a prototype of their product.

With the explanations given, it is apparent that the basic understanding of the SPB degree programme strengthens the competences developed by NextSkills across all dimensions. The students experience a high level of application relevance throughout all semesters due to the high degree of personal responsibility and freedom to make decisions, to manifold possibilities to experience a high level of application relevance throughout all semesters, to shape the lecture content for their own needs, to enhance critical reflections in the team as a result of systemic feedback loops throughout the entire study programme, and last but not least, due to the possibility to grow steadily in the team. In addition, they learn to deal with a positive failure culture during product development. Failure is a gain in knowledge that must be used in a structured way during the further stages of sustainable product development.

3.2 Promoting Competencies Through TRIZ in the Study Programme

Based on the previously discussed competence profiles, selected examples will be used to illustrate the extent to which TRIZ supports the anchoring of these profiles in the SPB study programme. Thereby, the explanations of competences in Sect. 3.2 are based on the NextSkills study by Ehlers [9].

Subject Development-Related: Here, the student and their personal abilities are at the centre of the competency analysis. The aim is to develop oneself in such a way that it is possible to participate productively and creatively in the working and living environments of tomorrow and to play an active role in one's own further evolution. This involves organising oneself as part of a community in order to be able to deal effectively with future challenges [9].

A competence relevant to this elaboration is *ambiguity competence*. Recent studies clearly show that ambiguity has a significant impact on innovation decisions [13], and these in turn play a crucial role in product development at SPB. Ambiguity competence is defined as the ability to recognise ambiguity, heterogeneity, and uncertainty and to understand them. Furthermore, it also means to deal with them in a productive way and to be able to act as a decision-maker in different and also conflicting roles. This competence can be enhanced with the TRIZ methodology. As already mentioned, students in the SPB programme are expected to develop their own product in the first semester. In doing so, they very often come up against questions to which there are no clear answers: Should the product work according to this or that functional principle? Is manufacturing process A or B an option? This kind of uncertainty, or rather, openness to solutions, is hardly known from the everyday school routine so far. With the support of various TRIZ tools, solutions can be successfully searched in a structured format. For example, engineering contradictions can be eliminated with the help of the contradiction matrix and the innovation principles might be applied, and also solution approaches can be structured with the help of the Effects Database, which provides answers to queries in form of a list of effects.

In this context, it is also worth considering the competence of *self-efficacy*. Self-efficacy aims on strengthening the self-confidence to perform in various challenges with one's own abilities, to take responsibility, and to be able to make appropriate decisions. Because of the systematically structured approach to problem solving with TRIZ, the students are provided with tools by which they can analyse their project in order to strengthen their self-efficacy. Furthermore, they learn how to tackle supposedly unsolvable problems or paradoxes and ultimately receive concrete support in the search for solution strategies for example by using tools like the TRIZ methods for cause and situation analysis and function analysis/function model.

Moreover, the openness and "thinking outside the box" in the search for solutions with TRIZ tools such as feature transfer, effects databases, and innovation databases encourages an engagement with topics outside the initially defined subject area. Consequently, on the one hand, *learning competence* as the ability and willingness for self-directed learning and, on the other hand, *decision-making competence* as the ability to weigh alternative decisions against one another and to be responsible for a choice based on them are strengthened.

The Smart Little People (SLP) method also supports *initiative and achievement competence*, as a very motivating example. SLP models any process and seeks solutions to conflicting situations by assuming an army of little people at work within the contradiction. They are capable of performing any action that students want them to perform, and hence make it easier for the students to contribute ideas and suggestions to their team even without sound specialist knowledge. The self-motivation and the desire to contribute something are thus not inhibited at all or significantly less inhibited by the fear of saying something "incompetent". All ideas are developed by the little people, and therefore allow the students to not focus on the process but on solutions.

The explanations given above illustrate that the future skills in the subject development-related area envisaged in the study programme are supported to a large extent by TRIZ.

Object-Related: The object-related competencies are developed and expanded by TRIZ even more clearly than the subject development-related future skills.

Innovation competence is the central aspect within the framework of competence teaching for the SPB degree programme, to which all TRIZ methods contribute. Through the development of a sustainable product over all semesters, in which the learning objectives of the SPB course are implanted, the students are constantly challenged to develop innovative solutions and applications. With the knowledge, application and critical reflection of the TRIZ methodology, students are well prepared to drive innovations as an integral part of any organisational subject, topic, and process [14]. With these skills, students are empowered to contribute to the organisation as an innovation ecosystem.

In the SPB programme, the *design thinking competence* cannot be separated from innovation competence. The self-image of a business engineer serves as an intermediary between different disciplines. He mediates between different characters within a project team and thus has to strengthen his ability to conciliate. The focus is to carry out creative development processes in an open-ended manner with regard to given problems and topics and to involve all stakeholders in a joint process for problem and solution design. This is even more relevant today as 73,2% of businesses surveyed consider the importance of creative thinking as part of design thinking to increase within the next five years [15]. Thereby, design thinking competence stands as a synonym for TRIZ competence.

Organisation-Related: The organisation-related competences refer to dealing with the social, organisational, and institutional environment. It includes the *future and design competence* as the willingness to try something new, the openness to change, and the desire to further develop situations into other, new, and previously unknown visions of the future. TRIZ supports students not only in the development of new products but also in the further development of existing products on the market. The trends in the development of technical systems and the S-curve analysis contribute to the expansion of competence in the aforementioned context.

Since the vast majority of the tools contained in the TRIZ method kit are centrally designed for communication, *communication competence* is also deeply enhanced. Ideas and results are discussed, developed further in dialogue, and critically scrutinised as a result. Hence, the ability to defend one's own idea against the sceptical questions of team members and others is an important experience that is learned when working with the TRIZ tools.

4 Experiences Gained so Far

The following are examples of some experiences gained in the SPB business engineering programme using TRIZ to enhance future competencies over the first several semesters. To date, about 110 students have participated in three TRIZ-driven innovation terms: As of summer 2022, followed by winter 2022/2023 and summer 2023.

The SPB programme starts with an orientation week, which focuses intensively on team building. The kick-off case study is to rescue the Titanic [16] with the use of TRIZ tools. Its outcome is primarily based on an elementary resource analysis, supports getting to know each other, and establishes the foundation for further collaborative work on the product idea over the remaining semester. The experience of using TRIZ tools to find a

possible solution to save all passengers on the Titanic within a few hours of teamwork is a great motivation for the students to continue working with TRIZ methods in the following semesters. In this way, curiosity and enthusiasm for TRIZ creativity methods can be achieved right at the start of the course. Figure 3 gives an insight into the work and the results from the Titanic case study during the orientation week.

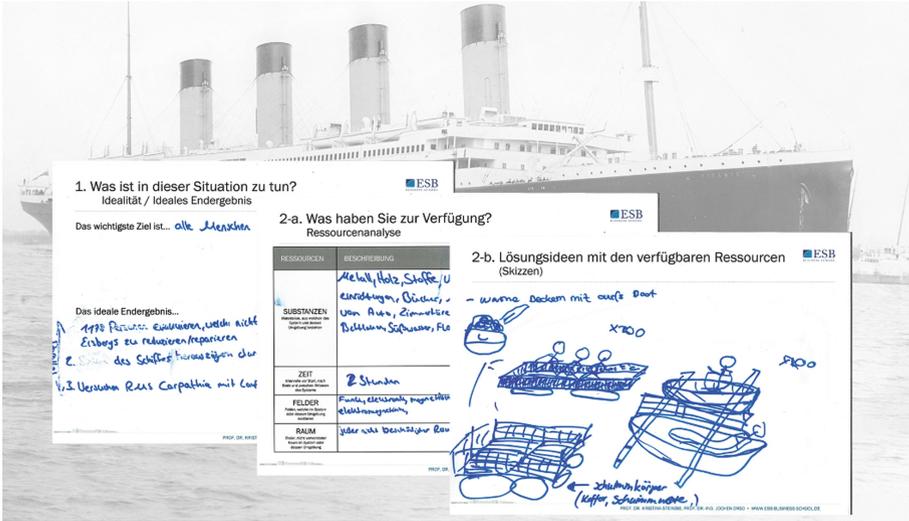


Fig. 3. Orientation week with Titanic Case, 03/23/2023. Source: SPB Students, Titanic Image in Public Domain.

The focus of the first semester, as described in Sect 3, is to develop a real-life sustainable product idea. The application of the little people method makes it feasible to find everyday challenges, discuss them in an open-ended manner [17], and, based on this, structure initial creative approaches for product ideas with a focus on sustainability. For this purpose, the students are provided with little people stamps. Experience shows that students use the stamps with great pleasure. A creative discussion with a lot of dedication is stimulated. In this regard, an initial discussion about the concept of the ideality of products is also introduced. The intensive analysis of the issue of what exactly the customer actually wants—what an ideal product would look like—steers the discussion paths in the search for a product idea. This leads to completely new ways of thinking, which can then be further developed within the team. The following Fig. 4 gives some impressions of the application of TRIZ tools in the first year of the SPB programme.

The SPB programme, and with it the application of different TRIZ tools for competence enhancement, is still in the start-up phase. SPB will have completed its first TRIZ-based run in four semesters. Therefore, the lessons learned so far can be primarily related to the first two semesters. Current discussions in the lecture hall are and will be guided by the idea of innovation through the use of more and more different methods.

As the ESB Business School is AACSB (Association to Advance Collegiate Schools of Business) accredited, the acquisition and improvement of competences is to be

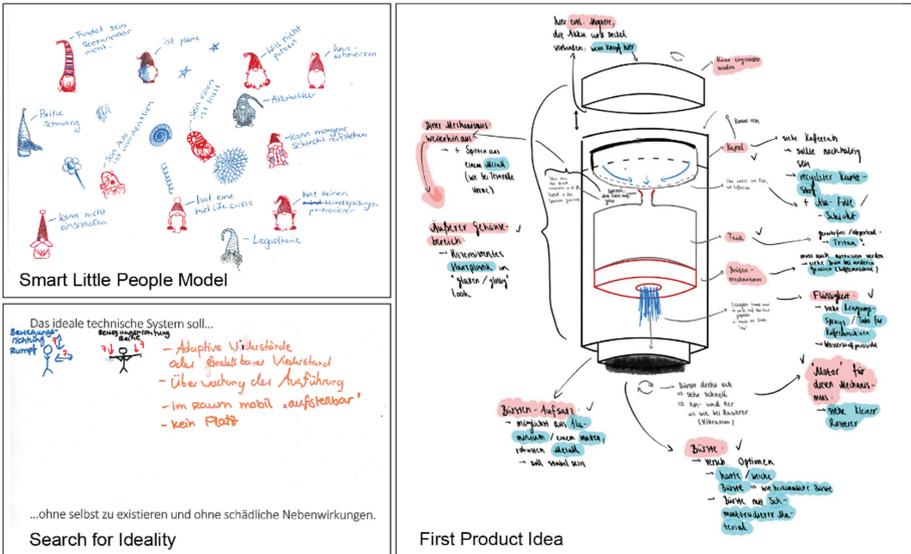


Fig. 4. TRIZ tools used for first-year students (selected examples), 03/24/2023. Source: SPB Students.

anchored and measured in the Assurance of Learning circle [18]. This circle allows to monitor whether students acquire skills which the SPB programme is aimed to offer. TRIZ will directly contribute to the goal of application skills in the product realisation process fostering the methodological approach. As this goal will be measured for the first time in February 2024, no results or experiences can be presented here yet.

5 Outlook

The aim of the SPB programme is to send students into the job market with competencies that will be relevant in the future. Within this process, TRIZ tools will support innovative action in a high diversity throughout the entire study programme. As a result of the change that then takes place in the everyday mindset, students are thus well equipped not only for success at the university but, above all, for the increasingly complex and dynamic requirements of the job market.

In the future, there will be an elective TRIZ class in the SPB sixth semester, which will systematically reprocess the methods already used in the course of study and ultimately lead the participants to a Level 1 certificate. It is to be hoped that the enthusiasm for the application of the methodology will then be carried over by the graduates into their working environment.

For future research activities, a methodologically sound analysis of the achievement or enhancement of competencies through TRIZ is pending. It will be essential to review the framework for action established in this paper to measure the extent to which the expectations of the competencies have been fulfilled.

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Problem Modelling for Sustainability in the Business Environment by Linking TRIZ and Systems Engineering

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Abstract. Sustainability has become more important nowadays. Due to the volatility in raw material and energy supplies, together with increasing market requirements for environmentally friendly products, manufacturing companies face the following challenges: a) reduction of environmental impact from own material supply and manufacturing processes (sustainability at the company's level) and b) reduction of environmental impact from products (sustainability at the product level). In dealing with both topics, a company must fulfill multiple targets, in several cases with contradictory requirements. Specially it happens, when fulfilling the environmental targets increases the costs of a product but doesn't increase its main parameter of value (MPV). In the case of the window fitting systems, which is handled in the present research, the MPV is the maintaining of the window state (open, close, tilt and lock). A wholistic picture is needed to understand all the influences and prioritize the topics at both levels (company and product). In the present research, the author uses the linking of TRIZ and Systems Engineering methodologies for quantification between company-level and product-level problems with a deeper analysis of sustainability requirements along the product life cycle and the environmental impact of a company.

Keywords: Sustainability · Circular Economy · System Engineering · Model-Based Systems Engineering (MBSE) · System model · Multi-Domain Matrix (MDM) · Influences · Engineering Contradiction · TRIZ · Life Cycle Assessment (LCA)

1 Introduction

The nowadays challenges of the humanity are the scarceness of resources, climate change and the threat for the global ecosystem caused by the human activities. Beginning with the UN-conference in Rio de Janeiro (1992), sustainability and sustainable development are on the agenda in policy and economy [1]. The defined targets for sustainable development were formulated in the Convention of the United Nations Climate Change Conference in 2015 (also known as the Paris Agreement) [2].

Conventional business models are focusing on the most rapid usage of the (economic, but also personal and social) resources to create the highest possible added value. Meanwhile, the sustainable development and thus sustainable business models are focusing on the long-term effects for the economy, nature and society [3]. The objectives are:

- For the conventional product development and manufacturing, dealing with the engineering contradictions between components and functions. Also, the manufacturing process is taken into the consideration: process steps and flow of material, energy and information. The main goals are the effectiveness, increasing product value, its functionality, and the efficiency, decreasing of costs (materials and manufacturing effort).
- For the sustainable product development, according to the definition above, further two criteria are to be taken into the consideration: environmental and social impacts.

In the second case specially, the environmental requirements can increase the effort of the product development, industrialisation, and distribution. This challenge includes not only the product itself, but also the company processes, also not directly related to the value creation, such as logistics and employee commuting.

The previous research has shown that linking of TRIZ with Model-Based Systems Engineering (MBSE), helps to analyse and visualise complex problem models, including components, functions, processes and requirements ([4] and [5]). The previous approach though was targeting the product, covering the usage process, but not the organizational processes. Also, the environmental impact was covered only partially, e.g. through harmful functions (material, energy and time consumption during the product usage stage).

To deal with the initial problem of the sustainable product development, following research questions were formulated:

1. Can the wholistic problem model be created to include both views of the product and organisational level?
2. How to track the relations and quantify problems (engineering contradictions) between product life cycle and company activities
3. Is it possible to develop the methodology for sustainability approach, which can be implemented for any company and any product, not depending on the specific problems of any industrial sector?

To develop a system model, as described in the previous research ([4] and [5]), firstly it is essential to describe the environmental impacts from the company and from the product view, and to find the right structure for the quantification of these kinds of impacts. This part is covered in the Sect. 2.1.

The question, how to integrate the sustainability topics in the problem model, is investigated in the Sect. 2.2. The wholistic approach is defined here, to use it for the problem modelling and further analysis. For the case study, the author uses the window fitting system for tilt&turn windows, which are common in the Europe.

Main findings from the problem model, including the answer to the second research questions, are described in the Sect. 3.1, following with the discussion about the applicability of the problem model for other products, companies and industrial sectors (Sect. 3.2). The necessary steps within the chosen approach are depicted in the Fig. 1.

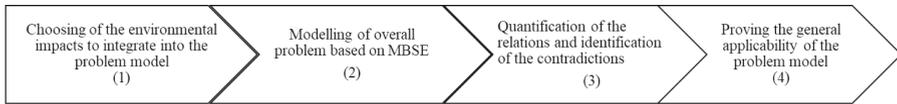


Fig. 1. Approach for sustainability problem modelling.

Finally, in the last section, the author summarizes all the findings and provides the recommendation for the practical implementation of the results as well as the outlook for the further research.

2 Problem Modelling for the Environmental Impact

As described in the chapter above, the present research is dealing with the environmental impact of the product and company (organization). First, the environmental influences should be defined, to be able to quantify them. And as the second step, the structure of environmental influences must be listed both for the product and for the company.

2.1 State-of-the-Art Quantification of Environmental Impacts at the Example of the Window Fitting Systems

Since the UN conference in Rio de Janeiro [1] the environmental approaches were developed at different levels. R. Benmoussa in his work provides a well-grounded overview of the different methodologies, regulations and tools [6]. According to this research, the most known approach for sustainability at the product level is the life cycle assessment (LCA). The framework for it is described in the ISO14040 [7] and other complementary standards. Specifically, for the European building and construction industry, there is the norm EN 15804:2012, which defines the requirements for the environmental product declarations in this sector. Thus, the product life cycle consists of the following phases [8]:

- Phase A: Product creation (with the subphases A1-A5)
- Phase B: Product Usage (B1-B7)
- Phase C: Disposal (C1-C4)
- Phase D: Recycling and recycling potential

These phases are implemented in the problem model, described in the Sect. 2.2

The rules for organisational level were developed after the UN initiatives on climate protection and resulted in the Greenhouse Gas (GHG) Protocol. It defines the emissions, contributing to the increasing of the GHG effect in the atmosphere [9]:

- Scope 1: Direct emissions caused by the combustion (stationary and mobile) as well as the emissions from coolants and heating agents.
- Scope 2: Indirect emissions from the energy consumption, e.g. electricity from the public grid
- Scope 3: Indirect emissions from the upstream (e.g. purchasing of goods) and downstream (e.g. processing and disposal of sold goods) activities. This systematic includes all the activities at the company level. It is also implemented in the problem model together with LCA, as described above.

The combination of LCA and GHG also brings another advantage. The environmental impacts in both cases can be quantified using the carbon-dioxide equivalent emissions as the parameter [6–9].

The last dimension in the problem model is the product itself, consisting of several components and fulfilling several functions. The use case of the present research is the window fitting system for tilt&turn windows, as shown in the Fig. 2.



Fig. 2. Example of tilt&turn window fitting systems [10].

As mentioned in the Sect. 1, one of the targets for the present research is to develop the problem model, which could be applicable for any product. For this reason, the author defined the most generic window fitting system, containing the components, which are common for different product families in this industry, e. g. handle, locking parts, stay. Also, the window (frame + glas) as a super-system component must be included in the model. Window fitting system performs the following functions: Open, Close, Lock and Tilt.

2.2 Application of the Environmental Impact in the Problem Model

The first step in the problem modelling is to create the main matrix. As described in [4], the standard parameters are requirements, functions, processes and components. As one of the findings of the previous research, the author also included harmful functions in the problem model, which are the increase in energy and material consumption, transportation effort and reduction of product life-time. These functions correspond to the eco-design categorization in [11]. The product life cycle is located under the domain Processes. To differentiate the processes at the company level from the product level, the GHG scopes 1–3 emissions of the company are located in the domain Activities.

The overall matrix is represented in the Fig. 3 below. In the second step, the influences in the matrix are quantified with the same logic as applied in [5], having the positive influences with the factor 1 and engineering contradictions between the matrix elements with the factor 10. All the interactions between the elements of the problem model are also visualised in the Fig. 3 (marked with the dark colour). For example, all the relations between the processes (LCA) and the activities (GHG) are quantified. And there is no

quantification between the functions and the activities (GHG) because there are no direct relations between these elements.

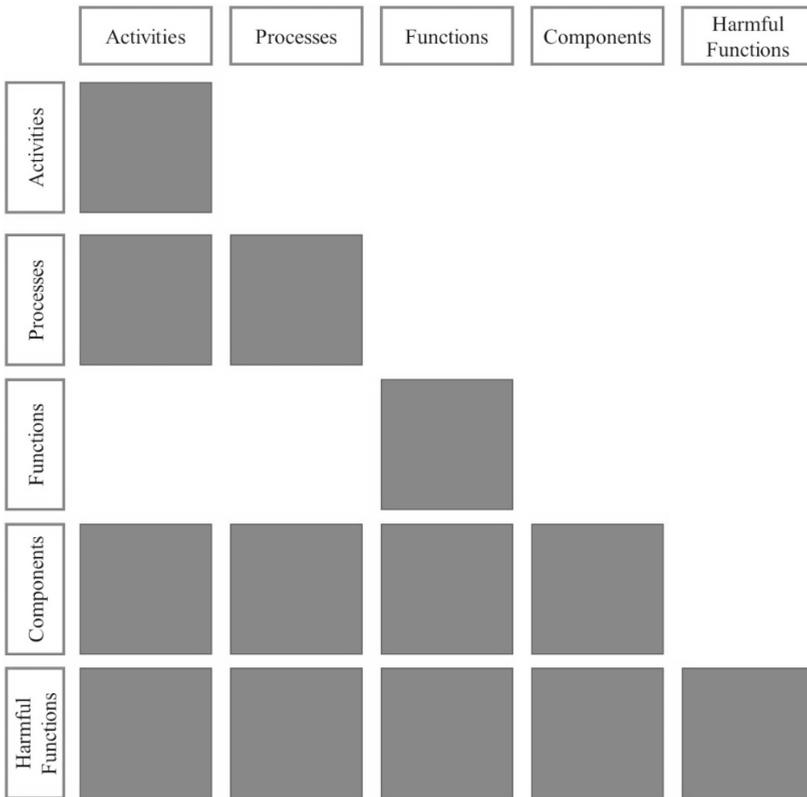


Fig. 3. The multi-domain matrix (MDM) of the problem model.

3 Problem Analysis and the Results

3.1 Main Findings from the Problem Model

The principal graphic visualization of the problem model (MDM) is shown in the Fig. 4. The wholistic representation of the problem model includes all the influences in the system, combining the company and product level views. Furthermore, using the filter functions, criticality level for the elements and quantification of relations, the specific problems for the most critical elements can be highlighted (see Fig. 5).

It allows the deep-dive analysis of the contradictions between them, as well as the further contradictions from the relations with other system elements. Product life cycle phases A3 and A5 in the Fig. 5 below are filtered out as one of the conflict pairs in the MDM.

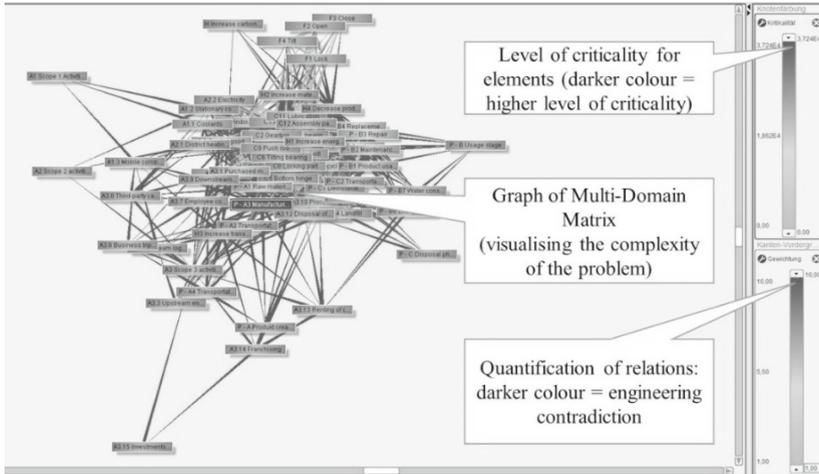


Fig. 4. Graphic visualization of the problem model (principle representation from LOOME0®).

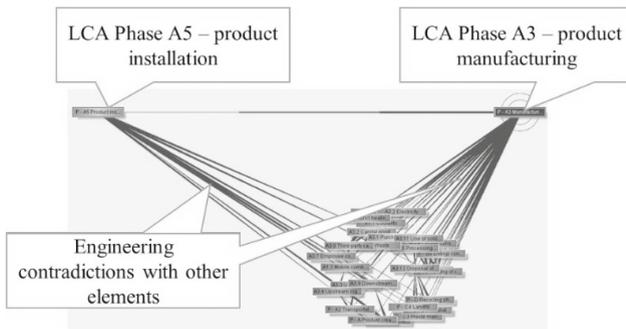


Fig. 5. LCA phases A3 and A5 as a conflict pair, with further contradictions (principle representation from LOOME0®).

The general contradiction can be described as following:

IF we reduce the complexity for product installation (LCA-A5),
THEN we reduce the CO₂-emissions in LCA-A5,
BUT we increase the complexity of product manufacturing (LCA-A3).

Different solutions for these contradictions can be evaluated by the economic value (cost-effort) and the environmental impact (increase/reduce CO₂-emissions).

The indirect relations between system elements, which are not having an interaction with each other, can be tracked through the whole model (chain of contradiction). Thus, the MDM can provide an answer to the question: what is the environmental impact of the product function “Tilt”? As shown in the Fig. 2 above, there is no direct relation of any product function both to the environmental impacts from the product LCA and to the company activities. Nevertheless, the question can be answered by calculating of the indirect relations of the function “Tilt”.

3.2 Applicability of the Approach for Different Industrial Sectors and Products

The environmental impacts in the MDM are represented by the domain processes (product level) and the domain activities (company level). The structures used in both domains were developed at the regulatory level to be applicable for any company in any industry, having different products and value chains. Also, the harmful functions for the environmental impact can be implemented for different use cases, as described both in the present research and in the eco-design approach in [10].

The only product specific domains are the components and the functions. Problem modelling for these two domains is covered by the standard TRIZ-tools [12]. The tools for analysis and improvement of the useful functions, as well as elimination of the harmful functions, are an integral part of TRIZ, as described by Maccioni and Borgianni [13]. It means, that the sustainability problems can be addressed with TRIZ-tools. The universality of the approach is represented in the Table 1.

Table 1. Applicability of the domains in the problem model for different products and industries

Nr.	Domain	Universality of domain	Source
1	Activity	Universal	GHG
2	Process	Universal	LCA
3	Component	Product specific	State-of-the-Art TRIZ
4	Function	Product specific	State-of-the-Art TRIZ
5	Harmful function	Universal (when the highest level of the environmental impact is kept)	Eco-design

4 Conclusion

4.1 Boundaries of the Sustainability Problem Modelling

The present research is focused on the definition and modelling of the high-level sustainability problems: product life-cycle phases and the emissions from the company activities, as described in the Sect. 2.1. The following issues were not covered here:

- Weighting of different product life-cycle phases and company activities in relation to each other.
- Consideration of the costs for every type of emission, and the cost-effectiveness of potential solutions, which increase the sustainability.
- Carbon footprint was used as the only parameter to compare the negative environmental impacts of the system elements. The norm [8] defines more parameters, e.g. contamination of soil, water and air.

4.2 Summary and Outlook for the Further Research

The findings of the previous research on the combination of the model-based systems engineering with TRIZ methods were successfully applied also for sustainability issues. The answering of the questions, manifested in the Sect. 1 above, was the core point of the present research:

- The problem model can be developed not only for the product level, but also the company level activities as a fully integrated part of the multi-domain matrix. The approach was tested using the window fitting system as a case study.
- The advantages of the multi-domain matrix can be used to track the indirect relations between any system elements, even if they are not interacting with each other. Moreover, the interactions can be quantified directly, e.g. by the criticality level of the system elements or by the evaluation of the contradictions in the direct and indirect relations.
- The described method for integration of sustainability impacts into the product model is based on the standard methods of life-cycle analysis (LCA, GHG and eco-design), meaning the unlimited applicability of the in the present research developed tools for every company and different products.

For the further practical application as well as for the deep-dive scientific research, there is a possibility to split the universal domains (as in the Table 1) into the specific elements, see Table 2. The quantification possibilities, mentioned for the detailed data below, can be explored to develop mathematical models, helping for the calculation of environmental impacts for different scenarios of product development and company activities.

Table 2. Proposals for the further research and practical application.

N.r	Domain	Further practical application and research
1	Activity	The GHG Scope 1–3 activities can be divided into the sub-activities <i>Example:</i> Scope 3.1 “Purchased materials” can be differentiated by the material type (steel, plastics, aluminum, zinc) with different emission factors
2	Process	The life-cycle processes can be divided into the sub-processes <i>Example:</i> Process A3 “Product Manufacturing” can be divided into the different steps (e. g. stamping, galvanizing), having specific energy consumption
3	Harmful function	The harmful functions can be formulated more specific, with quantification corresponding to the company goals. For example, the reduction of the material wastes till year XXXX by X%

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The Law of Reliable Resource Supply: Making Altshuller's Laws of System Evolution Sustainable

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Abstract. This paper explores the integration of sustainability aspects into Altshuller's Theory of Solving Inventive Problems (TRIZ), a central component of which is the collection of laws concerning the evolution of technical systems. Building on Altshuller's eight laws generated through the principle of idealization, we argue that these laws, with their inherent focus on system efficiency, overlook the necessity of reliable resource supply. We note the paradox where a system developed per these laws could potentially cease to exist prematurely due to resource depletion, despite compliance with all efficiency-oriented guidelines. This paradox emphasizes that sustainability extends beyond mere efficiency, an insight underpinning Müller-Christ's approach to sustainability management, which treats efficiency and sustainability as contradictory management rationalities. We argue that achieving sustainability necessitates extending the time horizon for cost-benefit analysis, beyond immediate cost reduction. We propose a framework for incorporating sustainability into Altshuller's laws by delineating three resource types based on their consumption modes, establishing resource availability as a crucial feature of artificial instrumental systems, and applying the principle of idealization to derive the law of reliable resource supply. Additionally, we suggest design principles for managing these three resource types, promoting more sustainable system development.

Keywords: Laws of Technical System Evolution · Energy · Resources · Sustainability · TRIZ

1 Altshuller's Laws and Their Lack of Sustainability

One of the key components of Altshuller's Theory of Solving Inventive Problems (TRIZ) is the collection of laws of the evolution of technical systems [1]. As demonstrated in [2], the principle of idealization allows for generating Altshuller's eight laws by identifying

This paper is to a large extent a translation of a section of the to date unpublished synopsis of my (JS) cumulative dissertation, which is written in German. Many of the ideas of this piece emerged over the years in conversations with Dr. Kartik B. Ariyur. To acknowledge the influence of these productive discussions, he is listed as a co-author.

necessary features of artificial instrumental systems and by projecting them to their most ideal extreme under the constraints of resource scarcity and competition. The result are trends toward maximally efficient systems.

This focus on efficiency, however, overlooks the necessity of reliable resource supply. Even if we have 100% efficient systems, if the resources that they depend on run out, the systems will cease to exist. This raises the paradox that a system could be developed according to all Altshuller's eight laws and still stop existing long before even the most primitive biological species disappeared. That sustainability cannot be reduced to efficiency is one of the fundamental observations underlying Müller-Christ's approach to sustainability management [3]. Paper [3] describes the management rationalities of efficiency and sustainability as contradictory in nature: To optimize the ratio of benefits to costs, the logic of efficiency is oriented towards cost reduction. Contrarily, the renewal of resources incurs additional costs [3]. Since the benefits of these forward-looking expenditures often only become apparent later, this worsens the short-term cost-benefit calculation. Sustainability can therefore not be reduced to efficiency without projecting a sufficiently long time horizon.

To integrate the aspects of sustainability into Altshuller's laws, first we distinguish three types of resources based on the mode of their consumption. Second, we make the case that resource availability is a necessary feature of artificial instrumental systems. Third, we apply the principle of idealization to derive the law of reliable resource supply and to draw conclusions in the form of design principles for how to deal with each of the three resource types.

2 Types of Resources from a Thermodynamic Perspective

Resources play a central role in Müller-Christ's approach to sustainability management [3] as they form the instrumental basis of all economic activity or work. Just like in TRIZ, they are broadly understood as means within means-end relationships. Although this definition encompasses both material and immaterial resources, I will restrict my discussion here to material resources and adopt a thermodynamic perspective to draw conclusions for the trends in technology development as per [1].

The matter or energy available in a closed system is limited and, according to the first law of thermodynamics, can neither be created nor destroyed, only transformed. Consequently, the maximum possible efficiency (i.e., the ratio of utilized energy to expended energy) in performing work is 1. Since only a portion of the expended energy can be converted into work and the rest is dissipated as heat, the efficiency is always less than 1, except for systems that convert useful energy into heat. Due to the first and second laws of thermodynamics, economic processes inevitably lead to a constant energy and resource depreciation, i.e., the production of heat that cannot be fully reconverted [4].

The fact that the richness of life was able to develop on planet Earth is primarily due to the Sun, which consumes its own hydrogen resources in a fusion process, providing energy freely available. These resources are estimated to last another 5 billion years, before our Sun turns into a red giant and is expected to consume Earth along with Mercury and Venus [5]. The potential of solar energy on Earth is globally around 100000 TW, which is about 4 orders of magnitude higher than the 18 TW (as of 2018) of total human

energy consumption [6]. About 1% of solar energy is converted into wind [6]. Nuclear decay within the Earth’s core contributes less than 50 TW to Earth’s energy balance – a contribution 4 orders of magnitude smaller than the solar potential [6]. Tidal energy is another order of magnitude below this [6].

The remaining 5 billion years in which the Sun supplies the Earth with energy is roughly the same period (4.6 billion years) that has passed since the Earth, along with the other planets of our solar system, formed from stardust and gas [5]. The chemical elements composing this matter have an even longer history in our approximately 14 billion years old universe [5]. Their occurrence in the solar system and on Earth is thus absolutely scarce. An overview of their origin can be found in Fig. 1.

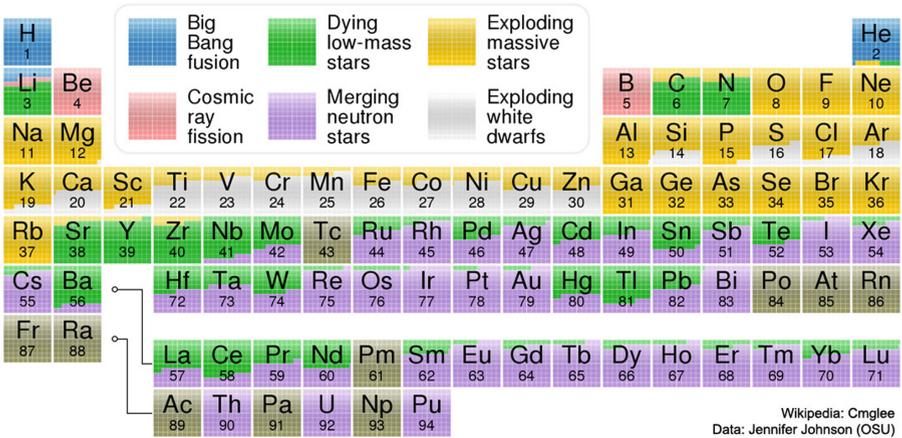


Fig. 1. Periodic Table of Elements with information about the manner of formation of respective the atoms [7].

Due to violent collisions and radioactive decay, the matter of the Earth was largely molten at the time of its formation. The denser elements sank to the Earth’s core while the lighter ones remained on the surface and cooled. To this day, the Earth has a dense metallic core, which is about 6000 °C hot at the center, and it supplies the planet with heat from within for further billions of years. This core is enclosed by a less dense mantle of rock, which in turn is surrounded by an even less dense crust [5].

This constant supply of energy from the outside (solar energy, gravity in the solar system and galaxy) and from the inside (heat from the Earth’s core) was and is necessary for life to develop on Earth over millions of years. For, like all forms of economic activity, life is also based on continuous metabolism, for which the same laws of energy conversion apply. Without a stable energy supply, the energy depreciation associated with vital metabolism would lead to the end of all life in a relatively short time.

The evolution of life on Earth is thus possible only because (i) the energy resources subject to constant depreciation are provided stably over time (Sun, Earth rotation, geothermal energy, etc.), while (ii) the finite quota of other vital resources (e.g., carbon, water, etc.) is returned to the cycle without significant loss of quality. Thanks to the energy

freely provided from outside, the organic system of primary producers (production of biomass through phototrophy),¹ consumers (herbivores and carnivores), decomposers (bacteria and fungi), and detritivores (animals that feed on dead organic matter) ensures that the quality of resources from a life perspective is even upgraded (topsoil, etc.), which, due to the additionally stored energy, allows for ever more complex life [8]. To categorize types of resources, the common distinction is between renewable and non-renewable resources (see e.g., [8, 9]). However, this distinction is misleading, as renewal or non-renewal primarily depends on whether the energy for the respective process is expended. In this sense, almost everything is renewable. From an energy balance perspective, however, nothing is radically renewable, at least as long as we adhere to the first two laws of thermodynamics. Rather, a transformation takes place in which a part of absolutely scarce energy is lost as heat.

Instead of the usual distinction between renewable and non-renewable, for the purpose of this work, an alternative distinction of resource types is made based on their principal consumption rate. The consumption rate is defined as the ratio of consumed quantity to produced quantity in any time interval:

$$\text{ConsumptionRate} = \frac{\text{QuantityConsumed}}{\text{QuantityProduced}} \tag{1}$$

- Type 1: A consumption rate that is principally less than 1 occurs when resources are tapped that are freely available anyway. In this case, consumption can never exceed production, so the limit of the consumption rate is a maximum of 1. This is the case for the use of solar energy, wind energy, geothermal energy, and tidal energy.
- Type 2: Resources with a consumption rate that is principally greater than or equal to 1 refers to resources that are absolutely scarce. Through recycling, the consumption of such resources can be balanced again.²
- Type 3: Resources whose consumption rate can be greater, less than, or equal to 1 are renewable resources, such as biomass, fossil fuels, topsoil, or waste (Table 1).

Table 1. Differentiation of resource types based on their consumption rate.

Type 1 Consumption rate < 1	Type 2 Consumption rate > 1	Type 3 Consumption rate < > = 1
Solar, Wind, Tidal, Geothermal	Minerals, Metals, Nuclear Fuel	Biomass, Topsoil, Fossil Fuels, Waste

¹ For taxonomy and productivity of phototrophic life, see [10].

² Through processes like nuclear transmutation, the production of a resource can be de facto larger than the consumption of the same. Although this seems to be rather far-fetched from pragmatic points of view, the possibility exists. If this process proves to be meaningful, the corresponding resource could be reclassified as a Type-3 resource.

All three resource types are scarce in their own ways:

- Type 1: The rate of energy supply is limited (for instance, the sun provides approximately 1000 watts per square meter on a cloudless noon at the equator – the rate is highly dependent on time and location).
- Type 2: The absolute occurrence of a particular resource is limited (e.g., the gold deposits on Earth; for an overview of typical concentrations of selected metals in the Earth's crust, see [8]).
- Type 3: Both the occurrence and its reproduction rate are limited (see, for example, reserves of fossil fuels in [11]; the fossil fuel reserves that humanity has depleted in just a few hundred years took several hundreds of millions of years to form).

3 Sustainable Resource Consumption

Sustainable resource management is achieved when the consumption and reproduction rates of Type-2 and -3 resources are balanced. As this requires additional energy, it is only possible if Type-1 sources are used for energy supply. Unsurprisingly, therefore, almost all life is either directly or indirectly dependent on the Type-1 resource solar energy (see, e.g., [8]). Phototrophic bacteria and plants, which are directly dependent on solar energy, convert solar energy into organic-chemical energy carriers, while creatures that feed on plants or on organisms further up the food chain consume this energy according to the predator-prey scheme as Type-3 resources.

Consumption in the predator-prey scheme leads to Lotka-Volterra cycles (see, e.g., [8]), which describe the relationship between predator and prey populations (see Fig. 2).

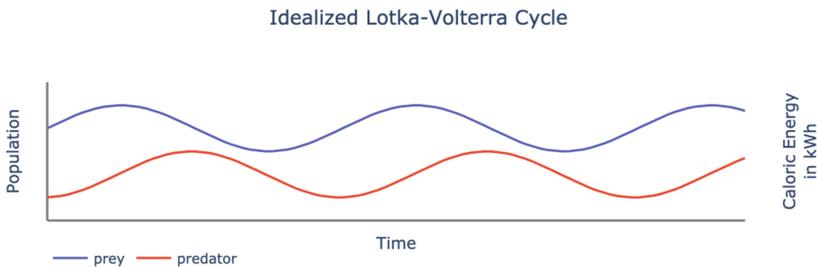


Fig. 2. Idealized Lotka-Volterra cycle. The larger the prey population, the more food reserves are available to the predator population. As the predator population grows, the prey population is decimated more rapidly. The supply situation for the predator population worsens, its population decreases, and as a result, the population of the prey species can recover. For real measurements of this coupling, see [8], who present the data from [12] and [13].

The larger the prey population, the larger the food source available to the predator population. As a result of this favorable supply situation, the predator population grows, which is accompanied by increased consumption of the prey population. Consequently, the prey population shrinks, thus worsening the supply situation for the predator population. The predator population then also decreases, thus reducing pressure on the prey

population. Gradually, the prey population recovers (i.e., it grows), and the cycle begins anew.

The prey population on the y-axis can also be represented as a caloric energy amount (see Fig. 2). A predator population whose consumption rate is adapted to the regeneration rate of the prey population would not be subject to such fluctuations and would be sustainable.

4 Humanity's Unsustainable Energy Consumption

An examination of humanity's energy consumption reveals a heavy reliance on Type-3 resources. As of 2021, 77% of global consumption stemmed from fossil fuels, which took several hundred million years to form (see Fig. 3) [5, 14]³. The consumption rate of humanity, which will deplete all resources within a few hundred years, is thus several orders of magnitude higher than the regeneration rate of fossil fuels, and is consequently unsustainable (for remaining reserves, see [11]). Biomass and biofuels also fall under Type-3 resources, accounting for 7% of global energy consumption. To the extent that their regeneration rates match the consumption rate, they can be considered sustainable in at least this respect. Wind energy, solar energy, and hydropower, as Type-1 resources, make up 11% of the global energy supply. They enable the sustainability of Type-3 resources within the Earth system (see Sect. 3). Of the remaining percentages, nuclear energy accounts for 4% of global consumption and, as a Type-2 resource, must be classified as unsustainable. The remaining 1% is comprised of other renewable energies.

In light of Lotka-Volterra dynamics, it can be observed that humanity remains in a growth mode, which is consequentially accompanied by a growth in energy consumption (see Fig. 4). However, since less than a fifth of this consumption is sustainable, a disaster looms (regardless of the issue of climate change). Even if our technologies had an efficiency rate of 100%, the problem of the lack of energy carrier renewal and thus the corresponding Lotka-Volterra dynamics would persist. Maximum efficiency in resource utilization is therefore not sufficient for sustainability, which is why sustainability cannot be reduced to efficiency alone (see [3]).

With the expansion of energy use from Type-1 resources, humanity is returning to the path of proven biological evolutionary principles. However, to truly become sustainable, several more turns would have to be taken. Unlike biological energy transformation systems, which fully return to the resource cycle, wind and solar installations are not only dependent on Type-2 resources, their recycling is not guaranteed. For instance, [20] estimate that currently less than 10% of consumed photovoltaic modules are recycled in the US. This approach to avoiding the impending Lotka-Volterra collapse is thus still far from the elegance of biological material cycles.

³ The data in [14] is sourced from [15] and [16]. [14] ensures comparability between energy forms and datasets by (i) converting to terawatt-hours and (ii) converting non-fossil energy sources to their fossil input equivalents (thereby treating non-fossil energy sources as if they had the same inefficiencies as fossil fuels; without this conversion, the percentage of fossil fuels in the worldwide mix would be larger).

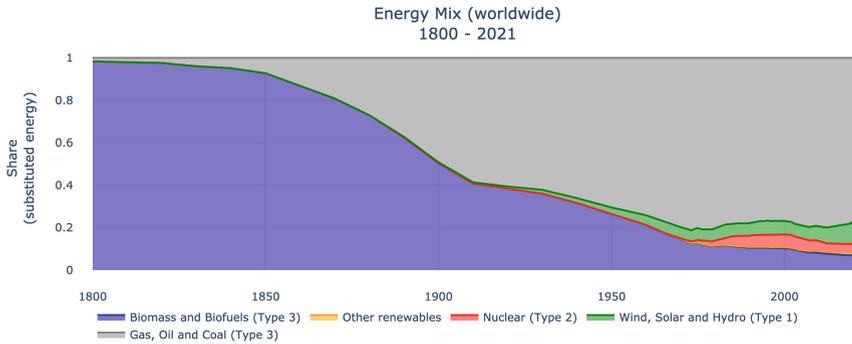


Fig. 3. The graph depicts the proportion of energy sources in the global primary energy mix. The underlying data comes from [14], compiled from data by [15] and [16]. [14] ensures comparability between energy forms and data sets by (i) converting to terawatt-hours, and (ii) converting non-fossil energy sources to their fossil input equivalents (this treats non-fossil energy sources as if they have the same inefficiencies as fossil fuels; without this conversion, the percentage of fossil fuels in the global mix would be larger).

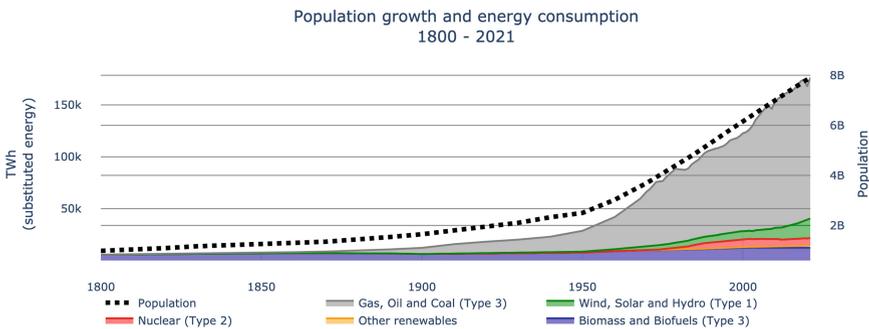


Fig. 4. The graph shows the absolute primary energy consumption by energy sources and the world population. The large proportion of Type-3 resources indicates the onset of a Lotka-Volterra cycle. For underlying data and the substitution of non-fossil energy sources, see Fig. 3. The population data set comes from [17], which is derived from data by [18] and [19].

5 The Law of Reliable Resource Supply

Altshuller's TRIZ [1] is lacking a reflective resource perspective. Since the mid-19th century, it is evident that humanity has begun to turn away from renewable Type-3 resources, increasingly resorting to fossil fuels instead (see Fig. 3). The growth of the proportion of fossil energy carriers in the global energy mix continued until the early 1970s, after which it began to stabilize at around 80% (see Fig. 3 and 5).

Since Altshuller's TRIZ is based on patent analysis ([1, 21]) and the first patent law in the Russian-speaking world was only signed in 1812 (see [22]), the patents Altshuller and his colleagues could refer to in their studies, beginning in the 1940s/50s, emerged during this period of growing use of fossil energy carriers. Altshuller's awareness of the importance of energy is evident in his laws of technology development ([1, 2]). In

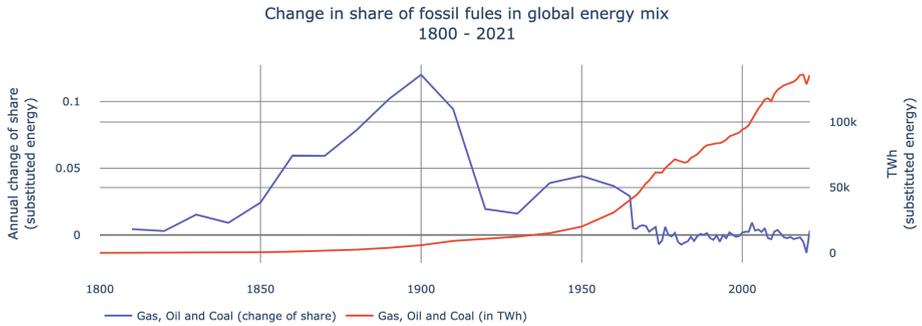


Fig. 5. Change in the proportion of fossil energy carriers in the global energy mix. Since the 1970s, there has been little change in relative consumption, although absolute consumption continues to increase linearly.

fact, the conversion of energy by technical systems is the first of his eight laws of the evolution of technical systems, which are:

- 1) The Law of System Completeness
- 2) The Law of Energy Transmission
- 3) The Law of Synchronization
- 4) The Law of Increasing Ideality
- 5) The Law of Uneven Development of Sub-systems
- 6) The Law of Transition to the Super-system Level
- 7) The Law of Transition from Macro to Micro Level
- 8) The Law of Increasing Use of Substance-Field Systems

For a more detailed determination of these laws, see [2], which shows that Altshuller's eight laws can be derived from the concept of artificial instrumental systems by identifying its necessary features and by projecting them to their most ideal extreme under the constraints of resource scarcity and competition. However, Altshuller gained them from the analysis of patents ([1, 2]). This inductive approach has two drawbacks:

- Since the laws have not been derived from any principle, the conditions of their validity remain unclear. The boundaries of the validity of Altshuller's laws were made explicit in [2]. In this context, it is shown that Altshuller's inductive approach based on patent analysis should rather serve to validate and falsify deduced trends or laws, but not to infer them.
- As Altshuller's inductive approach can only refer to a limited history of technology, it remains blind to long-term trends that contradict the choices made in this limited timeframe.

This second weakness leads directly to Altshuller's disregard for the resource dependency of instrumental systems and the resulting implications. For Müller-Christ's approach, however, this dependency is fundamental and is even understood as the origin of the contradiction between sustainability and efficiency [3].

In Sect. 3, we already pointed out what genuine sustainability implies in the context of Type-1, Type-2, and Type-3 resources. If Altshuller had not only analyzed technical

patents, but also solutions occurring in nature (attempts at this can be found, for example, in [23] or [24]), he should have noticed that the millions of years of evolution of life inevitably depended on sustainable use of resources. The principles of thermodynamics are crucial for such sustainable use. Altshuller was certainly aware that energy can neither be created nor destroyed, but only transformed. However, the consequences of this could only be found to a limited extent in patents during the era of fossil energy carriers, and therefore did not find their way into Altshuller's laws of technology development. Since the rate at which energy can be made available as needed using fossil energy carriers is much higher than the rate at which the sun supplies a limited area with energy, systems have been able to become increasingly energy-intensive since the 18th century. However, this intensity was purchased through the rapid consumption of existing resources. The systems developing from this are therefore standing on shaky ground. This leads to the paradox that a system could be developed according to all Altshuller's eight laws of technical system evolution and still stop existing long before even the most primitive biological species disappeared. Laws of technology development that can describe only a few hundred years are neither laws nor are they significant in an evolutionary context, which involves millions of years. To establish a stable foundation, Altshuller would therefore have to add another law to his principles:

9) The Law of Reliable Resource Supply

As shown in [2], Altshuller's laws can be generated through the principle of idealization - i.e., by assuming desirable extreme values for necessary parameters of instrumental systems. Applied to the resource question, it can be observed that every instrumental system is made from resources and that it consumes additional resources as long as it is to deliver its primary function. The availability period of these resources can be questioned. The longer this period, the better the prospects for the potential longevity of the system in question. According to the principle of idealization, the value of the parameter of the resource availability period should therefore be maximal. Based on this assumption, design principles for all three resource types can be inferred. Accordingly, the Law of Reliable Resource Supply suggests,

- that Type-2 resources (i.e., non-renewable resources) are recycled,⁴
- that Type-3 resources (i.e., renewable resources) are not consumed more than they are regenerated,
- that Type-1 resources are transformed in such a way that sufficient surplus energy is provided to recycle the necessary Type-2 resources and allow the necessary Type-3 resources to regrow, and
- that at the end of the energy supply chain necessary for recycling and regeneration of Type-2 and Type-3 resources, there are Type-1 resources.⁵

⁴ This demand corresponds to the principle of circularity in the bio-economy (see [26]).

⁵ For the thermodynamic necessity of the renewal of Type-2 and -3 resources by Type-1 resources, see, for example, [27].

Systems that develop contrary to this law mark regressions, as they will phase out of existence earlier from an energetic perspective than those systems relying entirely on the use of Type-1 resources.⁶

However, even Type-1 resources do not last forever. The sun is expected to expand into a red giant in about 5 billion years and likely engulf the Earth [5]. If it were possible to generate similar supply periods using Type-2 resources, these artifacts could be regarded as quasi-Type-1 resources. Nuclear fusion – essentially a replica of the sun on Earth – is the most promising candidate here. It is estimated that humanity could be supplied for several million years in this way [25]. Whether this will succeed, however, remains uncertain. From this, another design principle can be formulated:

- Utilize Type-2 or Type-3 resources in such a way that they can open up supply periods that, from a human perspective, correspond to those of Type-1 resources.⁷

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⁶ However, this is only the case if the unsustainable energy-intensive systems have not completely eradicated the sustainable ones.

⁷ We are grateful for the suggestion of one of the anonymous reviewers to illustrate the law of reliable resource supply by the example of ammonia production. In 1898, Sir William Crookes raised the problem of the depletion of the naturally occurring nitrate fertilizer sourced from Chile and predicted starvations by 1921 if no solution was found [28]. Only about 10 years later, Carl Bosch and Fritz Haber demonstrated how ammonia could be produced by using the abundant nitrogen from the air in combination with hydrogen, pressure, a catalyst, and a heating and cooling cycle. According to [28], our world population would be 40% smaller without this (or a similar) invention. From the perspective of the law of reliable resource supply, the Haber-Bosch cycle has replaced a Type-2 resource (the natural nitrogen from Chile) necessary for the creation of Type-3 resources (agricultural products) by making use of an abundant Type-2 resource. However, 5% of today's natural gas consumption worldwide are consumed by this process [28]. In other words, in its current form, the process depends on a scarce Type-3 resource. To make its production sustainable, the hydrogen used for ammonia production needs to be sourced from an abundant Type-2 resource such as water powered by Type-1 energy resources, which can be achieved by electrolysis [29].

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Problem Analysis for Green Industrial Policy

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Abstract. This paper addresses the importance of holistic problem analysis in the design of green industrial policies. Specifically, we show that the problem analysis that underpins emerging green industrial policies reduces existential environmental challenges to one objective -greenhouse gas mitigation neglecting other crucial environmental challenges and the tradeoffs between them. This narrow approach can lead to inadvertent support for industrial “solutions” that exacerbate risks like biodiversity loss, toxic pollution, and resource depletion to a degree that undermines the central objective of preserving a livable planet. Our analysis highlights these common shortcomings and provides a fuller characterization of the problems that green industrial policy needs to contend with to fulfill its objectives. Building on this assessment, we discuss how green investment and government procurement policies, in industrialized and developing nations alike, can adopt more holistic problem analysis as a starting point for analyzing tradeoffs between environmental objectives in policy implementation. We specifically propose a methodology that with the assistance of artificial intelligence could be immediately used to improve the selection of projects funded by the US Department of Energy through the Inflation Reduction Act, as well as other green public investment policies, to optimize improvements along various dimensions of pressing environmental challenges. Our analysis and proposals offer guidance to policymakers seeking to improve the environmental outcomes of green industrial policy and to avoid unintended adverse environmental impacts. This paper introduces the challenge of systematic problem analysis and trade off analysis to the field of green industrial policy design.

Keywords: Sustainability · Green Industrial Policy · Green Public Investment · Economic Transformation · Problem Analysis · Tradeoffs · Artificial Intelligence

1 Introduction

Mounting global environmental challenges have spurred growing interest in green industrial policy the concerted use of various types of public policy tools to alter production systems in line with environmental objectives. Green industrial policy agendas have emerged in both industrialized and developing countries with massive funding streams being dedicated to their deployment. The effectiveness of these policies in solving pressing environmental problems, however, hinges on implementation what precise criteria

are utilized to assess and select projects for funding, which projects are given preferential treatment, and how their impacts are monitored and evaluated.

However, both academic explorations and practical applications of green industrial policy are in their nascent stages and discussions have so far omitted systematic discussions of the set of relevant environmental challenges and corresponding parameters for green industrial policy design [1–7]. Although there is a significant literature devoted to problem analysis for sustainable engineering and industry (for example, [8–10]), the insights from this literature have not been translated into the realm of public policy, where industrial policy design is mostly guided by methodological traditions rooted in the social sciences, public administration, macroeconomics and finance.

Having worked in the green industrial policy space for more than a decade, the lack of holistic problem analysis is becoming increasingly apparent. However, we are not aware of works offering easily implementable solutions to the problem. This paper seeks to help fill that gap through three contributions that we hope will stimulate efforts at systematic problem analysis in green industrial policy research and practice, as well as further exploratory translations of TRIZ methods to economic policy design more generally:

- i. A critical examination of the problem analysis embodied in emerging green industrial policy agendas that is, an inductive identification of the problems these policies have been designed to solve, and an empirical and deductive identification of problems relevant to the objective of preserving a livable planet that have been unduly neglected. While we do not attempt a complete, systematic characterization of the set of the existential environmental challenges our species faces, we propose that policymakers can take a simple first step toward improving the design of green industrial policies that is, policies that seek to reshape production methods and production systems to secure a livable planet by simply acknowledging a broader set of relevant environmental problems and corresponding parameters to be improved in industrial production, beyond greenhouse gas emissions. This kind of holistic mapping of problems and corresponding parameters is a first step for developing trade-off analysis methodologies in green industrial policy design and implementation.
- ii. A discussion of the risks posed by green industrial policies founded on incomplete problem analyses, and in particular incomplete analysis of tradeoffs between “green” objectives.
- iii. A proposal for making green industrial policy more holistic, which can be supported by artificial intelligence, including a methodology and a tool immediately applicable to the implementation of the Inflation Reduction Act and to similar policies for green public investment.

It bears highlighting that the central purpose of this paper is to contribute to better design of *public policy* that is, it focuses on the TRIZ-typical identification of secondary problems and resulting tradeoffs in the domain of public policy design, rather than directly to the domain of engineering. Because public policy (especially green industrial policy today) so heavily influences industrial development and innovation, improving policy design can more effectively catalyze sustainable industrial production and engineering solutions.

The paper is structured in three sections. Section 2 examines the landscape of emerging green industrial policies with a focus on the United States and its flagship green industrial policy, the Inflation Reduction Act of 2022. We examine the implicit and explicit problem analyses inherent in emerging green industrial policies, as embodied in legislative texts and official government documents, and show that although policymakers understand the primary function of green industrial policies to be the transformation of production systems to preserve a livable planet the concrete policies they have advanced are largely limited to a much more narrow function: greenhouse gas emissions mitigation.

We argue that the reduction of the problem of green industrial policy to this single challenge poses a fundamental risk to the integrity of green industrial policy because, although greenhouse gas mitigation is necessary to achieve the primary goal of preserving a livable planet, it is not sufficient: scholarship on existential environmental threats clearly shows that a host of other environmental problems need to be overcome to fulfill the primary goal of preserving a livable planet. These include a host of environmental risk factors inherent in industrial production, such as biodiversity loss, toxic pollution, natural resource depletion, and more. Consequently, green industrial policy design must factor in all these parameters and the tradeoffs between them (for example, to assess whether or to what extent a green technological upgrading project should be supported by green industrial policy funds, policymakers should assess how the project will affect all parameters relevant to the primary objective of preserving a livable planet).

In Sect. 3 we discuss how, in the absence of a more holistic understanding of the challenges of green industrial policy, the more narrowly-focused design of green industrial policies currently being advanced may exacerbate various environmental risk factors, thereby undermining their explicit primary goal of preserving a livable planet.

To contribute to the design of more holistic green industrial policies, in Sect. 4 we illustrate the potential of policy solutions based on more holistic problem analysis. First, we discuss early efforts to design policy solutions based on fuller problem analyses, namely through the incorporation of environmental lifecycle analysis into green public procurement policies. We then propose a tool that can help introduce more holistic thinking into the methods policymakers use to select projects and target funds in emerging green industrial policies around the world, which primarily use the policy vehicle of public investment. Specifically, we have built a prototypical AI-supported web application for approximating the impacts of projects on relevant environmental parameters, and the tradeoffs between them. Using the example of the US Inflation Reduction Act and the funding it allocates to the Department of Energy's Loan Programs Office, we discuss how this assessment methodology can both motivate and form the basis for tradeoff analysis and facilitate the resolution of tradeoffs by both incentivizing applicants to anticipate and mitigate the harmful effects implied by their proposals (thereby minimizing the number of tradeoffs encountered by the investor/funder), and selecting proposals to find the optimal balance between the emerging tradeoffs.

Although this paper identifies shortcomings in the problem analyses that form the basis for emerging green industrial policy paradigms, it does not aim to fully correct for those shortcomings. More systematic assessments are needed on a policy-by-policy, nation-by-nation, basis to understand the specific ways in which governments can improve the quality of their green industrial policies.

Nevertheless, our framework, illustrative examples, prototypical web application, and methodological proposals may help guide policymakers in the design of green industrial policy solutions including immediate modification of existing green public investment policies that yield better environmental outcomes and avoid adverse effects that unintentionally undermine the primary objective of preserving a livable planet.

2 Problem Analysis in Emerging Green Industrial Policies

2.1 Emerging Green Industrial Policy See the “Greening” of Industrial Production as a Problem of Emissions Reductions

Attempts to use public policy to curb the environmental impact of industrial activity have a long history. Most types of modern production of useful goods have some degree of negative environmental impact. Such impacts, in turn, usually translate either directly or indirectly into negative impacts on human health. To mitigate those impacts, countries have traditionally resorted to different forms of regulation, such as emissions caps, pollution fees, or technology adoption requirements, intended to mitigate the amount of pollution created as a byproduct of industrial production.

In recent years, however, as the extent and urgency of environmental threats has grown to unprecedented levels, governments have moved toward increasingly ambitious approaches to production-sector transformation. “Green industrial policy” agendas have emerged around the world including major programs like the European Green Deal Industrial Plan [4] and the US Inflation Reduction Act [5, 6]. Green industrial policy has also become a popular topic in the academic sphere, with most works devoted to descriptive accounts of emergent policies, modeling of emissions reductions scenarios, or discussions of institutional arrangements and policy tools relevant for a green transition [1–3].

Both the academic literature and the practice of green industrial policy share a common understanding of the basic challenge of green industrial policy: the preservation of a livable planet. But, the concrete policies and policy prescriptions advanced under the umbrella of green industrial policy tend to be largely limited to a much more narrow function greenhouse gas mitigation.

Let us take the example of the emerging green industrial policy in the United States. In 2022, the United States Congress passed the Inflation Reduction Act [5]. Largely considered to be a “climate bill,” this legislation devotes an unprecedented amount of public funds to support the energy sector (Table 1). Most funds are devoted to “clean” energy programs, and to the cleanup of heavy industry and certain types of transportation. Smaller amounts of funding are devoted to other environmental objectives, like the cleanup of toxic sites and the mitigation of toxics.

Although a mixture of environmental concerns are embodied in the spending categories of the IRA, it is clear that renewable energy is the central and almost exclusive focus of the bill. Furthermore, the rationale given for focusing on renewable energy, both in the legislation and in the discourse of policymakers and commentators, is predominantly rooted in the challenge of climate change.

The same rationale underpins green industrial policy measures beyond the Inflation Reduction Act. For example, the government’s “Buy Clean” policies for green public

Table 1. US Inflation Reduction Act–Breakdown of Investments [11].

Sector	Investment (in billions of US\$)
Energy	250.6
Manufacturing	47.7
Environment	46.4
Transportation and electric vehicles	23.4
Agriculture	20.9
Water	4.7
Total	393.7

procurement one of the government’s most agile tools for industrial policy deployment exclusively focus on greenhouse gas emissions standards [7]. In fact, the language used to describe the initiative centers even more specifically on carbon emissions reductions: “The Federal Government is the largest purchaser in the world, with annual purchasing power of over \$650 billion. To harness that procurement power to support low-carbon, made in America materials, President Biden charged his Administration through his December 2021 Federal Sustainability Plan and Executive Order 14057 to launch a Buy Clean Task Force and initiative to promote use of low-carbon, made in America construction materials” [7].

Beyond the US context, similar rationales are in use in other polities experimenting with green industrial policy. The EU’s “Green Deal industrial Plan” [4] also squarely targets the energy sector and zones in on greenhouse gas emissions as the “problem” to be mitigated.

The academic literature on green industrial policy mirrors this trend in policy practice. That is, its conceptualization of green industrial policy similarly centers on climate change and more specifically greenhouse gas emissions from the energy sector as the core problem to be tackled [1–3].

As important as climate change mitigation and emissions reductions are for the preservation of a livable planet however, they are not sufficient.

2.2 “Greening” Industrial Production Requires Much More Than Emissions Reductions

The way we make many useful goods from steel for housing to fertilizer for food uses natural resources unsustainably and produces all manner of air, land, and water pollution that severely undermines human health and the ability of the planet to support life in the long run (see, for example [12] and [13]). There is growing awareness that threats like biodiversity loss and soil degradation may pose as large an existential threat to human survival as climate change [14, 15]. While the tangible impacts of some of these processes are not as thoroughly quantifiable or extensively modeled as climate change due to their extreme complexity, empirical evidence has been sufficient to generate a broad intuitive understanding that a planet without a diversity of species and soil that

cannot produce nutritious food is not likely to be able to support life. As the United Nations Food and Agriculture Organization puts it: “12 million hectares of topsoil are lost every year. 25% of the earth’s surface has already become degraded. This could feed 1.5 billion people [...] we have about 60 years of harvests left—and then?” [16].

As alarming as these problems are, today’s green industrial policies almost completely neglect to incorporate them. They mistake the particular (climate change) for the general (complex, interlocking ecosystems in crisis).

While we do not attempt a complete, systematic characterization of the set of the existential environmental challenges our species faces, we propose that policymakers can take a simple first step toward improving the design of green industrial policies that is, policies that seek to reshape production methods and production systems to secure a livable planet by simply acknowledging a broader set of relevant environmental problems and corresponding parameters to be improved in industrial production, beyond greenhouse gas emissions. As a heuristic, one can look to analysis underpinning the United Nations Sustainable Development Goals to identify environmental challenges that, on the basis of overwhelming scientific evidence, have been elevated to the status of global policy challenges. These include at least the following (themselves interrelated):

- i. **Biodiversity loss.** Rapid ongoing biodiversity loss threatens the resilience of life on earth, which depends on the preservation of diverse forms of life to sustain ecosystems capable of adapting to changing environmental circumstances. Biodiversity loss is due to various factors including the two challenges below.
- ii. **Natural resource attrition and degradation,** such as deforestation and the degradation of productive soil which threatens access to food.
- iii. **Dangerous levels of waste and several types of pollution.** Pollutants severely harmful to humans, other forms of life, and ecosystems include a host of air emissions including and *beyond* greenhouse gases as well as various forms of toxic and ecosystem-threatening land pollution and water pollution. In addition to causing systemic problems like climate change and ocean acidification, these cause direct harms to life forms, and threaten biodiversity.

If the primary function of green industrial policy is to preserve a livable planet, green industrial policies have to be designed in a way that adequately assesses their likely impacts on all of the above challenges and corresponding parameters. If only one critical parameter (e.g. greenhouse gases) is contemplated, this can easily lead to policies that improve that parameter at the expense of other critical parameters, unwittingly leading to a net negative impact on the primary objective of preserving a livable planet.

This is not to say that a green industrial policy can only be considered “green” if it improves all relevant parameters. In some cases it may be very reasonable to pursue policy interventions that improve one parameter at the expense of another. What is not reasonable is not to acknowledge all relevant parameters, not to weigh the trade offs between them, and not to attempt to resolve those tradeoffs either by ensuring that policies include design features that motivate applicants to find innovative solutions to tradeoffs or by pursuing compensatory measures through complementary policies. In Sect. 4 we illustrate how this approach can be applied to existing green industrial policies.

But first, to clarify the risks of designing policies based on incomplete understanding of environmental challenges, the section that follows analyzes the risks of reducing the core problem of green industrial policy to greenhouse gas emissions reductions.

3 What Problems Should Green Industrial Policy Try to Solve? Gaps in Dominant Green Industrial Policy Problem Analyses and Their Risks¹

This section elucidates the risks inherent in the design of green industrial policies based on incomplete problem analyses.

3.1 Missing Problem #1: Non-greenhouse Gas Pollutants

As mentioned above, the vast majority of green industrial policies are squarely focused on solving the problem of greenhouse gas mitigation as the core challenge to be tackled in the quest to preserve a livable planet.

However, policies exclusively focused on reducing greenhouse emissions can easily “fail to contribute to a more livable planet if they do not factor in highly dangerous pollutants that are *not* greenhouse gasses. Iron and steel facilities, for example, emit lead and other hazardous air pollutants [18], exposure to which has been demonstrated to cause adverse health effects like chronic and acute disorders of the blood, heart, kidneys, and reproductive system [12]. Lead accumulates in bones, blood, and soft tissues of the body and can affect development of the central nervous system in young children, resulting in devastating neurodevelopmental effects even in minuscule amounts [17, 19].

In addition, “toxic pollutants like lead contaminate land and water in addition to air and can even be transmitted through consumer products [20]. Therefore, industrial policies that aim to make the planet more livable need to take into account, and aim to reduce, the full range of hazardous pollutants associated with particular industries, as well as the various vectors through which those pollutants impact human health” [17]. Failure to do this can lead to counterproductive measures that may reduce greenhouse gas emissions without reducing toxic pollution or even making it worse.

3.2 Missing Problem #2: Land, Water, and Ecosystem Harms

Green industrial policies may adequately account for all relevant pollutants but still undermine the livability of the planet if they fail to factor in the broader impacts of the industries they seek to transform on critical ecosystems.

At the moment, the almost exclusive focus of green industrial policies on greenhouse gas mitigation has also implied a singular focus on air pollution. Land and water pollution has been excluded from concerted attempts to transform industrial production. This is

¹ Parts of this Sect. 3 are adapted from a previous publication [17] co-authored by one of the authors of this paper (Isabel Estevez). Sentences that have been directly transposed are in quotations and correspond directly to the contributions from Isabel Estevez to [17].

not to say that industrial land and water pollution is altogether forgotten in countries' policy agendas (in the US, for example, the Environmental Protection Agency regulates industrial water pollution through regulation derived from the Clean Water Act). But concerted attempts to invest in the transformation of industries like the effort to shift the energy sector to renewable energy in the US's IRA are exclusively focused on reducing *air* emissions from the energy sector and do not contemplate the land or water pollution generated by these industries. This creates the risk of supporting industrial activities that reduce air pollution while increasing land and water pollution.

Furthermore, even policies that adequately target the reduction of all hazardous pollutants may not account for the problem of unsustainable extraction of scarce resources. This is the case for both the US IRA [5] and the EU's Green Deal Industrial Plan [4], neither of which contemplate resource scarcity. The omission of resource sustainability creates the risks that projects funded by green industrial policy may actually "*degrade* the ability of ecosystems to produce critical goods efficiently for example, depleting soil through tillage, threatening food security, or depleting aquifers in water-scarce areas for industrial production" in the medium term [17]. "The production of hydrogen through electrolysis, for instance, is highly water-intensive supplying hydrogen for a 288-megawatt power plant using 100% hydrogen would require the equivalent of an Olympic-size swimming pool of water every 12 h [21] so, unless it is produced in a setting with great water abundance, hydrogen production could potentially threaten neighboring food production or access to drinking water" [17].

Industrial transformation policies can also "deplete biodiversity or damage ecosystems to such a degree that they are unable to support life at all. For example, in the lithium-rich Andean regions of Argentina, Bolivia, and Chile, Indigenous farmers increasingly compete with miners (and implicitly downstream industries like electric vehicle battery manufacturing) for highly scarce water supplies. In Chile's Salar de Atacama, lithium and other mining activities consumed 65% of the water [22], causing groundwater depletion and environmental degradation to the point that local communities were forced to abandon ancestral settlements. Policies aimed at industries like solar, which rely on large-scale expansion of mineral extraction in delicate ecosystems and vulnerable communities, must factor" those impacts into their accounting and analysis of costs and benefits [17].

Currently, the green industrial policies embodied in the IRA and the EU's Green Deal industrial plan do not require industries to take into account resource depletion either at the targeted industrial facility or in its related value chains.

4 Toward a More Holistic Green Industrial Policy

Section 3 highlighted some of the risks inherent in industrial policy design that fails to adequately account for the full scope of critical environmental challenges posed by industrial production. However, designing industrial policies in a way that comprehensively addresses those risks is no easy task. It poses great methodological and data collection challenges as well as the development of frameworks for analyzing—and ideally promoting the resolution of—the tradeoffs that inevitably arise from attempting to solve multiple environmental challenges at once.

Notwithstanding these challenges, below we discuss some immediately applicable methods to improve green industrial policies by adopting a broader problem-analytical framework. Note that this section only addresses tradeoffs between environmental objectives, not tradeoffs between environmental objectives and technical, social, or economic objectives, which should also be addressed.

4.1 Green Procurement Policies: Improving Environmental Product Declarations

Let us take, for example, the case of federal clean procurement “Buy Clean” policies in the United States. Currently, US Buy Clean policies exclusively target greenhouse gas emissions reductions. US Buy Clean policies give preferential treatment in public procurement to products that meet certain environmental standards as reflected in Environmental Product Declarations (EPDs) [23] that use life cycle analysis [24] to measure the environmental impacts of products. However, at the moment, the EPDs required for green procurement only measure environmental impact in terms of greenhouse gas emissions. As proposed in [17], to more adequately capture the environmental impact of products, policymakers could specify the Environmental Product Declaration standards to also include disclosures of a broader set of environmental parameters, like non-greenhouse gas toxic emissions, resource and biodiversity depletion and ecosystem resilience.

This same logic can be extended to emerging global green industrial policy frameworks with procurement components, such as the United Nations Industrial Deep Decarbonization Initiative [25] led by the United Kingdom and India which is also likely to influence green procurement policy in both industrialized and developing countries.

4.2 Green Public Investment Policies: Improving Selection Methods for Energy Projects Mechanism with AI Tools

The product-level approach above can also be applied at the project-level to assess projects for green public investments like those included the US Inflation Reduction Act. As discussed above, the IRA allocates hundreds of billions of dollars of public funding largely to renewable energy supply chains and projects and is expected to leverage substantial additional private funds. In the case of the IRA, reductive problem analysis is encoded at the level of statute (the legislation itself), which systematically poses greenhouse gas emissions reductions as the single environmental parameter to be optimized in green energy projects. However, this constraint does not prevent funding administrators from using more holistic criteria to score and prioritize projects.

AI and TRIZ-based solutions can be deployed to make this feasible. [8] presents a 11 × 11 correlation matrix of eco-requirements such as *energy consumption*, *air pollution*, or *acidification* indicating whether its improvement tends to result in the improvement or in the deterioration of the other ecologically relevant parameters.² These tendencies towards improvement or deterioration of the other parameters are based on patent studies

² The full list of parameters is: Energy consumption, Air pollution, Acidification, Safety risks, Chemical waste disposal, Depletion of abiotic resources, Toxicity, Eutrophication, Photochemical oxidation, Water pollution, Solid Waste.

and expert opinions. The matrix suggests that developing a solution for one of the 11 ecologically relevant parameters deteriorates on average 3 other ecologically relevant parameters. Thus, it would be unreasonable to assume that we can ignore secondary problems down the line when trying to solve for one of these dimensions.

As a consequence, it would be equally unreasonable from the perspective of policy makers and administrators to fund projects without properly assessing the impact of the project on all dimensions relevant to the overarching goal of preserving a liveable planet. By building a procedure of assessing the impact on all dimensions into the procurement process combined with the binding commitments to select projects with the aim of achieving the optimal combination from the perspective of the overarching goal, two benefits can be expected:

- i. applicants are incentivized to anticipate and resolve secondary problems (which can be supported by TRIZ tools such as ARIZ-85C [26, 27] before applying for grants since it will maximize the likelihood of being selected, and
- ii. administrators are obliged to fund the optimal combination of projects avoiding the pitfall of undermining the overall goal of preserving a liveable planet by overlooking compounded secondary problems.

However, it is time consuming to assess every proposal across all dimensions. To automate this process, AI can provide support. A large language model (LLM) can assess a sufficiently well defined proposal by assigning 1 for a likely positive impact, -1 for a likely negative impact, and 0 for no impact with regard to each dimension. Such a model combined with appropriate prompt engineering could be made available on the website of the funder using the latest LLMs. Applicants can then check in advance the secondary problems indicated by the model. If the model is wrong, applicants can highlight in their proposal why the model is wrong. In case it indicates a real secondary problem, applicants can increase their chances of being selected by developing a solution for the secondary problem right from the start.

To illustrate this approach, we have built a prototype in the form of a publicly available web application [28]. The underlying prompt engineering is subject to ongoing development discussed in the methodology section of the website. The GitHub repository is publicly available and the evolution of the prompts can be inspected there thanks to version control [29].

5 Conclusions

The growth of interest in green industrial policy in recent years is a positive sign. It marks growing recognition of the fact that the scale of the global environmental challenges we face will require large-scale transformations of our production systems.

However, as we have discussed in this paper, emerging green industrial policies are currently not guided by holistic problem analysis that encompasses the scope and extent of existential environmental threats.

Specifically, the singular focus on greenhouse gas emissions mistakes the particular (climate change) for the general (complex, interlocking ecosystem crises) and thereby neglects a host of problems that must also be addressed by green industrial policy. These

include non greenhouse gas toxic emissions, biodiversity loss, and natural resource attrition, among others.

Many of these problems are difficult to quantify and model due to their extreme complexity, but they nonetheless have to be taken into account. Policymakers must use creative methods to incorporate more comprehensive problem analysis (and more comprehensive solutions) into their policy design.

This paper has sought to contribute to more holistic industrial policy design by analyzing the risks involved in neglecting factors like toxic pollution and resource attrition when designing green industrial policies. We have also illustrated how two specific policies green government procurement and green public investments in the energy space could be immediately improved to better address the full scope of environmental challenges we face. To support those improvements, we have developed a prototypical AI-supported web application for approximating the impacts of projects on relevant environmental parameters, and the tradeoffs between them.

We hope our analysis, methods, and estimator tool can support further efforts at building more holistic green industrial policies, based on more complete understandings of the problems that green industrial policies need to address in specific contexts.

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General Vision of TRIZ



TRIZ Ideas in a Systematic Presentation

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Abstract. Genrikh Altshuller started working on the theory of inventive problem solving (TRIZ) almost 70 years ago. The whole subsequent period is a continuous development of TRIZ, both by the founder himself and by his associates, students, and followers.

I developed my own version of TRIZ by combining modern achievements of systems theory and classical TRIZ. At first I called my author's approach the PN-method (P.N. are my initials), then the Recommendations on Systemic Problem Solving. At present I think that the most acceptable variant of the title is "TRIZ Ideas in a Systemic Presentation". The content of my approach is stated in 8 written and published books and many articles.

The following material outlines the structure of the approach and then compares it with classical TRIZ to show the significant differences. The amount of information provided is determined by the allowable size of the article. Particular questions of the approach, its detailing, and analysis of examples of application - all this is in my books. I formulated TRIZ-contradiction in a modified form. My approach allows to concretize the notion of ideality by means of twelve system aspects. TRIZ suggests using the abbreviation MATCEM. I think the transformation of MATHEM into TEI is correct. I offer the model of system "technical result embodiment". The application of my approach to the patenting stage of a new technical solution, as well as its other useful use, is shown.

Keywords: New TRIZ Approach · PN-method · Innovation · Technical Creativity · Invention · Problem-Solving · Inventiveness

1 General Information

The approach I have developed is obtained by combining classical TRIZ [1] and modern achievements of systems theory [2–4]. In this connection, when starting to solve any problem, one should rely on the basic concepts of systems theory and identify the system that generates this very problem. Such a system can be represented as follows (Fig. 1).

In the presented system the elements, connections, boundary separating it from the environment, input, output and interaction with the environment are highlighted. It should be noted, distinguishing the system from the structure of the problem is an.

In the presented system the elements, connections, boundary separating it from the environment, input, output and interaction with the environment are highlighted. It should

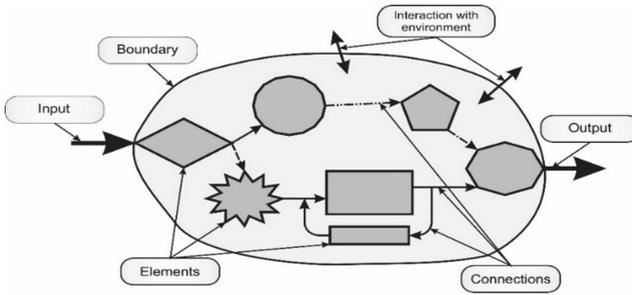


Fig. 1. Graphical representation of the system.

be noted, distinguishing the system from the structure of the problem is an independent creative work. It is simple to define a system when, for example, you hold a pen in your hands: here is the body of the pen (element 1), here is the cap (element 2), and here is the ink reservoir (element 3)... There are connections between these elements (ways to connect elements to each other)—connection 1, connection 2, connection 3 etc. The thought of a person and the effort of his hand, moving the pen when writing, is the input of the system. The footprint on paper is the output of the pen system. Interaction with the environment can consist in the fact that a person is distracted, for example, by external sounds during writing. For this reason, the written text may contain errors. This is the simplest example. What if it is a wireless computer network? What if it is a failure of a complex technical device and the root cause is not obvious? It is clear a priori that in the latter cases, even taking into account all the elements of the system is a difficult task. It is even more difficult to accurately determine the connections between them. With this example, I show that my approach is suitable for solving not only technical, but also any other problems.

Then the selected system should be considered in 12 system aspects, that is, 12 times to change the point of view of the essence of the problem (Fig. 2), the names of aspects are given in the same figure.

The ten systemic aspects are well known; I have borrowed them from systems theory [4, 5]. Two aspects, virtual-modelling and reconstructing, are suggested by me; their names are the subject of discussion and, possibly, clarification. The most general idea of the direction of aspects is given by their names, full information can be found in my books [6–8], as well as in my video [16] and other videos posted on the same channel.

The inclusion of virtual-modelling and reconstructing aspects in my approach is predetermined by the high intensity of technology development associated with artificial intelligence and global digitalization.

Each of the selected aspects includes a certain set of system actions, the performance of which allows obtaining the desired solution of the problem. For example, the element aspect contains the following actions: change, take into consideration new properties of an element or its parts; change property parameters (dimensions, shape, mass, symmetry, homogeneity, color, temperature, etc.); change the position of an element, etc. A total of 86 system actions are contained in all aspects; I have compiled a list of them on the basis of generalization of TRIZ tools and provisions of the theory of systems.

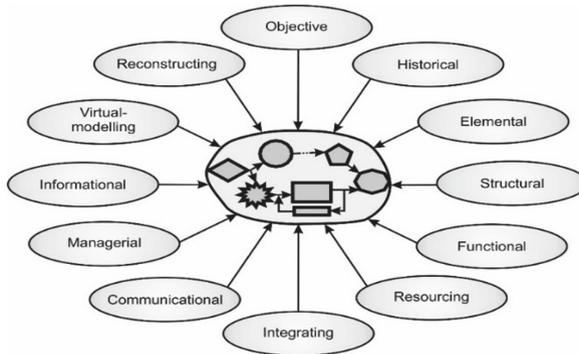


Fig. 2. Systematic consideration of the object of analysis.

2 TRIZ-Contradiction

A solution obtained by performing one or a set of system actions can be strengthened by formulating and solving a TRIZ-contradiction. TRIZ-contradiction is known in the TRIZ community as a physical contradiction. The main difference of my proposed term “TRIZ-contraction” is that, using system concepts, it can be called supersystemic in relation to the term “physical contradiction”. Among other things, I believe that the use of my proposed term contributes to popularization of TRIZ, because even an outsider, having mastered this tool, will subconsciously understand that there is some TRIZ, even if not known to him, and he could solve an important problem for himself with its help.

I emphasize that, based on system preconditions, I formulated TRIZ-contradiction in a modified form in comparison with known in TRIZ formulations of physical contradiction: “TRIZ-contradiction is a situation in which conditions of a problem impose contradictory requirements to one of components of the following list:

- the analyzed system as a whole;
- element of this system;
- the connection between the elements;
- resource consumed by the system;
- function performed by the system;
- the interaction of the analyzed system with its environment.

This definition is more complete than the known ones, and takes into account all the components shown in Fig. 1 and characteristic of any system. Accordingly, this definition is systemic. The most close to my definition of TRIZ contradictions is given by the author of the book [17]: “As part of the physical contradiction, it is envisaged to present diametrically opposite requirements for a certain part of the technical system.” This definition of contradiction probably mentions the system for the first time. However, this definition is not complete and the differences are obvious.

Examples of conflict resolution results:

- the analyzed system as a whole: all parts of the umbrella are folded (modern umbrella);
- element of this system: only the dome of the umbrella folds. It is an umbrella-cane;

- the connection between the elements: the hinge in the connection of the dome and the handle of the umbrella works only when unfolding;
- resource consumed by the system: the amount of fuel consumed by the engine depends on the load;
- function performed by the system: the escalator at the airport moves only if there are passengers;
- the interaction of the analyzed system with its environment: the umbrella is held overhead only when it rains or the bright sun shines.

3 Ideal System

One of the main concepts in TRIZ is that of ideality, including the concept of an ideal system: there is no system, but the function is fulfilled. It is clear a priori that an ideal system defined in this way is some theoretical abstraction, just like “an absolutely black body”, “an ideal gas” in physics, “a point”, “infinity” in mathematics, etc. This unattainable limit, nevertheless, has an enormous heuristic power and determines the gradient of the researcher’s aspirations when dealing with a problem. In work [1], the ideal is defined as follows: the ratio of the sum of useful functions performed by the system to the sum of payoff factors (all cost elements) should tend to infinity. There is no further detail.

My approach allows to concretize the notion of ideality by means of twelve system aspects: the transformations proposed within each aspect, if they are the best, in fact - locally ideal, in the aggregate should also lead to the final ideal solution. Thus, the concept of ideality introduced in TRIZ is decomposed in my approach into twelve smaller components, each of which can be evaluated by its own criterion. Taking the above into account, a system can be called ideal for specific conditions of application if it has:

- each object (element, connection) in its composition has an independent value, functionality and is there and when it is really needed;
- structure is optimized according to some criterion and usually has a hierarchical or network structure;
- the potential of each object is fully spent on the quality performance of its main function and additional/supporting functions;
- mass, dimensions and material, energy and information resources consumed by it during the life cycle are of minimal importance;
- a new systemic quality that does not belong to any of its constituent objects manifests itself;
- optimal interaction with the environment is ensured;
- the required variety of control actions is realized or mastered;
- the required informational diversity manifests itself;
- there is a prospect of development;
- models or fragments of virtual reality in a reasonable amount are included in the analyzed system;
- the proportion between the humans participating in the system and the devices built on the basis of artificial intelligence is optimized;

- the purpose of creating the system and its actual functioning correspond to each other.

Note that the presented criteria can be measured quantitatively and allow evaluating the creative work both during its performance and after its completion. The final index of ideality can be determined by a procedure equivalent to multi-criteria optimization with an assessment of the contribution of each particular aspect to the final index of ideality. In classical TRIZ, this possibility is completely absent.

4 Other Changes in TRIZ Structure

Now I will focus on other significant differences between my approach and classical TRIZ.

Classical TRIZ is a result of competent, thoughtful generalization of inventors' experience, which represents empirical data. I believe that the noted empiricism of TRIZ has not been overcome until now: theoretical generalization of the material accumulated within TRIZ has not been and still is not available. System theory, coupled with TRIZ, can serve as such and allows considering TRIZ in a transformed context:

1. A new interpretation, as shown above, has been given to TRIZ contradiction and ideality.
2. TRIZ has a large number of tools for creative problem solving [1]: 40 techniques for solving technical contradictions, 11 principles for solving physical contradictions, and 76 standards for inventive problem solving. On the one hand, this is good, because a researcher has an opportunity to choose the most appropriate one for solving a particular problem. On the other hand, it is bad, because there are a lot of tools, but there are no rules for their selection to the conditions of the problem to be solved. As a result, a researcher starting work on each problem finds himself at a fork in the road, and is forced to seek an answer to the question: which of them should be chosen, to move effectively to the desired result? Behind this is an enumeration of options, because all of these techniques, principles, and standards are in a row. Of course this is not a trial and error method, but there are still too many options. In my approach, all these TRIZ tools are included in system actions and, most importantly, are ordered by levels in the form of tree branches. By choosing one branch as a solution variant, all other branches are excluded from consideration, which reduces the workload many times over. I also emphasize that I have excluded technical contradictions from circulation, and the solutions obtained earlier with their help logically follow from fulfillment of system actions. G. Altshuller insisted on a similar transformation of TRIZ in his time, pointing out that the development of the concept "physical contradiction" made technical contradiction superfluous. Next. If we take a close look at the list of 11 principles of physical contradiction resolution [1], it becomes obvious that it is not full and is drawn up in violation of the rules of classification of the concepts. In particular, proportionality of division is violated (the volume of the divided concept must be equal to the sum of volumes of division members), division is performed not on one basis (it is impossible to take two or more signs to perform division). For example, in the typical list of principles the division of contradictory properties in time and space is indicated, and a little further in the

same list it is recommended to endow the system with property C, and its part with property anti-C. But, after all, properties C and anti-C coexist either in space or in time, there can be no other. The incompleteness of methods is eliminated by the following recommendation: it is necessary to take into account all components of the analyzed system, to consider them in 12 system aspects and on this basis to receive the spectrum of TRIZ-contradictions. There are only two options for solving such contradictions - in space and in time. Besides the consistency of the procedure of contradictions resolution, this approach allows demonstrating the interrelation of creative work with the basic notion of psychology called “here and now”, which is focused on fulfillment of necessary requirements in actual time and in actual place.

3. The basic concept of the standards for inventive problem solving is the “vepole”, which is depicted as follows [1] (Fig. 3):

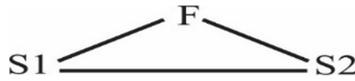


Fig. 3. Graphical representation of the vepole.

As shown in Fig. 1, in the typical scheme of the system one element (substance S1) is connected with another element (substance S2) by a connection depicted by a line, not a triangle, as shown in Fig. 3. I believe that all information traditionally associated with the field F in the vepole can be associated without difficulty with one - a single line of connection used in the typical scheme of the system. In this case the semantics of graphic image is not reduced, but the image itself is significantly simplified. If in the analyzed problem, for example, there are 100 elements of the system, the criterion of simplicity gets a weighty value, because it will be necessary to represent only 99 lines of communication instead of 297, conditioned by the typical scheme of the vepole. The change I propose increases visualization of the scheme and corresponds to the implementation of the convolution line known in TRIZ for improvement of TRIZ itself. Besides, giving the interaction of substances S1 and S2 by means of field F the form of one line, as it is accepted in the theory of systems, corresponds to the basic concepts of graph theory and, accordingly, mathematical methods become available for optimization of the structure of the analyzed system.

4. In classical TRIZ, the strongest tool is ARIZ, an algorithm for inventive problem solving. ARIZ (ARIZ-85B) is a complex structure that provides for 124 actions even when passing through it once [1]. As is known, the general methodological rule of working with any problem is: the complexity of the method of solving the problem should not exceed the complexity of the problem itself. Obviously, 124-step procedure does not always conform to this rule. Moreover, ARIZ is a procedure with a strictly established, determinate sequence of steps to be performed. At the time when the first versions of ARIZ were developed, it was natural and corresponded to the spirit of that time. Today, however, the reality around us has become different; the concepts of “stochasticity”, “uncertainty”, “flexibility” and

similar concepts are predominant. Agile-methodology, the main distinctive feature of which is flexibility, is intensively developing [9, 10]. My approach, having 12 aspects and 86 system actions, doesn't demand their full activation for every next task; these aspects and system actions are rather a list than a sequence of their fulfillment. In addition, they are ordered by hierarchical levels, so the amount of work performed is significantly reduced and in solving each next task - it is different, i.e. flexible. For example, after practicing the target aspect - setting the goal of solving the problem - it becomes obvious to the researcher that the goal can be achieved by saving resources, that is, by engaging the potential of the resource aspect. Accordingly, he chooses one of the 12 aspects, within which there are only 9 system actions, and then he works only with them. For example, the information aspect with a similar sequence of actions may turn out to be involved in solving another problem. After completion of work with system actions, if possible, the TRIZ-contradiction is formulated and resolved, and the final result of the work is determined. In other words, the general sequence of work with the problem takes the following form (Fig. 4).

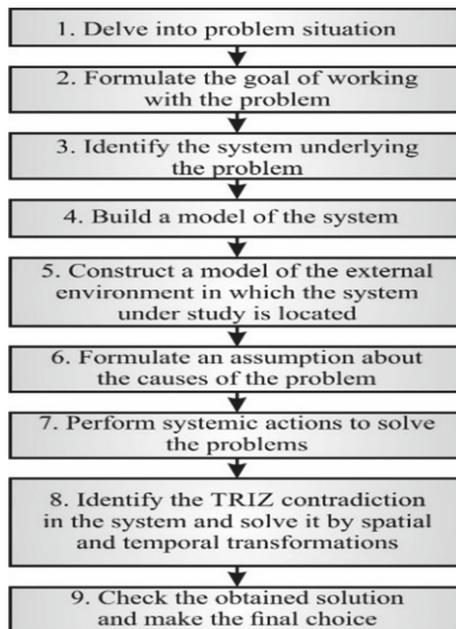


Fig. 4. Schematic representation of the sequence of actions in systemic problem solving.

5. In the theory of systems it is accepted that the input of the system can be: the substance (materials), energy and information. People paid attention to the necessity of inclusion of the above components in the composition of systems not at once, but according to the periods of development of civilization, among which technosphere, energy

sphere and infosphere are distinguished. Each of these periods corresponded to the predominant development of one of them. It is considered that the first period comes from the depth of millennia and ends in the XX century. This is the mastering of the material nature of the world, the creation of material production and the formation of an understanding of the material nature of the world. The second period begins in the 18th century with the steam engine and probably ends in the 20th century with the development of thermonuclear energy. This is the development of the energy resources of the solar system, the creation of energy abundance, the understanding of the unified nature of energy and its relationship to matter. The third period is associated with the stage of mastering information. This is the period in which we are currently living. Now let's see what classical TRIZ offers us. Within the technosphere, variants of solid body contact have been developed - at a point, along a line, along an area, and along a volume. TRIZ recommends: having received a problem, for example, in the contact of bodies at a point, one should apply other variants - contact along a line, along a surface, along a volume. Within the framework of the energy sphere, TRIZ suggests using the abbreviation MATCEM, i.e., when searching for a solution, one should consistently consider the variants of mechanical, acoustic, thermal, chemical, electric and magnetic energy. As for the infosphere, i.e. working with information, there are no TRIZ recommendations at all: at the turn of the 1960s, information was not as important as it is now, so there are no recommendations. My approach, on the other hand, has an informational aspect that is directly aimed at working with information. The virtual-model and reconstructive aspects are also informational. I believe that if we take the position of active supporters of classical TRIZ, the abbreviation MATCEM should be changed, for example, to MITCEM or MATCEMI, thus adding an informational component to the energy sphere. In the latter case, the letter "A" will retain the acoustic impact, meaning it is the energy component, not the information component. However, I think it is more correct to transform MATCEM into TEI, where technosphere, energy sphere, and infosphere are united respectively, each with its own set of subordinate influences. In particular, information in any analyzed task can participate in the most different kinds, having the possibility to influence all human senses, or be fixed by special devices.

6. Classical TRIZ invariably emphasizes its systemic nature. It is difficult to argue with this. But, it should be added, it is characterized by the systematicity that existed half a century ago. Systemic theory then and systemic theory now are different things. Indicative in this respect is the number of systemic aspects taken into account in the analysis of the system. When C.L. von Bertalanffy, the developer of systems theory in the early 1950s, was just beginning to promote the results of his research, it made sense to talk about no more than three systems aspects: elemental, structural and integrative. At the turn of the 1960s and 1970s, seven systemic aspects were said to be sufficient: elemental, structural, functional, integrative, communicative and historical. Today I propose 12 systemic aspects. It is quite obvious that the 12 aspects of the situation provide more information than earlier variants. In his time Edward de Bono, an internationally renowned specialist, spoke of the six hats of thinking. Following the tendency outlined in the systems theory the number of hats would probably have to be reconsidered today as well. The total number of systemic actions included in the aspects exceeds the total number of methods for solving

technical and physical contradictions contained in the classical TRIZ. I believe that this provides what the system theory is praised for - providing a truly comprehensive consideration of a particular situation and creating a basis for all transformations that is possible. Classical TRIZ, given the empirical nature of its formation, has no such comprehensiveness.

7. Classical TRIZ is based on the experience of inventors. The subject of invention is technical devices, which predetermined the terminology used in TRIZ. For example, one of the techniques for solving technical contradictions is to replace a mechanical system with a hydraulic or pneumatic one. This is not the only technique with purely technical terminology. A legitimate question is how to apply this technique to solve, for example, organizational and managerial problems. Terminological difficulties of adaptation of TRIZ to any other problems, different from technical ones, are a priori obvious. TRIZ specialists reasonably argue that TRIZ is suitable for solving all kinds of problems. I do not deny this assertion, but what about terminology? How, for example, to use the established TRIZ terminology for L. Semenova, who specializes in non-technical TRIZ issues [18] - leadership, motivation, conflict resolution, making important decisions in an organization, family relations, etc.? - She has to do her own adaptation of technical terms to the specifics of her issues! Of course, L. Semenova's TRIZ experience and professionalism allow her to cope with this task, but why do this extra work? But how can a student of law, medicine, commerce or any other humanitarian field, who has no experience in the use of TRIZ, solve this same problem? Will they always interpret correctly, for example, the already mentioned phrase "replace a mechanical system with a hydraulic or pneumatic system"? I believe that the systems terminology used in my approach looks preferable here, and it is much easier and more natural for a student who has taken a course in systems theory to use, for example, the following phrase: "replace an element with another one with alternative properties. By an element each student will understand differently: for example, to replace a manager with a rigid management style with a more democratic one, or to replace a salesman who is unable to smile with a smiling one.

5 Other Options for Using the Author's Approach

The material set forth above is most relevant to the creative stage of searching for a problem solution. But as the developed approach is systematic, it can be applied with no less success at other stages of work with the problem demanding the decision.

In particular, it is suitable for a comprehensive analysis of the initial situation in which the problem "hides". The topic of analyzing the initial situation is complex. Her research is entirely devoted, for example, to the book [19]. Its author describes various options, including his own author, based on the classical TRIZ. Positively evaluating the book [19], I must note at the same time that a comprehensive (system) consideration of the initial situation was not received as a result, although the author even subjected his algorithm to processing more than 15 times. In this case, it is also necessary to subject the initial situation to a 12-aspect analysis, that is, to consider it from all sides [13]. The only difference here is the change in the imperative form of systemic actions to the questioning form. Above I gave an example of system actions of the elemental aspect for the case of work at the creative stage: change, take for consideration new properties

of an element or its parts; change the parameters of properties; change the position of an element, etc. At the stage of analysis of the initial situation, the same actions will take the following form: what properties are characterized by a concrete element or its part? What parameters characterize the properties of this element? What is the position of this element, etc.? A similar procedure should be performed with the system actions of all other aspects. The result of such work is a systematic and truly comprehensive analysis of the initial situation.

At the stage of patenting a new technical solution [15] to identify its differences from the prototype, it is enough to compare the result of an actually implemented action with the obtained in the performance of system actions of my approach. If one corresponds to the other, it can serve as a confirmation of the success of the claims. If, on the other hand, the author of the invention has difficulty making the claims, then the systemic steps can be used as hints - they indicate how to move from the prototype to the new solution. The clue here is that the author can go through the systemic actions included in my approach and choose among them, instead of coming up with possible transformations. In addition, the system terminology has an extremely high generality, which, when used in the course of writing claims, creates the conditions for umbrella patenting, which has recently become increasingly important.

The approach developed by me is in full measure suitable for application at a stage of embodiment (materialization) of creative result. It developed the ideas set forth by many authors, for example, [20–22]. I offer the following model (Fig. 5) of system “technical result embodiment” [15].

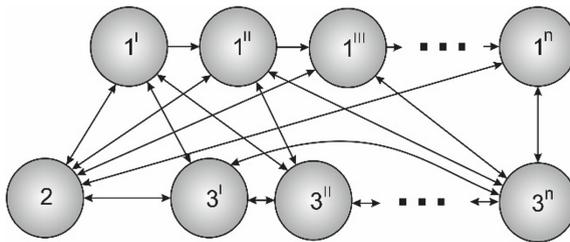


Fig. 5. Model of the system “technical result embodiment”: $1^I - 1^N$ - technical device at different stages of its manufacture; 2 - researcher; $3^I - 3^N$ - interlocutors involved in or influencing the manufacture of a technical device.

The symbols $1^I - 1^N$ here denote the technical device which is to be made, at various stages of its readiness. That is, this is the creative result that the researcher intends to implement. Number 2 indicates the researcher who is interested in the realization of his creative result. Number 3 refers to colleagues and other collaborators with whom the researcher is bound to communicate as he or she works to bring his or her result to fruition. There may be many such collaborators, and they may be different at different stages of the work.

As follows from the analysis of Fig. 5, a system is depicted here. This system generally corresponds to the general image of the system (Fig. 1). Accordingly, the work algorithm considered earlier for the creative stage is fully applicable here as well, although

in this case there are significant features. In particular, working with element 1 of the model, we can talk about the researcher's work with a technical system. In this work, the object and subjective parts of the task are distinguished. In my book [11] they are considered in detail. Work with element 3 of the model is work with people, with so called "soft" systems. Here it is predominantly subjective work. Overcoming resistance of colleagues to the introduction of a creative result, arguments, negotiations, conflicts with them—all these processes are considered in the context of the approach developed by me. Numerous books are devoted to their research, for example [23, 24]. Systematic basis my approach allowed to order many issues of the listed processes, in fact-to give them more systematic, and to make them accessible in application to the technical specialist who is not the professional specialist on negotiations or the consultant on the resolution of conflicts.

For example, system element 2 (researcher) communicates with elements 3 (by its colleague) (Fig. 5). This situation demonstrates that there is one connection between elements 2 and 3. Let the result of communication not meet the expectations of the researcher. In this case, the researcher adds non-verbal means of communication—gestures, facial expressions, changes the timbre of the voice, and so on. The researcher may not know all these nuances of communication in detail. Using my approach, he should only know one thing: if one link between elements 2 and 3 is not enough to achieve the desired result, you need to change the parameters of this link, add new links, etc. But the researcher performs the same actions when creative solving a technical problem using my approach. That is, once having mastered my approach, the researcher can apply it in a variety of situations, including both in solving technical problems and in the process of communicating with his colleagues and other people. I consider this versatility of my approach convenient and profitable in a variety of situations.

In addition to the presented material I can note that in my book [12] the questions of stimulation of an ordinary person to creativity, realization of search - "what to invent?", forecasting of the future creative result, determination of reasonable correlation of logical and intuitive in the process of creative problem solving, choice of the preferable variant of the solution from a set of possible ones were reflected. Taken together, all the issues discussed in my books allow organizing practical innovation work in any interested company, as well as forming a corresponding educational course in educational institutions. My practice allows me to assert that in both cases the results will be high, corresponding to the modern level.

The next step in the implementation of my approach will be the development of its computer version, based on modern advances in digital technology and artificial intelligence. Certain actions in this direction have already been taken.

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Partially Defined Boolean Functions in TRIZ

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Abstract. The most recognized area where Boolean functions are used in TRIZ is, presumably, the cause-effect analysis, with logical operators indicating how causes trigger the effects. An AND operator denotes logical conjunction, while an OR operator denotes logical disjunction, and both are fully defined functions, i.e., an explicit output value is specified for each combination of the arguments. This paper focuses on partially defined Boolean functions incurring uncertainty due to some output values indicated as unspecified or unknown. It discusses the opportunities and threats of using such functions to describe project requirements and relations between the causes in cause-effect models. The approaches to tackling the uncertainty resulting from such function definitions are also presented, which is deemed to be instrumental for TRIZ researchers and practitioners.

Keywords: TRIZ · Cause-Effect Chains Analysis · Root Conflict Analysis · CECA · RCA+ · Boolean logic · partially defined function · requirements analysis

1 Fully Defined Boolean Functions in TRIZ

The cause-effect analysis is a powerful paradigm used for decades in many application areas [1, 2]. It evolved into several mature methods like Root Cause Analysis (RCA) [3], Why-Why (or 5 Whys) [4], Fault Tree Analysis (FTA) [5], and others. In the TRIZ world, the cause-effect analysis appears primarily as Cause-Effect Chains Analysis (CECA) [6, 7] and Root Conflict Analysis (RCA+) [8, 9]. Other approaches [10, 11] seem less prevalent. Despite a few conceptual differences, both mainstream methods use diagrams built of boxes reflecting disadvantages or negative effects (also positive effects in RCA+), logical operators, and arrows indicating the flow of causality.

When any of the causes contributing to a given effect can trigger this effect, we use an OR operator or several arrows pointing to the same box indicating alternative causes (logical disjunction). When all contributing causes must be active to trigger the effect jointly, we use an AND operator (logical conjunction). They are described in Table 1 below with truth tables used in the digital design domain to describe Boolean functions by indicating respective output values for each combination of input values (shown in a transposed form to save the page space). Active and inactive causes/effects are reflected by the labels 1 and 0, respectively. As can be seen, the outputs (y values) are explicitly indicated for all columns, i.e., these functions are fully defined.

Table 1. Truth tables for logical AND and OR functions; $x1, x2$ are inputs, and y is the output.

$y = x1 \text{ AND } x2$				
$x1$	0	0	1	1
$x2$	0	1	0	1
y	0	0	0	1

$y = x1 \text{ OR } x2$				
$x1$	0	0	1	1
$x2$	0	1	0	1
y	0	1	1	1

2 Partially Defined Boolean Functions in System Requirements

In one of the latest projects, the customer defined the required system’s behavior for some specific combinations of the control parameters’ values without any requirements regarding other legitimate combinations. To simplify the model, let us assume that there are only two parameters, $x1$ and $x2$, having only two distinct values each (low vs. high). Regardless of the actual nature and quantization of the parameters, they may be described as binary variables by assigning the labels 0 and 1 to the respective states or ranges. We may also describe the required system operation mode y as a binary variable (turn off vs. turn on) and use truth table notation again, as shown in Table 2. Now, in addition to 0 and 1, we also have the X symbol denoting the values which have not been specified. Such undefined values introduce some uncertainty to system requirements.

Table 2. Truth table describing partially defined logical function.

$$y = 0 \text{ for } x1x2=00; \quad y = 1 \text{ for } x1x2 = 11$$

$x1$	0	0	1	1
$x2$	0	1	0	1
y	0	X	X	1

Since we are not obliged to generate any particular y value for the cells marked with X , they are usually called *don’t cares*, and we may insert 0 or 1 in each position in any configuration we like. In the digital design area, these undefined cells are filled with a binary pattern simplifying the hardware implementation due to a better minimization of a function without violating the requirements [12]. Since every *don’t care* cell may become 0 or 1, each undefined value doubles the number of possible variants. In our example, we have 2 undefined values, so the original partially defined function may be converted into $2^2 = 4$ different fully defined functions.

Table 3. Four variants derived from a partially defined function shown in Table 2 by replacing each X with 0 or 1 in all possible combinations.

$x1$	0	0	1	1	$y1 = x1 \text{ AND } x2$ $y2 = x1 \text{ OR } x2$ $y3 = x1$ $y4 = x2$
$x2$	0	1	0	1	
$y1$	0	0	0	1	
$y2$	0	1	1	1	
$y3$	0	0	1	1	
$y4$	0	1	0	1	

As shown in Table 3, the first two variants are equivalent to AND and OR functions described in the previous section. The remaining two cases seem even more attractive because they prove that the required system operation may be achieved using only one control parameter as the input.

This effect gets a massive boost when the number of parameters increases. If similar requirements are stated for 3 parameters, there are 8 possible combinations of input variables with only 2 explicit output values, as in Table 4 below.

Table 4. A truth table for a partially defined function of 3 variables with 6 *don't cares*.

$$y = 0 \text{ for } x_1x_2x_3 = 000; \quad y = 1 \text{ for } x_1x_2x_3 = 111$$

x_1	0	0	0	0	1	1	1	1
x_2	0	0	1	1	0	0	1	1
x_3	0	1	0	1	0	1	0	1
y	0	X	X	X	X	X	X	1

For 6 *don't care* items, we have $2^6 = 64$ possible variants, including AND and OR of all arguments, single causes, ANDs of two arguments (see Table 5) and 56 others.

Table 5. 8 of 64 possible fully defined variants derived from the function shown in Table 4.

x_1	0	0	0	0	1	1	1	1
x_2	0	0	1	1	0	0	1	1
x_3	0	1	0	1	0	1	0	1
y_1	0	0	0	0	0	0	0	1
y_2	0	1	1	1	1	1	1	1
y_3	0	0	0	0	1	1	1	1
y_4	0	0	1	1	0	0	1	1
y_5	0	1	0	1	0	1	0	1
y_6	0	0	0	0	0	0	1	1
y_7	0	0	0	0	0	1	0	1
y_8	0	0	0	1	0	0	0	1

$$y_1 = x_1 \text{ AND } x_2 \text{ AND } x_3$$

$$y_2 = x_1 \text{ OR } x_2 \text{ OR } x_3$$

$$y_3 = x_1$$

$$y_4 = x_2$$

$$y_5 = x_3$$

$$y_6 = x_1 \text{ AND } x_2$$

$$y_7 = x_1 \text{ AND } x_3$$

$$y_8 = x_2 \text{ AND } x_3$$

3 Partially Defined Boolean Functions in Cause-Effect Analysis

In some cases, partially defined functions may also appear during cause-effect analysis. As pointed out in [13], if we only know that a disadvantage appears for two contributing causes acting simultaneously, we cannot tell if the relation between the causes in the diagram should be modeled with AND or OR.

Indeed, contrary to system requirements, where *don't care* values increase the chances for generating solutions, they bring additional challenges in cause-effect analysis, especially for a higher number of contributing causes. This difference comes from the need to identify or verify the causal relations between the analyzed events or states.

If there are two phenomena, $x1$ and $x2$, which are observed as correlated – i.e., they both do or do not appear – the possible relationships between them include [14]:

- $x1$ causes $x2$ (direct causation),
- $x2$ causes $x1$ (reverse causation),
- $x1$ and $x2$ are both caused by a third (common) cause,
- $x1$ causes $x2$, and $x2$ causes $x1$ (bidirectional or cyclic causation),
- there is no relation between $x1$ and $x2$ (the correlation comes from a coincidence).

Therefore, no reasonable conclusion about the existence or direction of the cause-effect relation may be made solely from the fact that $x1$ and $x2$ are correlated. It is assumed that proper identification of causal relation requires four elements: a correlation of $x1$ and $x2$, a sequence in time ($x2$ appearing not earlier than $x1$), a plausible explanation for $x2$ to follow from $x1$, and eliminating the possibility that $x1$ and $x2$ have a common cause. The mentioned explanation is usually provided by indicating a known mechanism, e.g., transferring energy between physical objects, a chemical reaction, an optical effect, etc.

We need to recognize logical relations between the analyzed disadvantages to understand their impact on system operation and remove one or more causes to eliminate the unwanted effect depending on these relations. While removing just one of the AND-connected causes is sufficient to eliminate the effect, all the causes must be eliminated if they are OR-connected (which may be confirmed using truth tables given in Table 1). These rules are described by De Morgan's laws, saying that the negation of OR is equivalent to AND of negated arguments and vice versa.

The considerations regarding partially defined functions presented in the previous section imply that two disadvantages, $x1$, $x2$, which are observed as correlated, may represent one of the four variants discussed before ($x1$ AND $x2$, $x1$ OR $x2$, $x1$ is the only cause, $x2$ is the only cause). In addition, $x1$ may cause $x2$, or $x2$ may cause $x1$, or $x1$ and $x2$ may cause each other, or they may result from a common cause or some intermediate causes may be involved in between, or the apparent correlation comes from a coincidence [14].

On top of this, some quantitative and cumulative causes (such as heat, noise, etc.) do not follow the rules used for qualitative causes [15]. In particular, De Morgan's laws are not obeyed when switching from analyzing cumulative disadvantages to looking for cumulative solutions, typically aimed at crossing a specific threshold level rather than removing all causes, as in the case of a logical OR.

For instance, we may eliminate the effect of an excessive subsystem cost resulting from the excessive cost of the component $x1$ OR excessive cost of the component $x2$ by eliminating either of the input causes, i.e., by decreasing the cost of $x1$ OR by decreasing the cost of $x2$ (not necessarily both of them, i.e., using logical AND, as De Morgan's law requires).

4 Handling Partially Defined Boolean Functions

Partially defined system requirements seem like a gift to the analysts, as they are less constrained in generating solutions. Therefore, such a situation increases the chances of providing a solution meeting specific priorities (e.g., a quick implementation).

For instance, if the customer indicated air temperature and relative humidity as the control parameters with the actions specified only for two combinations (as in Table 2), we would be free to use either logical AND or logical OR to combine the inputs since both operators fulfill the conditions. Moreover, such formulation of the requirements suggests that monitoring one parameter may be sufficient, and in such a case, we would likely prefer to trigger the action using air temperature, which is easier to measure than relative humidity. On the other hand, we may use secondary parameters reflecting specific interrelations of other parameters. For instance, we may react to the voltage level averaged from a periodic signal rather than measure its amplitude and duty cycle or react to the kinetic energy of a moving object instead of measuring its mass and speed.

To address the cause-effect analysis domain, let us consider a reasonably realistic scenario when the causes contributing to a given effect are qualitative and independent (i.e., do not cause one another directly or indirectly and do not have a common cause). We want to tackle the unknown logical relations between them using regular AND/OR operators for such a configuration.

Assuming that the causes are connected with OR, we should eliminate all of them. This approach covers all variants mentioned before, even if the causes are dependent, so it is safe logic-wise. However, it may be costly (in terms of money, time, effort, etc.) and, consequently, not necessarily appealing business-wise.

Assuming AND function between the causes, we need to eliminate just one of them to remove the unwanted effect, so this approach seems more promising. Furthermore, we may search for the cause with the lowest estimated removal cost. Unfortunately, with a partially defined function, we cannot be sure that the unwanted effect will be eliminated after removing a particular cause, so we should analyze them individually.

5 Summary and Further Work

When a partially defined function appears as a description of the required system operation, each unspecified value in the truth table virtually doubles the space for candidate solutions (unless such a function comes from an incorrect requirements analysis). Hence, the more *don't cares*, the better perspectives on devising a viable solution.

When a partially defined function appears during the cause-effect analysis – be it CECA, RCA +, or any other method – the team should decide if the risk resulting from uncertainty about the logical relation between the contributing causes is worth the additional effort necessary to find them. The other choice is to give up further analysis and assume the causes to be OR-connected, which implies accepting the safest and supposedly the most expensive scenario. Assuming the causes to be AND-connected, on the contrary, leads to a trial-and-error approach, which is not appreciated in the TRIZ world, yet it gives a chance to focus on eliminating a single cause with minimal cost.

Further work may address a systematic approach to investigating interrelations between the contributing causes by designing tests to confirm or deny hypotheses about

specific logical operators involved. Since this activity resembles testing logical circuits, it seems justified to expect the Boolean differences used in the digital design domain to be appropriate for this application [16]. Such a difference is calculated as a logical XOR (Exclusive OR) of a function with a given input set to 0 and set to 1 to identify output sensitivity to changes on this input, and possible results are constant 0 (insensitive), constant 1 (unconditionally sensitive) or expression (conditionally sensitive).

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Functional Value of TRIZ Components - Universal Concept and Direct Implications

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Abstract. In TRIZ, explicit Value Analysis methods based on Function Analysis crucially depend on the functional value of a component as a measure for its functionality. In this work a meaningful, universal concept for the functional value of components - or systems, respectively - is derived from scratch by exploiting the requirement of invariance under valid component operations. As a key result, functionality is generally determined by net functional contribution and not necessarily by absolute functional performance. This is in clear contradiction to the empirical approaches used in standard Value Analysis in TRIZ sofar, and therefore provides an essential part for more advanced Value Analysis frameworks such as VA++. The derived concept allows to achieve deeper insights and correct, consistent results. Some of the most important implications for both theory and practical application are explained and demonstrated in detail.

Keywords: TRIZ · Value Analysis · Functionality · Ideality · Function Analysis · Functional Value · Trimming · VA++ · Systematic Innovation

1 Introduction

In Value Analysis as developed by Miles, a key point is that “All Cost Is for Function” [1, ch. 2]: An end customer of a product, for example, demands it to do something or to please someone, and is willing to pay for this functionality - as long as the corresponding costs are in an acceptable relation from his or her perspective. Accordingly, the task for the manufacturer is to focus the product costs to those particular product features and aspects that are of real relevance for the desired functionality. In a more general setting, Value Analysis (or Value Methodology in a wider sense) allows to analyse distinct types of systems, such as products, processes, projects, services, and organizations [1, 2]. The prime parameter for describing the competitiveness of such a system is its value, determined by the functional performance of the system divided by the resources, which are required for that [1, 2]. Since increasing value serves as the guideline for any improvement or innovation activity, it is essential to have means for its evaluation, or at least its qualitative estimation. For this very

purpose Value Analysis involves the process of Function Analysis, in which the relevant functions, that are responsible for the functional performance, are first identified and classified; then the necessary resources (e.g. cost, time, etc.) are allocated to them. Eventually, this should indicate the best opportunities for value improvement. This elaboration takes time and effort and requires system knowledge. According to the VM Guide, “[t]his process is perhaps the single most important and useful technique in Value Methodology; however, it is the most difficult to [...] put into practice” [2, p. 53]. From TRIZ perspective, there is quite some methodical overlap. The above definition of value, for example, is generally regarded as very close - if not identical - to the TRIZ key concept of ideality, which is regularly described by system functionality per generalized costs and harms, cf. e.g. [3–6]. Consequently, the mindset about which system should prove more successful in a competitive environment is rather similar in both Value Analysis and TRIZ, resulting in the same methodical guideline for the selection of innovation and improvement activities in typical practical applications. Moreover, also modern TRIZ contains an important method denoted as Function Analysis. Developed by Gerasimov and Litvin, cf. [7], it is found in typical newer TRIZ text books and standards, e.g. [3–6, 8]. TRIZ Function Analysis might seem similar to its methodical counterpart of the same name in Value Analysis at first glance. But despite some parallels, the differences between the two methods are quite significant. To start with the obvious similarity, Function Analysis in both Value Analysis and TRIZ might come up with identified functions of the system denoted by the same shorthand functional description. For example, the TRIZ main function of a truck is to ‘transport goods’, which resembles the basic function found in Value Analysis. However, the deeper conception for identifying functions is generally different. While in Value Analysis the focus is set on the purpose or benefit of the system - or its functionality, respectively -, TRIZ functions are determined by their actual - often physical - impact or effect according to a stricter logical set of rules. In other words, Value Analysis asks, why the functions are eventually performed, whereas TRIZ deals with the questions of what they actually do. A finalized Function Model resulting from TRIZ Function Analysis is extremely useful for understanding the whole functional interplay of the system and its environment - the so-called supersystem - as well as all of the system internal functions, that are essential for making it work. Regarding the functionality of the system, main and further additional functions performed on the supersystem are systematically identified by default, but a more detailed customer or user perspective is typically missing. This is an important issue also for TRIZ in general, and it has been addressed by various approaches, cf. e.g. [9, 10]. One particular way to make up for this is to involve the concept of main parameters of value (MPVs), cf. e.g. [8, 11]. Whereas the pure function denomination only makes clear, what it actually is about, additional properties or further aspects of the function, which are for example related to or derived from the MPVs, allow to describe its performance in more detail and need to be properly elaborated. Taking them into account is essential for a meaningful functional evaluation, i.e. for addressing the question,

how good a user or customer considers the corresponding functional performance really to be. As an example, the truck mentioned above has the main function to ‘transport goods’. The actual functional performance, however, is determined by a variety of further aspects of this transport-function, such as the (top) speed, the volume or load of the goods, the temporal availability, and so on. Also further circumstances like the corresponding fuel consumption and lifetime are relevant for evaluating the overall functionality of the truck itself. It should be emphasized, that an implementation of Value Analysis based on TRIZ Function Analysis needs to take care of these particular issues thoroughly, and that such a functional evaluation of functions according to MPV aspects typically is far more sophisticated than the previous procedure of finding them. This means, a significant amount of additional analytical work has to be done on top of an already fully elaborated TRIZ Function Analysis. Moreover, it is important to realize, that the functional evaluation of a function regularly also depends on components and their parameters, which are not directly involved in that very function in the Function Model, i.e. they are neither performing nor receiving the function directly. For example, some of the top level aspects of the main function ‘transport goods’ of the truck, such as speed and acceleration, depend on the engine, the shape of the vehicle body, as well as the mass of any component of the truck.

2 VA and VA++ in TRIZ

It seems promising to explore new combinations of Value Analysis and TRIZ methods in general, cf. e.g. [12, 13]. Nevertheless the focus of this work is rather different: It follows an already existing approach of explicitly incorporating Value Analysis methods in TRIZ based on Function Analysis, which is typically referred to as ‘Value Analysis’ in the TRIZ community as well. This very specific TRIZ approach is abbreviated as VA in the following, to avoid confusion with Value Analysis or Value Methodology in a wider sense. Moreover, here and in the following, Function Analysis refers to the TRIZ method by default. Instead of assigning costs - typically derived from the components - to functions representing functionality, VA works by assigning functionality - via the functions found in Function Analysis - to components. This slight shift in procedure and perspective allows a subsequent analysis of the situation directly on the level of components and their ideality or value, respectively. Since the TRIZ notion of component is very generic and covers both the system itself and its parts as well, this sets up an interface to a variety of other TRIZ innovation and improvement methods such as e.g. trimming [3, 4, 6, 8, 14, 15]. Known to a major part of TRIZ practitioners and theorists, standard VA is quite established. For example, it is incorporated in renowned TRIZ certification curricula [6], part of software-based innovation or invention approaches [16–19], and used in many typical TRIZ projects, from innovation to patent circumvention activities, cf. e.g. [20–22]. In a recent work, however, standard VA is demonstrated to provide shockingly wrong results even on very simple sample cases, which is due to two

independent errors or misconceptions in the VA key procedure [23]. As described above, VA aims to determine the functionality of components out of the functions found in Function Analysis. In doing so, the functionalities of both functions and components are represented, measured, or evaluated by corresponding functional values. Now, the first error is to assign the functional values of functions by an empiric function ranking algorithm only based on the functional structure. Thus, results are rather straightforward to achieve, without any further analysis or evaluation phase involving sophisticated team discussions and controversial expert opinions. However, exactly this complete lack of system insight makes them more or less arbitrary and far from being reliable. The second error is about the functional value of a component, which is simply determined by its functional performance, i.e. by summing up the functional values of all those functions the component actually performs or provides. This might seem reasonable at first glance, but actually stands for a deep misconception as elaborated in the following section. It is important to realize, that variants of standard VA relying on more sophisticated or even simpler algorithms, cf. e.g. [8, 22, 24], are equally affected. In contrast, correct and meaningful results are accessible in the framework of VA++, an approach of the next generation requiring both issues to be addressed properly, as indicated in its name [23]. Concretely, the functionality of functions needs to be evaluated involving deeper expertise and system knowledge as pointed out above, even if this means quite an amount of extra work for the team in practical application, and the functionality of components has to be determined by a profound and consistent concept, which is derived from scratch in the following.

3 Concept Derivation

The concept of a functional value δ representing the functionality of a component - or a system, respectively - according to VA++ is elaborated in this section rather formally. For the concept to be meaningful and consistent, a requirement has to be fulfilled: Simply breaking down the functionality to sub components must always keep the total functionality constant. Only splitting up something and dividing it, is obviously not consistent with an increase or decrease of the total, at least in the type of theoretical setting to be dealt with here. To give a concrete example, when analysing an ordinary bicycle, the functional value of the component ‘wheels’ has to equal the total of the functional values of its decomposition, i.e. the individual functional values of both the ‘front wheel’ and the ‘rear wheel’ summed up. Moreover, this requirement for the functionality is in full analogy to breaking down the total costs of a system to its parts. Also there, the sum of all partial costs assigned to the sub components naturally has to equal the overall system costs in total. Phrased in a more formal way, a meaningful concept for the functional value has to be invariant under valid component operations such as combination or decomposition. With δ_C denoting the functional value of any given component C , this requirement can be expressed as and is fully equivalent to

$$\delta_C = \delta_A + \delta_B, \quad (1)$$

where the two arbitrary components A and B represent any valid decomposition of C . In other words, A and B are arbitrary, distinct sub components of C , which make up C in combination

$$C = A \oplus B. \quad (2)$$

Here and in the following, the symbol \oplus denotes the combination of components according to TRIZ methodology. As a basic assumption, the functionality of a component may only depend on those functions, it is directly involved in. In a formal description, let \mathbb{F} denote the set of all the functions, the component C is directly involved in, i.e. they are performed by C , on C , or both. Then, the universal approach for the functional value is

$$\delta_C = G(\mathbb{F}) \quad (3)$$

with a general mathematical function G , which is unknown and not accessible within the scope of this work. However, to make progress, let \mathbb{F}^* be an arbitrarily chosen subset of all of the identified functions \mathbb{F} with these two additional properties:

- Property P1: Each function in \mathbb{F}^* can be represented by a functional value f .
- Property P2: Any two of such functional values f are summable.

Thus, according to property P1, \mathbb{F}^* only contains those functions directly involved with C , which - despite all of their underlying complexities - are somehow measured in rather simple functional values. Property P2 eventually ensures, that those functional values are of the same unit or dimensionless, respectively, such that it is possible to add them up in any constellation without any consistency problem. It should be pointed out, that any functions which are elements of \mathbb{F} , but not of \mathbb{F}^* , are not considered any more in the following. As a consequence, the functional value δ_C of the component C is exactly evaluated with respect to the particular set \mathbb{F}^* of the selected functions only. The restriction of the above approach Eq. (3) to the subset of functions \mathbb{F}^* may be expressed by the formulation

$$\delta_C = G^*(f_1, \dots, f_n),$$

where f_1, \dots, f_n are the functional values of all n functions contained in \mathbb{F}^* , and G^* again is an unknown, general mathematical function. Property P2 allows the functional values f to be added up in any constellation, such that a slightly simpler, but still rather general approach can be chosen:

$$\delta_C = f_G(\phi_{\text{out}}, \phi_{\text{in}}). \quad (4)$$

Here, ϕ_{out} denotes the sum of all those functional values f of functions performed by C , whereas ϕ_{in} denotes the sum of all those functional values f of functions performed on C . For clarification, this definition makes the special case of a self-function performed by the component C on itself contribute to both ϕ_{out} and ϕ_{in} . Due to their underlying directional dependence, ϕ_{out} and ϕ_{in} are also referred to as functional flow in the following. The mathematical function f_G

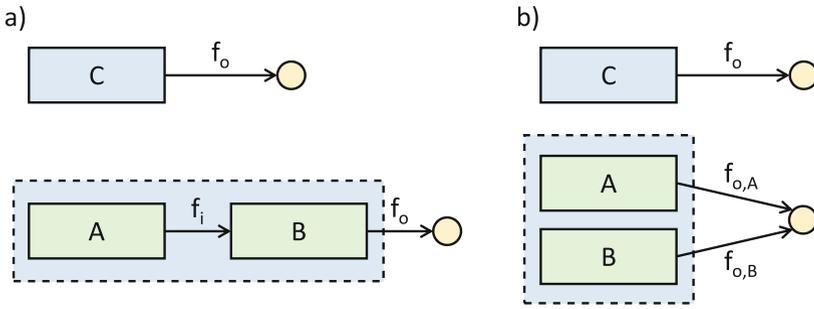


Fig. 1. Two simple special cases of a component C , which performs a function of functional value f_o and is decomposed into the two components A and B . a) Serial internal arrangement of A and B involving an internal function of functional value f_i . b) Parallel internal arrangement of A and B , with each of the two components partially contributing to f_o .

only depends on these two parameters, which are directly evaluated from the corresponding functional values in a simple straightforward way.

A key intention of this work is to identify a concept for the functional value δ of a component, which is valid in general - in particular in the sense of universal applicability in all different system or component configurations. Thus, two simple special cases can be considered and exploited in the following. Both are depicted in Fig. 1. The graphical representation is analogous to regular TRIZ Function Analysis. However, there are some slight adjustments for a compact and convenient handling of general situations, which are used throughout this work:

- An arrow tagged with a functional value f represents a function of that particular functional value.
- An arrow tagged with a functional flow ϕ represents the sum of functional values f of any number of functions that might be there. This even includes the particular situation of no function, for which $\phi = 0$ naturally.
- The circular symbol is a placeholder representing any (number and constellation of) other component(s) not explicitly shown otherwise.

The first special case according to Fig. 1a) represents a component C performing a function of value f_o , and shows how this works out internally, when C could be decomposed into the two components A and B in a serial arrangement. For this constellation, the approach of Eq. (4) directly leads to

$$\delta_C = f_G(f_o, 0) \quad \delta_A = f_G(f_i, 0) \quad \delta_B = f_G(f_o, f_i).$$

Exploiting the general requirement Eq. (1) yields

$$f_G(f_o, f_i) = f_G(f_o, 0) - f_G(f_i, 0),$$

which directly implies

$$f_G(\phi_{out}, \phi_{in}) = f_G(\phi_{out}, 0) - f_G(\phi_{in}, 0). \tag{5}$$

Setting $\phi_{\text{in}} = 0$ in Eq. (5) shows that $f_G(0, 0) = 0$, which means that a component of no functional involvement at all is of zero functional value. For the sake of brevity, a mathematical function f depending on one parameter only may be defined by

$$f(\phi) = f_G(\phi, 0).$$

This function then has the property $f(0) = 0$ and allows to simplify the approach of Eq. (4) under consideration of the finding Eq. (5) according to the first special case to the following intermediate result:

$$\delta_C = f(\phi_{\text{out}}) - f(\phi_{\text{in}}). \quad (6)$$

Therefore, the functional value of a component has to be determined by the difference of one and the same function f applied to ϕ_{out} and ϕ_{in} , respectively, if the concept should be able to validly describe a more or less trivial situation such as the one depicted in Fig. 1a).

As a next step, the focus is set on the second special constellation as visualised in Fig. 1b). The function of value f_o performed by the component C is performed by both sub components A and B in a parallel arrangement. With $f_{o,A}$ and $f_{o,B}$ denoting the functional values of the functions performed by A and B , respectively, the following condition has to be fulfilled naturally:

$$f_o = f_{o,A} + f_{o,B}.$$

According to the intermediate result Eq. (6) as derived above, it is possible to determine the functional values for all three components in this constellation to be:

$$\delta_C = f(f_o) \quad \delta_A = f(f_{o,A}) \quad \delta_B = f(f_{o,B}).$$

The general requirement Eq. (1) leads to the condition:

$$f(f_o) = f(f_{o,A}) + f(f_{o,B}).$$

Just for the sake of clarity, this condition is rewritten in terms of $x = f_{o,A}$ and $y = f_{o,B}$, stating:

$$f(x + y) = f(x) + f(y).$$

Thus, f has to fulfill the additivity property characteristic for a linear function, and it is possible to write

$$f(\phi) = \lambda \cdot \phi$$

with a constant factor λ , which allows to simplify Eq. (6) even further. Eventually, according to both special cases of Fig. 1, namely a serial and parallel arrangement, the only option for a generally valid, universal concept for the functional value δ of a component C is given by:

$$\delta_C = \lambda \cdot (\phi_{\text{out}} - \phi_{\text{in}}). \quad (7)$$

Hence, Eq. (7) is a necessary condition, but it still needs to be checked, if it is also satisfying. For this purpose, it is tested on the most general functional setting,

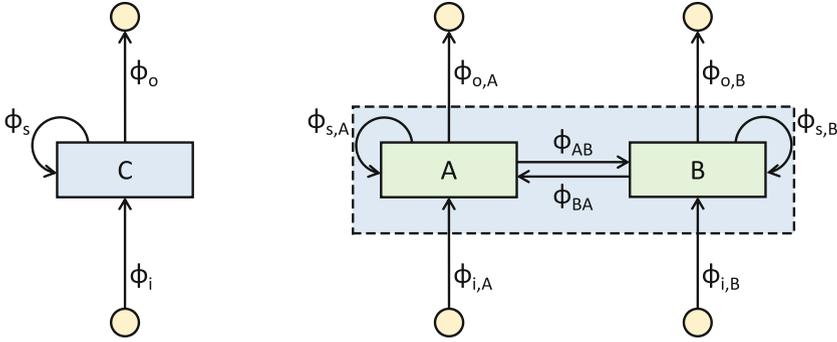


Fig. 2. (Left) A component C in the most general functional setting, performing an arbitrary number of functions to any constellation of other components, which is represented by the total functional value - or functional flow - ϕ_o . Analogously, the functional flow ϕ_i stands for the total functional value of an arbitrary number of functions performed on C by any other component(s), and ϕ_s is the functional flow due to an arbitrary number of self-functions performed by C on itself. (Right) An arbitrary decomposition of C into two components A and B , involving any possible resulting functional configuration. Obviously $\phi_o = \phi_{o,A} + \phi_{o,B}$ and $\phi_i = \phi_{i,A} + \phi_{i,B}$ for consistency reasons.

the component C could be involved in, together with an arbitrary decomposition into two components A and B , as depicted in Fig. 2. It should be pointed out that, as mentioned above, the functional flows ϕ represent any number and configuration of functions, even including none at all. However, since A and B combined are exactly identical to C , the following conditions have to be fulfilled with respect to the functions performed by or on them, respectively:

$$\phi_o = \phi_{o,A} + \phi_{o,B} \quad \phi_i = \phi_{i,A} + \phi_{i,B}. \tag{8}$$

Applying Eq. (7) to C results in

$$\delta_C = \lambda \cdot (\phi_o + \phi_s - \phi_i - \phi_s) = \lambda \cdot (\phi_o - \phi_i).$$

It should be noted here, that self-function loops of a component do obviously not contribute to its functional value in general: Identically appearing both in incoming and outgoing functional flows these terms simply cancel out each other. For the sake of brevity, this finding is directly taken into account in the following calculations. Then, the result for the decomposition is

$$\begin{aligned} \delta_A &= \lambda \cdot (\phi_{o,A} + \phi_{AB} - \phi_{i,A} - \phi_{BA}) \\ \delta_B &= \lambda \cdot (\phi_{o,B} + \phi_{BA} - \phi_{i,B} - \phi_{AB}). \end{aligned}$$

With the conditions according to Eqs. (8), this directly leads to:

$$\delta_A + \delta_B = \lambda \cdot (\phi_{o,A} + \phi_{o,B} - \phi_{i,A} - \phi_{i,B}) = \lambda \cdot (\phi_o - \phi_i) = \delta_C.$$

This clearly shows, that the functional value for a component according to Eq. (7) is not only necessary, but also satisfying. Therefore, it is the only choice for a meaningful concept inline with the assumptions, particularly fulfilling invariance under component operations according to Eq. (1) as required.

4 Implications

The derived universal concept is an essential part of VA++ and leads to a variety of implications and consequences regarding both theoretical aspects and practical application. Moreover, rather formal features of the above derivation might require a more detailed explanation for a better understanding. In the following, some of the most important issues are addressed.

4.1 Arbitrary System Size

Even though the derivation is based on only one component being decomposed into only two, the result obviously also holds for the more general situation of a system or component consisting of any number of components. The reason is, that any desired component operation or final component constellation may be achieved by multiple sequential decomposition or combination operations involving only two components each time. For example, a system $S = C_1 \oplus C_2 \oplus \dots \oplus C_N$ made of N components C_n can be decomposed into the two components C_1 and $C_2 \oplus \dots \oplus C_N$ in a first step. Then, in a second step, the latter component constellation can be further decomposed into C_2 and the corresponding remainder, and so on. Eventually, this leads to $\delta_S = \delta_{C_1} + \delta_{C_2} + \dots + \delta_{C_N}$. Thus, as required, the functional value of any combination is always equal to the total sum of the functional values of all of its parts, independent of their actual number.

4.2 Choice of Calibration Factor λ

The factor λ in Eq. (7) formally represents a degree of freedom in the concept, and may be freely chosen accordingly. Since it identically affects the functional values of all involved components, it can be regarded as a global calibration or normalization factor, which might also adjust the units, in which the functionality of a component is actually measured. However, it should be pointed out, that the VA++ user can easily choose the most suitable unit system right from the beginning, at the initially required evaluation of the function values f as referred to in property P1. Thus, setting $\lambda = 1$ is the simplest and most convenient approach, in which the functionalities of both functions and components are measured in the very same manner. Therefore, this standard calibration $\lambda = 1$ resulting in the simple relation

$$\delta = \phi_{\text{out}} - \phi_{\text{in}} \quad (9)$$

is used for the rest of this work.

4.3 Selection of Functions \mathbb{F}^*

Regarding the concrete functions and functionalities to be analysed, the result holds for any selected (sub) set \mathbb{F}^* of identified functions fulfilling the two properties P1 and P2 mentioned above. Expressed in a slightly oversimplified way: As long as it is possible to assign numbers (exact or estimated ones) to the chosen functions, and it is considered appropriate to add those numbers up, the derived concept for the functional value of components can be consistently applied. As a consequence, this leads to a variety of options in practical application. Of course, the selection could simply consist of all useful or all normal functions, as in standard VA. However, if the VA++ team considers it reasonable to only focus on a more specific sub set in accordance with their particular task, question, or perspective, it is possible to do so. For example, the team could concentrate on all those functions related to a specific system functionality or MPV, or acting in a similar way (e.g. holding), or involving the same fields (e.g. thermal), or performed at a specific time, or related to a specific, potentially local, sub set of components only, and so on. In this way, the whole analysis can also just be splitted up into several smaller, more focused ones. A particular key advantage is, that also functional values, which must not be added up, because they follow a different logical relation from customer perspective for some reason, are still accessible separately for a more advanced analysis. For example, harmful functions can be naturally evaluated, too. If they are evaluated in the same run together with the useful functions, one option to incorporate them is to assign positive functional values to the useful functions and negative values to the harmful ones. Eventually, a system performing a harmful function can make that up by also performing a useful function of higher value, since both values are just added. This might be adequate for some scenarios. In quite a lot of real situations, however, a customer is not going to accept such a kind of value argumentation in the end. Rather, the impact of the harmful function as such needs to be limited below a given threshold independent from the benefit of further useful functions. Here, the team could simply switch to two separate analyses, and focus on the useful aspect on the one hand, and then concentrate on the harmful impact on the other.

4.4 Consistency with Trimming

The derived concept is naturally consistent with advanced component operations such as trimming. As depicted in Fig. 3, a function of functional value f_t performed by component A on component B is (partially) trimmed, such that it is taken over by B itself. In addition to this particular function, in the most general setting, A and B might be involved in any number and configuration of further functions as indicated by the corresponding functional flows ϕ in the graphics. Before trimming, the functional values of the components are evaluated to be:

$$\begin{aligned}\delta_A &= \phi_{o,A} + \phi_{AB} + f_t - \phi_{BA} - \phi_{i,A} \\ \delta_B &= \phi_{o,B} + \phi_{BA} - f_t - \phi_{AB} - \phi_{i,B}.\end{aligned}$$

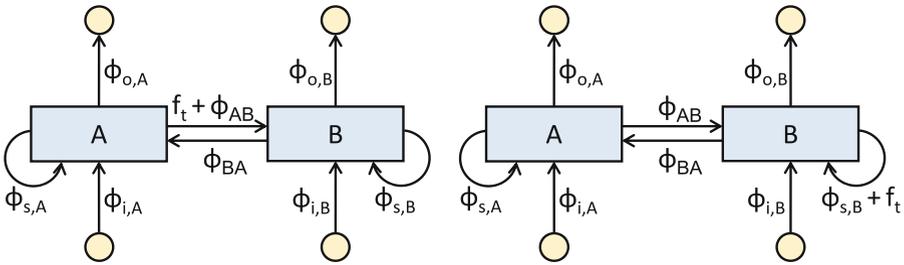


Fig. 3. (Left) A component A performs a function of functional value f_t on a component B . There might be an arbitrary constellation of further functions as indicated by the various functional flows ϕ . (Right) The function of value f_t is (partially) trimmed according to trimming rule B, i.e. it is not performed by component A anymore, but is taken over by component B itself. Such a trimming directly affects the functional values of both directly involved components: δ_A is reduced by f_t , while δ_B is increased by f_t . This result is fully consistent with the transfer of the according function from component A to component B .

After trimming the result is:

$$\begin{aligned}\delta_A &= \phi_{o,A} + \phi_{AB} - \phi_{BA} - \phi_{i,A} \\ \delta_B &= \phi_{o,B} + \phi_{BA} - \phi_{AB} - \phi_{i,B}.\end{aligned}$$

Thus, trimming leads to the changes

$$\begin{aligned}\delta_A &\rightarrow \delta_A - f_t \\ \delta_B &\rightarrow \delta_B + f_t,\end{aligned}$$

meaning the functional value f_t of the trimmed function is taken from δ_A and transferred to δ_B in full accordance with the actual function transfer between the components. This trimming pattern, in which the object of the function eventually performs the function (on) itself, is also commonly referred to as trimming rule B [6, 8, 14, 15]. A fully analogous consideration for trimming rule C, with the function performed on component B being transferred from component A to a third component A^* , results in the decrease $\delta_A \rightarrow \delta_A - f_t$ and the increase $\delta_{A^*} \rightarrow \delta_{A^*} + f_t$, while δ_B remains unchanged eventually. Summarizing, trimming simply implies the transfer of functional value from one component to the other - in exact correspondence to the actual function transfer.

4.5 Typical VA Issues

Based on the derived concept, VA++ resolves typical shortcomings of standard VA, from rather practical issues to significant conceptual problems. Standard VA only depends on the functional pattern between components, indicated by arrows, while the actual functional properties and aspects themselves are not taken into account at all. This feature of standard VA is not only one reason

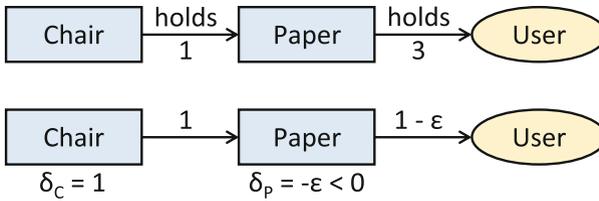


Fig. 4. A seemingly simple example of a paper sheet placed on a chair, cf. [24]. (Top) Function Model according to Function Analysis. The numbers indicate the functional values for both the functions and the components according to standard VA in TRIZ. (Bottom) Sample evaluation of functionalities according to VA++. The holding function of the chair is set to 1, whereas the holding function of the paper is assumed to be of slightly lower functional value. For example, most key features of the holding are still provided by the paper, but convenience and aesthetic aspects are somehow impaired. With $\epsilon > 0$ indicating the strength of this negative effect, the functional value of the paper turns out to be $\delta_p = -\epsilon$, which is negative. Thus, the paper ideality is supposed to be even worse than zero. Obviously, this is in full agreement with practical observations: There is no paper use in such a situation in reality, even if the paper is for free. In contrast, all variants of standard VA go totally wrong here, a free paper would even result in a skyrocketing ideality.

for its failure as also explained above, but it also poses a potential source for consecutive problems in practical application: Even the particular number of arrows drawn between a given pair of components has an immediate impact on the results already. Thus different Function Models, all of which are valid, lead to different outcomes, which are regularly wrong anyway. Unaware of these facts, the VA team might be misguided here and start an unnecessary and typically unsolvable discussion about how to model - e.g. split or combine - the function(s) appropriately. For example, a pipe has been identified to perform the two functions of holding and guiding a fluid. According to standard VA, the functional value of the pipe doubles, if the team draws two separate arrows from the pipe to the fluid, namely ‘holds’ and ‘guides’, in contrast to just one arrow tagged ‘holds, guides’. Such a weird effect is rather typical for a variety of issues and inconsistencies in practical application of standard VA. In the framework of VA++, however, the only question to the team is to elaborate the two decisive functional values f_h and f_g as a measure for the functionalities of the two corresponding functions ‘hold’ and ‘guide’, respectively. As obvious from the above derivation, the functional flow from the pipe to the fluid then is given by $f_h + f_g$, independent of the actual number of arrows chosen for the Function Model.

Focusing on more conceptual shortcomings, standard VA and all of its variants exhibit a strong tendency to overexaggerate the functional value of exactly those components that are located in the vicinity of the target component, e.g. eventually performing the main function of the system, compared to components situated deeper inside the functional network. For example, applying standard VA to a drone for autonomous package delivery results in a functionality of the clamp, that does nothing more than holding the package, which is twice

as large as the functionality of the engines, cf. [23]. Such a kind of effect basically appears because of two reasons. First of all, functions inside the system are considered to be of significantly lower functional value than those eventually performed by the system, e.g. to the target component. Secondly, components are always evaluated due to their functional performance only, not at all involving their functional input, which is in clear contrast to the universal concept Eq. (9) derived above. Thus, components close to the target are systematically overestimated, because they are assigned the highest functional values, while the essential functional input they regularly require from other system components is not taken into account. The notion of functions becoming more valuable from the core of the system towards the target component(s) can be even regarded a key design principle of all algorithmic variants employed for the empiric functionality evaluation sofar. However, although it is a good qualitative guideline in many cases, it is not true in general. How crucial this particular aspect really is for a deeper and correct conceptual understanding, can be seen in the analysis of a simple scenario briefly mentioned by Efimov-Soini and Chechurin [24]: A sheet of paper is placed on a chair, such that now the chair holds the paper, and the paper holds the user, as depicted in Fig. 4 (Top). Even though it is clear, that the paper is “adding nothing” [24, p. 23] to the functionality of the chair, this scenario is not resolved by standard VA or any of its variants sofar - and never can be for conceptual reasons. Following the original algorithm [17, 18], standard VA determines the functionality of the paper (3) to outperform that of the chair (1) tremendously, cf. Fig. 4 (Top). This effect might not be as drastic for other variants, but all of them eventually attach a functional value to the paper, which is designed to be higher than that of the chair. Note, that even handling this aspect correctly is not at all sufficient to come to an appropriate conclusion: The holding function of the paper for sure has to be evaluated positively, since it represents useful functionality. With a positive functionality and costs close to zero, the estimated ideality or value of the sheet of paper is trending to infinity. Clearly, this result is in full contradiction to reality: Typical chairs in offices, schools, or kitchens are not equipped with paper sheets, even if these are available for free. This shocking discrepancy between reality and common VA methods in TRIZ is resolved by VA++ quite naturally. Setting the holding function performed by the chair to $f_C = 1$, it is reasonable to assume a slightly lower functional value for the holding function performed by the paper, i.e. $f_P = 1 - \varepsilon$ with $1 \gg \varepsilon > 0$, cf. Fig. 4 (Bottom). The underlying reason is, that some of the original features of the chair can't be provided by the paper in exactly the same manner as expected by the user, in particular regarding convenience and aesthetic aspects, and the parameter ε serves as a measure for this functionality reduction here. Evaluating the functional value of the paper with the universal concept Eq. (9) directly yields $\delta_P = -\varepsilon < 0$. Thus, the paper is responsible for a negative functionality contribution: Although it performs a useful function quite well, its presence nevertheless impairs the overall system functionality. With an ideality supposed to be even negative, it's not surprising that such a paper is not used on chairs in typical real life situations. For clarification also a totally fic-

titious, super-thin, super-smooth, transparent or perfectly chair-coloured paper sheet, which goes unnoticed by the user, but doesn't add anything useful itself, is still expected to achieve no market penetration. Described by exactly $\varepsilon = 0$ such a paper identically performs the original function of the chair by perfectly transferring or copying all of its features and aspects. Nevertheless the corresponding functional value turns out to be $\delta_P = 0$, which represents the zero net functional contribution of the paper sheet and directly implies an ideality of zero. Conceptually, VA++ allows to include further aspects for a more detailed study in a straightforward way if necessary. For example, potentially harmful functions of the paper not considered here would make it appear even less attractive. In contrast, in a few rather specific cases or scenarios, additional useful functionality of the paper can overcompensate its slightly negative impact, eventually resulting in a quite positive ideality. A larger protective paper layer placed on the treatment couch in a doctor's office to stop germs, sweat, and more is a real case example for this.

4.6 System Perspective

The conceptual implications when considering a system are quite essential. To begin with, from system perspective all internal functions between system components turn out to be self-function loops and do not explicitly enter the resulting functional value as explained above. Rather, the functionality is purely determined by the functions between the system and its environment, the supersystem. In contrast to common practice and understanding, the system functionality is not identically given by its actual functional performance in general, but equally affected by its functional requirements or inputs. Thus it is fundamental to analyse the difference of outgoing and incoming functional flows, or - in other words - the functional value add or the net functional contribution of the system, instead of the functional performance alone. This insight explicitly indicates further options for improving and innovating systems by also reducing their functional input. For example, a car transports the driver and possibly also further passengers and luggage, while the driver needs to control the car. To develop a car performing the very same transport function, but with less or no control function required from the driver, i.e. a step towards self-driving cars, is obviously valued so highly, that not only traditional car companies around the globe make tremendous effort on this very issue. Albeit clear from MPV perspective to focus on the user's or driver's convenience by increasing car autonomy, there is no consistent conceptual link to TRIZ VA methods so far. In the framework of VA++ this connection is naturally provided: A reduction of necessary functional input directly increases system functionality, in the same manner as an increase of functional performance.

5 Resume and Outlook

This work derives a fundamental concept for the functional value of systems and components from scratch. As a direct result, functionality has to be measured

by the difference between functional performance and functional input, i.e. functionality is given by net functional contribution. This insight is an essential part of the advanced TRIZ Value Analysis framework VA++ and naturally resolves typical issues of standard VA techniques, cf. also [23]. The derived concept is fully consistent with trimming and establishes a deeper methodical link between Function Analysis, Value Analysis, and MPVs, which opens up new opportunities in TRIZ from both theoretical and practical perspective. For example, it establishes connections to TESE and system level considerations, and it allows to tackle situations, in which the separate evaluation of different functionality aspects is necessary for a meaningful analysis. VA++ explicitly indicates points of attack for potential ideality or value enhancement by reducing functional input, which might also have a potential impact on Value Methodology. Furthermore the conceptual findings elaborated in this work are expected to act as fundamental building blocks for advanced software-based innovation approaches, involving e.g. automated or semi-automated algorithmic or more sophisticated AI methods, focusing on functionality, ideality, or value of systems and their components.

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Use of Function Analysis in the Design of Multi-Functional Products

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Abstract. In the current developing world, Technical Systems are required to satisfy variable customers' needs. This means they should be designed to facilitate multifunctionality with a simultaneous reduction in resource usage consumed for products with many components having minimal functionality index. The proposed approach is to develop a method for components clustering on a functional level to identify functional modules being sets of components that perform a main function on a target component. Such clustering is quantified as a novel modularity index derived from the value equation used in TRIZ and coupled with existing modularity metrics. As a result of the work, a clustering mechanism for Technical System Components was proposed that facilitates the design of modular, multi-variant products. Additionally, the proposed method can help to assess the design from the point of view of its modular structure, indicating areas for further development, including Trimming and Contradiction Defining approaches. The proposed method can reduce the time and costs associated with a modular design. Additionally, designed Technical Systems can be more prone to modifications. In total, this approach can improve the adaptivity of a Technical System, reducing manufacturing costs.

Keyword: TRIZ · Function Analysis · Modularity

1 Introduction

Technical Systems are designed to satisfy variable customers' needs in many areas worldwide. This means they should be prepared to facilitate multifunctionality with a simultaneous reduction in resource consumed for products with many components having minimal functionality index. There are numerous studies on how to design effective and resource-friendly products, i.e., the approach described in [1] makes it possible to design multi-variant products that represent a systematic and structured application of system segmentation. An essential role in new product planning is played by the Theory of Inventive Problem Solving (TRIZ) [2, 3], in particular, Trends of Engineering System Evolution [4, 5] that indicate a set of changes that a Technical System will undergo during its development. Particularly interesting is the Trend of Increasing Ideality, which demonstrates the increase in functionality of products at simultaneous

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reduction of resource usage and harm delivered by them. One of the ways in which the ideality of a Technical System can be examined, assessed, and improved is to use Function Analysis (FA). There is existing research on applying Functional Analysis in forecasting Technological Processes and Technical Systems, i.e., [6]. Functional Analysis was also used to identify necessary functions in product design using Function and Behavior Representation Language (FBRL) [7]. Typically, Function Analysis is used to improve the functionality of new or existing products [8–10], particularly when combined with CECA/RCA [11] or Trimming [12–14], as well as a description of existing products, also in IT domain [15]. From the point of view of the design process of modular products, knowing the functions performed by each component makes it possible to cluster them together in the form of modules. Such an approach was already used in existing studies [16, 17]. Additionally, components of a Technical System (TS) were grouped by functional similarity, as shown in [18–21].

One of the most important issues regarding efficient development of modular products is connected with lack of unequivocal and standardized description of functions performed by Technical Systems [22, 23]. This leads to the idea of application of TRIZ, especially Function related tools like Function Analysis and Trimming, to identify and optimize functional relations between components, that can be used to define modules. It was shown in [12–14] that by describing functions performed by a TS, it is possible to increase its ideality as well as ideality of its components by maximization of usefulness, with simultaneous reduction of costs.

This paper builds on existing concepts of functional grouping and similarity in modular product design by developing a method for components clustering on a functional level to identify functional modules being sets of components that perform functions on the target component and supersystem components. Such clustering is quantified as a novel modularity index derived from the value equation used in TRIZ.

2 Description of a Multi-functional Product

A function in TRIZ is regarded as an action performed by the Function Carrier on a Function Object that results in modifying or preserving the parameters of the Function Object. This means that a function may change if:

- a) an action will be changed, i.e., acting upon a different parameter, or
- b) a Function Object will be changed.

The above implies that by the time the Function Object changes, there might be a change at the functional level of a Technical System. A Technical System (TS) capable of performing supersystem components functions is designed and developed to serve a strictly defined action on a Target Component. Considering a car trailer as an auto-transporter, its Target Component is a car, but it is also possible to transport sand on such a trailer. Using it this way on purpose will change the Target Component of the Trailer; still, the effectiveness of the same function (to hold) will be different for each of the Target Components (Fig. 1).

Nowadays, customers require products to be versatile and willing to use in many different scenarios. Additionally, producers maximize product similarity to streamline production by using the same or slightly modified products for other applications. The above

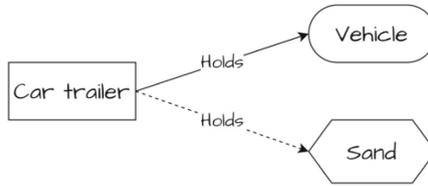


Fig. 1. Functional model of a car trailer dedicated to transporting vehicles.

statement indicates a need to develop a Multi-Functional Technical System designed to act upon more than one Target Component.

A Multi-Functional Technical System (MFTS) is defined as a set of components (material objects) that were consciously combined into a system assigned to perform a controllable useful function or functions on two or more supersystem components. An example of such a system is a Swiss Army Knife, which can cut material objects, move cups, or move screws (and many more). A Technical System that cannot be regarded as multi-functional is, for example, a pencil designed to mark paper, thus performing no useful functions on other supersystem components.

It must be mentioned that a Technical System (TS) can also perform Additional Functions on different supersystem components. Such functions can result from exploiting a TS when they naturally emerge or from a novel product application. But the difference between a Technical System performing many Additional Functions and a Multi-Functional Technical System lies in the value and effectiveness of those functions as perceived by customers. This is an important distinction, since a pencil, like most Technical Systems, are capable of performing number of different functions (to conduct, to move) on different components (electric field, solid objects). In the proposed definition, it is important to distinguish between those functions that represent value to the customers and those that represent functional resources of the analyzed Technical System that can be utilized to deliver this value. It means, that despite its capabilities (available resources) a pencil is not widely adopted neither as an electric current conductor nor as an object mover, hence it is not regarded as MFTS. The above indicates, that a product can be multifunctional in one moment of time, and non-multifunctional in another. This leads to the conclusion, that modularity can be a periodic feature of a technical system.

3 Functional Clustering of Components

For multi-functional products, there may be more than one target component. This means that similarly to the Functional Analysis for products, the significance of functions performed on those components is higher than the remaining functions. A set of components performing functions on any supersystem component is defined as the Functional Module. From the point of view of the MFTS, we can distinguish three main types of functional modules:

- Primary Functional Module, which is a set of components that perform useful functions on a target component of a Technical System.

- Additional Functional Module, which is a set of components that perform useful functions on a supersystem component.
- Auxiliary Functional Module is a set of components that perform auxiliary functions on components belonging to primary or additional functional modules.

An ideal modular system is such in which each module is responsible for performing strictly defined function. When it is detached from the system, the system loses said functionality. Consider an angle grinder as an example. The grinding wheel is regarded as primary module, since it performs function only on a target component of a TS. When it is removed, the grinder loses its functionality. For a cordless screwdriver, it contains two auxiliary modules (battery pack and screwdriver body) and one primary module (drill bit). The classification is unequivocal in the similar manner in which the main function is defined in Functional Analysis- it corresponds to the single function a TS (here, a module) was designed to deliver.

An example of a Functional Graph having Functional Modules defined is shown in Fig. 2. In this case, Auxiliary Functional Module comprises only one component (4), and component (i) is shared between the Primary Module and the Additional Module 1. Each component of a Technical System that performs any useful function on a supersystem component can belong to one or more functional modules. In this particular case, when each Functional Module contains unique components, we can observe disaggregation of functions as proposed by [24]. In other words, depending on a need for a function (F5), an Additional Module 2 can be added to or removed from the Technical System, improving functionality to cost ratio, thus increasing ideality.

On Fig. 2, component “i” belongs to both primary and additional modules. This indicates, that to realize functions on Supersystem component 1 and Target Component, it is necessary to have this component present within the system. From the point of view of disaggregation of functions, this is not a recommended solution. If we want to preserve one-to-one mapping of functional and structural components, this component should be grouped in either of those modules. In that case, when said module is removed from the system, the lack of “i” component may adversely influence the behavior of the other module, hence decreasing ideality of the entire Technical System.

Similarly to the classification of product architectures described in the paper [25], modular, integral, and bus-type architectures can be distinguished on a Function Graph that results from applying the Functional Analysis. On Fig. 3 shows an integral architecture with no distinguishable Functional Modules, whereas, in Fig. 4, modular architectures with and without an Auxiliary Functional Module are shown. Since the function can exist only if there is an interaction between components, selection of modular or bus-like architecture influences possible existence of functions, which leads to different functional relations between exemplary graphs. This represents the need of TS redesign when changing its architecture.

In an integral architecture, modules are not assigned to primary, additional, or auxiliary functions. This makes it very difficult to plan the development of MFTS, considering different markets and other factors. It is especially relevant when one of the supersystem components gets removed due to the variability in customers’ needs (different markets, for example). In such a scenario, modular architectures, as shown in Fig. 4, allow

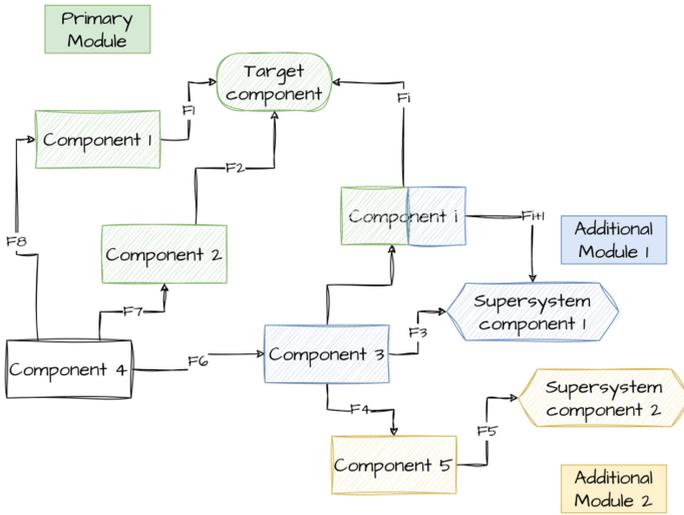


Fig. 2. Functional Graph of a Multi-Functional Technical System (MFTS).

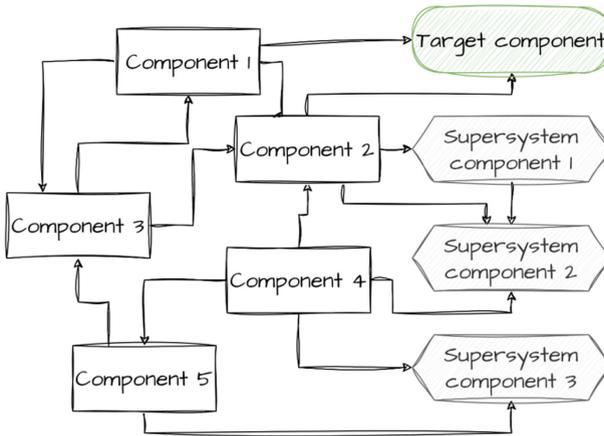


Fig. 3. Integral type architecture on a Function Diagram.

Trimming rule A to remove the Additional Functional Module for a corresponding supersystem component that was eliminated.

Taking into consideration current research in the field of modularity [23, 26] and System Architectures shown on Fig. 4, the following statement was formulated: in modular systems, there is a one-to-one mapping between the functional elements and the structural components in a product. In the proposed approach, functional elements are regarded as primary/additional or auxiliary modules that comprise components as function carriers that act on supersystem or system components. Those can be easily quantified at given granularity of a system and denoted as $N_{FC} [-]$. Similarly, structural components

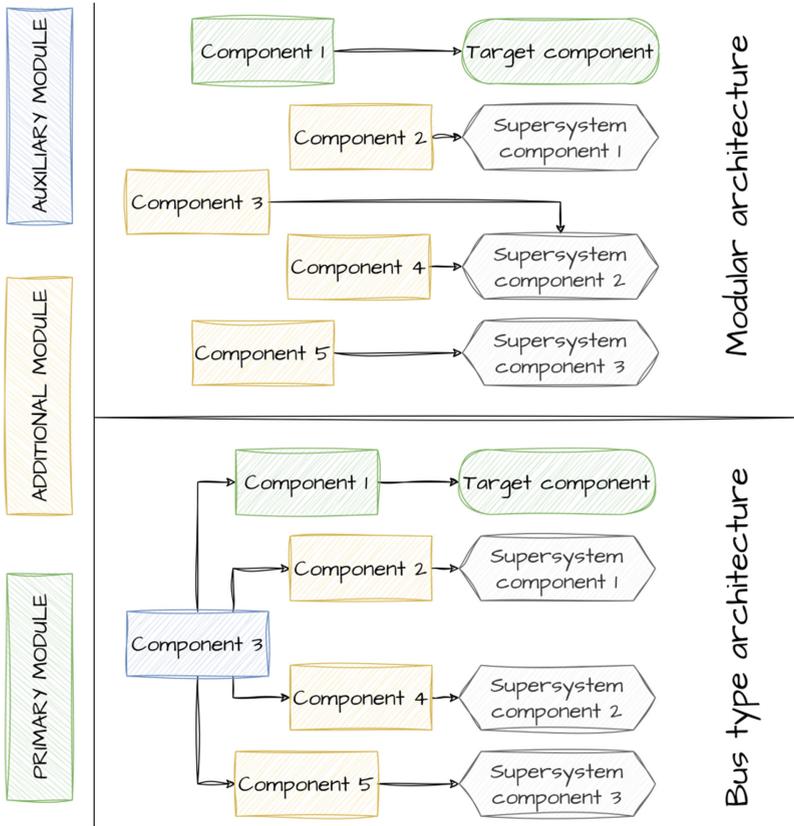


Fig. 4. Modular and Bus type architectures on Functional Diagrams.

that constituent the assessed module can also be quantified at the same granularity and denoted by N_{SC} [-]. This leads to the definition of the novel Functional Modularity Metric that assesses the correspondence between functional and structural components based on results of the Functional Analysis:

$$FMM = \frac{N_{FC}}{N_{SC}} \tag{1}$$

where:

N_{FC} - number of function carriers acting on supersystem or system components,

N_{SC} - number of physical components that contain function carriers, which can be easily detached from the rest of the system as an independent subsystem.

The FMM metric ranges from 0, when the analyzed cluster of components do not perform any functions on any other components, to 1 in the case where the cluster contains only those components, that directly perform a function on system or supersystem components, thus representing the complete disaggregation of functions [24].

An important conclusion can be drawn from the proposed metric, that minimizing number of components that does not perform any function on a module target (supersystem component, system component or system target) increases ideality of the module, and also ideality of the entire Technical System.

4 Case Study: Module Classification of a Car Trailer

Formerly described functional grouping of components using Functional Analysis was shown on an example of a modular car trailer that is used to transport a variety of loads including but not limited to excavators and granular materials like sand. Figure 5 shows two diagrams, one for the design variant used to transport the former and one for the latter. The diagrams represent the same trailer in two variants. In the design process of this car trailer, the first step was to identify target component, which was defined as a light excavator. Subsequently, set of additional functions was defined based on existing solutions and company experience based on conversations with customers. It was indicated, that besides being able to transport light excavator, it is important to take into consideration granular materials transport as well as possibility for quick wheel maintenance as an option. Those additional features were not requested by all customers; thus, it was decided to design an adaptive structure.

In a given example, Trailer bed together with Tracks are regarded as primary module. It means, that they were designed for the purpose of action on the light excavator. The Functional Modularity Metric for this module was equal to 0.05. This indicate, that the primary module is not disaggregated from the rest of the structure. For the spare wheel holder, regarded as an additional module, FMM is equal to 1 which means, that each of its components perform actions on supersystem component. In this particular example, wheel holder is made of single element that holds the wheel directly.

If a trailer primarily used to transport light excavators will be used to transport different cargo, there is a change in the target component of such a Technical System. In that case, a difference is observed from Excavator to Sand. When the trailer is no longer used to transport or to hold an excavator, there is no further need to perform any functions on the said excavator. This means that it is possible to trim out Additional Functional Module “Tracks” using Trimming Rule “A” since the object of function for “Tracks” no longer exists. This process can be continued for Track mount and Track supports. Similarly, if there is no need to hold a spare wheel, it is possible to trim the Wheel Holder, being an Additional Functional Module.

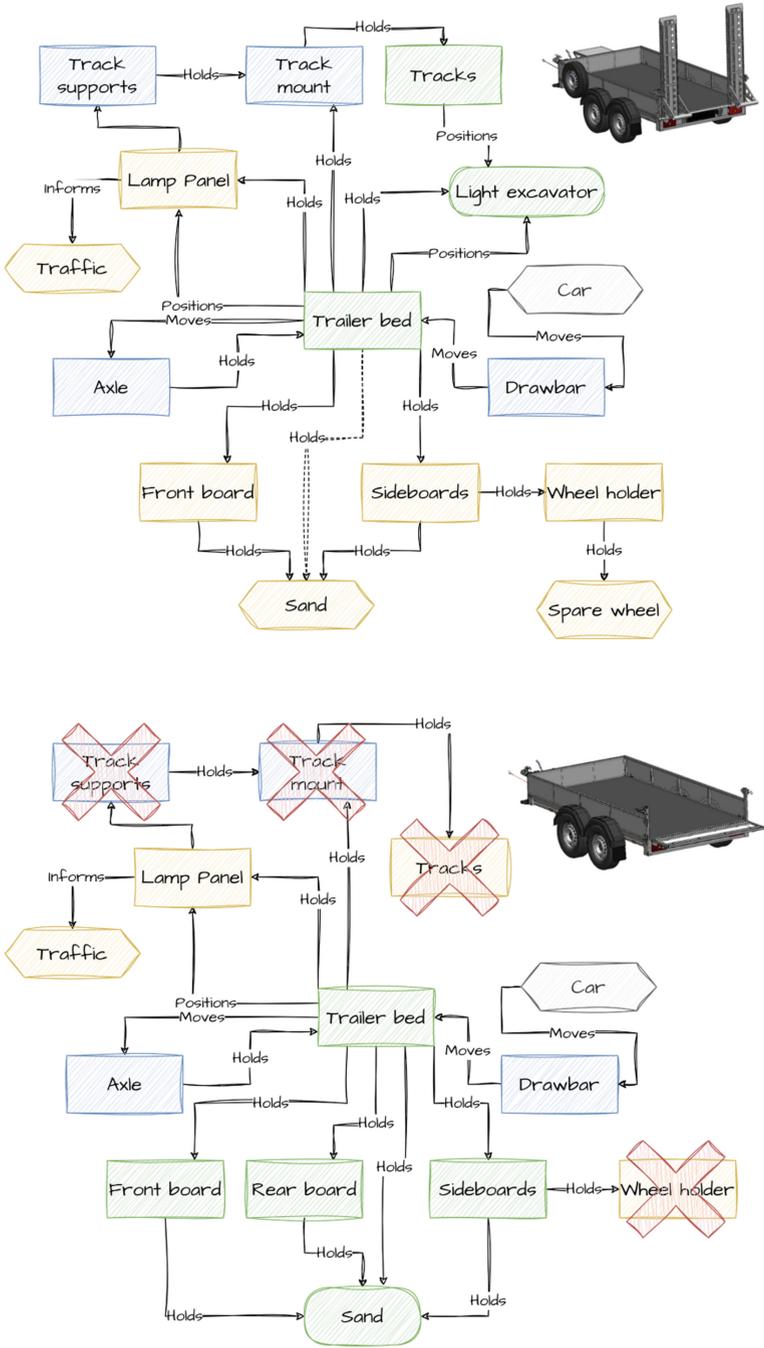


Fig. 5. Functional Diagram of a trailer used to transport excavators (on top) and the same trailer that was modified to transport sand (on the bottom).

5 Discussion and Summary

The proposed approach is based on identifying function carriers that perform actions on supersystem components and grouping them so that a set of components can be identified that directly act on it for each supersystem component. This offers an opportunity to cluster components, facilitating Design for Modularity [27, 28] by identification of components that should be regarded as one module. The presented case study offers an example of component classification and grouping that utilizes Trimming for Products to define Modular Product Variants based on customers' needs.

Considering Value Analysis, components acting directly on supersystem components (including those acting on target component) are of higher value than those acting on system components. It is thus vital to maintain those components that perform primary and additional functions, with simultaneous reduction of components performing auxiliary functions. Furthermore, similarly to the approach suggested by [29], it may be beneficial to group together those components that perform auxiliary functions into the modular platform, to which valuable Primary and Additional Functional Modules are connected.

There are still some questions to be answered in future studies. Is it possible to design a modular product from scratch using the proposed approach? The results presented in this paper suggest that by knowing supersystem components and additional functions performed by an MFTS, it is possible to formulate initial module sets that can be further developed using Computer-Aided Design and AI-Aided Design. It is also the subject of future study to examine the correspondence between the proposed grouping approach that originates at the functional level with the one already existing at the structural level. Is it possible to adopt existing modularity metrics to qualitatively measure the grouping of modules on a functional level? Also, it was shown that it is possible to define feasible modules based on defined Functional Modules. Still, it may happen that, especially if the additional function is performed by field, there might be a need to include an additional component in the said module that will act upon the field. Without it, the module would be impossible to design and manufacture. This means that the proposed approach's applicability boundaries are yet to be defined. Additionally, it is also interesting to consider application of Value Analysis to the selection process of initial Supersystem components, based on which modularity is being defined. In the proposed approach, supersystem components and corresponding functions were selected based on existing solutions and company experience with customers. In the current era of Artificial Intelligence development, including but not limited to LLM and GPT applications, it became easier to automate the process of supersystem components identification, which will be examined in future works.

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Functional Approach to Subversion Analysis in New Product Development

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Abstract. It is essential when developing a new product to identify and eliminate the most critical potential failures in the product before they occur. These potential failures can be eliminated in advance, making the new product development process faster and less costly. The primary tool currently used for this purpose is Failure Mode and Effect Analysis (FMEA), which identifies potential failures and their causes. However, since FMEA relies on the personal expertise of team members carrying out the FMEA, this tool is subjective and, hence, not very reliable. To make a potential-failure analysis more objective and robust, TRIZ offers a special tool called Anticipatory Failure Determination (AFD), which can improve or even replace FMEA. AFD provides a set of checklists to help detect typical failures and uses another TRIZ tool called Subversion Analysis to identify possible scenarios for these failures. Nevertheless, a brand-new product may have new critical failures that have never been encountered before and were not included in the checklists. Such failures may be missed by both FMEA and AFD methods. The aim of this work is to enhance the AFD and make it more reliable and easier to use to identify the most critical failures that can occur in a brand-new product. This goal is achieved through the combined use of Function and Subversion analyses. A case study is provided to illustrate the proposed approach.

Keywords: Anticipatory Failure Determination · AFD · FMEA · Function Analysis · New Product Development · NPD · Subversion Analysis · TRIZ

1 Introduction

It is essential in any new product development (NPD) to identify and eliminate, at a minimum, the most critical potential failures in the product before they occur.

There are several methods that are currently used for this purpose, such as Fault Tree Analysis (FTA), Failure Modes and Effects Analysis (FMEA), Hazard and Operability Analysis (HAZOP), etc. Of these tools, the most frequently used is FMEA [1] which is sometimes extended to FMECA (Failure Mode, Effects, and Criticality Analysis) [2].

FMEA is a well-documented method that was developed and described by the US military in 1949 and has since become a widespread tool used in various industries, not only for hardware development but also for software development [3].

FMEA usually starts by defining the basic functionality of a product and identifying potential failures associated with that functionality, such as non-performance or insufficient performance of a basic function, intermittent function, or the presence of an undesirable (harmful) function. The expert group then brainstorms possible failure modes that may lead to these functional failures, based on their previous experience with similar products or technologies.

Next, the experts assess these failure modes in terms of risk of occurrence and severity of consequences, calculate the risk priority number (RPN) for each failure mode and develop preventive actions to avoid the failure modes with the highest RPN.

Despite its general efficiency and popularity, the FMEA approach has inherent limitations, for example [4, 5]:

- Experts from different disciplines assess each failure mode differently and it is difficult to reach a consensus, which creates uncertainty when calculating its RPN.
- The relationship between the various factors contributing to the failure is ignored, and only individual component or unit failures are considered, whereas a system failure can be caused by a chain of failures.
- FMEA depends on the subjective analysis and experience of the engineers involved, which makes it difficult or impossible to apply to completely new products with which these engineers have no experience.

Researchers are trying hard to improve FMEA. For example, various mathematical tools, such as the Dempster-Shafer theory [6, 7] and a fuzzy beta-binomial distribution evaluation method [8] are used to address the uncertainty of RPN calculations; and a scenario-based FMEA was developed [9] to include undesirable event chains in the analysis.

These efforts, however, do not solve the main problem: how to reliably identify a full set of the most critical potential failures, failure modes and scenarios?

If a failure is known, related failure modes and scenarios can be found using a TRIZ tool such as Subversion Analysis, which effectively removes psychological inertia by inverting the problem from “What causes this failure?” to “How to create this failure using only the resources that are already in the system?” The inverted problem can be tackled using various TRIZ tools like ARIZ, Function Oriented Search (FOS), etc.

Applying the Subversion Analysis to the Ideal Final Result (IFR) [10, 11] or to the Substance-Field model [12, 13] of the system being analyzed makes it possible to identify generic functional failures that may occur in the system. This approach may be useful even for products that are at a very early stage in their development, when only a general concept or just a raw idea of the product has been generated.

The most comprehensive and popular TRIZ tool that utilizes Subversion Analysis for identifying failures in engineering systems is Anticipatory Failure Determination (AFD) [14], which is sometimes referred to as Anticipatory Failure Identification (AFI) [15]. This tool includes two parts [14]: AFD-1 (failure analysis) identifies possible scenarios of a failure that has already happened, and AFD-2 (failure prediction) is aimed at finding an exhaustive set of all failure scenarios that could occur in the system.

In contrast to FMEA, AFD [14] provides checklists summarizing previous human experience with failures. They include the most dangerous time periods, typical sources of increased risk and areas in the product where the probability of failure is highest.

It has been shown [16] that while the FMEA method is easier to use, better organized and more straightforward than AFD, the latter is more robust and works much better for NPD because it identifies more failure scenarios than FMEA and is able to identify non-obvious scenarios, i.e. to “invent failures.”

To combine the benefits of FMEA and AFD, both methods could be integrated into the Failure Mode and Effects Anticipation and Analysis (FMEAA) [17].

In addition to identifying and predicting technical failures in a specific product or process, AFD can also be used to predict business and management failures [15].

Although AFD is not as widespread as FMEA, many researchers use it and suggest various improvements to enhance its performance and functionality, for example:

- Some Axiomatic Design approaches have been used to improve AFD-1 and AFD-2 and to develop a new AFD-3 designed to analyze failures due to human errors, organizational errors, poor ergonomic design, and other problems of this kind [18].
- The cognitive reliability and error analysis method (CREAM) has been employed to make AFD applicable for predicting product failures caused by human error [19].
- The Fault Investigator Tool (FIT) [20] combines functional analysis, AFD and FMEA to rapidly diagnose product failures in after-sales service.
- In xTRIZ Anticipatory Failure Analysis [21], AFD is complemented by considering combinations of functions and resources that can lead to failure.
- The “Perturbed” Function Analysis (PFA) in combination with AFD was proposed to make FMEA easier and more robust [22], and a list of typical “noise factors” that can be used to create perturbations in the PFA was provided.

Despite these improvements and greater NPD efficiency compared to FMEA, the AFD and other methods using Subversion Analysis remain labor-intensive and subjective tools that rely on previous experience and checklists and, thus, possibly omitting a new product’s potential failures.

The high level of subjectivity not only hinders the reliability of AFD, but also makes it difficult or impossible to automate it with CAD or artificial intelligence (AI).

It should be noted that the use of Function Analysis does reduce the subjectivism of AFD [20–22] by focusing on failures related to the functions actually performed in the system, instead of brainstorming possible failures, but there is a contradiction here:

- On the one hand, a detailed function model is necessary to define an exhaustive set of failure modes and scenarios, but the more detailed the model, the longer the AFD procedure takes because you need to consider all possible failures in numerous functions performed in the system.
- On the other hand, a simplified or incomplete function model (e.g. some researchers suggest considering only the main function of the system) will speed up AFD, but some critical failure modes may be missed.

The purpose of this paper is to make failure prediction in NPD less time-consuming without compromising reliability.

In what follows, NPD refers to the development of a completely new product that is either at Stage 1 or at a transitional (from Stage 1 to Stage 2) stage of its evolution on the S-curve, which is the most challenging situation for AFD and FMEA.

2 Methodological Background of the Proposed Approach

The methodological basis for the proposed approach lies in the Function Analysis and Trends of Engineering Systems Evolution (TESE) [23], and more specifically, the S-curve analysis and the Trend of Non-Uniform Evolution of System's Parts.

The key points of this approach are:

- It is not necessary to predict all types of failures that may occur in a system at hand. Only the most critical potential failures - those that could prevent further development of the system at a given time - must be identified.
- Therefore, the purpose of failure prediction, just like the main goal of the system's development, depends on its stage of evolution on the S-curve: failures that are critical for a mature product may be less important for a brand-new product and vice versa.
- The specific components to focus on when designing a system, and hence when predicting failures, also depends on the stage of evolution of that system as defined by the Trend of Non-Uniform Evolution of System's Parts.

By focusing on the components and their functional failures that are most critical at the current stage of the system's evolution, failure prediction can be accelerated. As TESE is used to determine the components and critical functional failures, failure prediction also becomes less subjective.

3 Proposed Algorithm for Failure Prediction

The proposed algorithm for predicting and eliminating potential failure modes and scenarios is shown in Fig. 1. As can be seen from Fig. 1, steps 1, 2 and 8 are straightforward and should not pose a problem for the TRIZ specialist. Therefore, these steps are not discussed further in this paper.

In Step 3, the current focus of the NPD is defined based on the system's stage of development as shown in Fig. 2 [24].

For example, for a product in the first stage of the S-curve, the main goal of NPD is to make the product work. A product at this stage may only exist as a raw idea or product concept, and the aim of failure prediction is to find any potential failures that could interfere with the basic functionality of the product.

For a product at the transition stage, the goal is to make the product work properly, i.e., well enough to bring it to market (Fig. 2). At this stage, a prototype product is usually already built and working well in the laboratory, and failure prediction should be aimed at finding any potential failure scenarios that could disrupt the basic functionality of the product when it is used by the consumer.

In step 4, the system components that are most relevant to the current NPD focus can be identified using knowledge of the system: these components are usually unique and specifically designed for the new product being analyzed, while the other components of that product are usually commercially available, general-purpose parts and assemblies, such as sensors, pumps, motors, general purpose controllers, etc.

If the product is at Stage 1 on the S-curve and has not yet been developed in detail, it should be considered as a generic engineering system, which may include the engine,

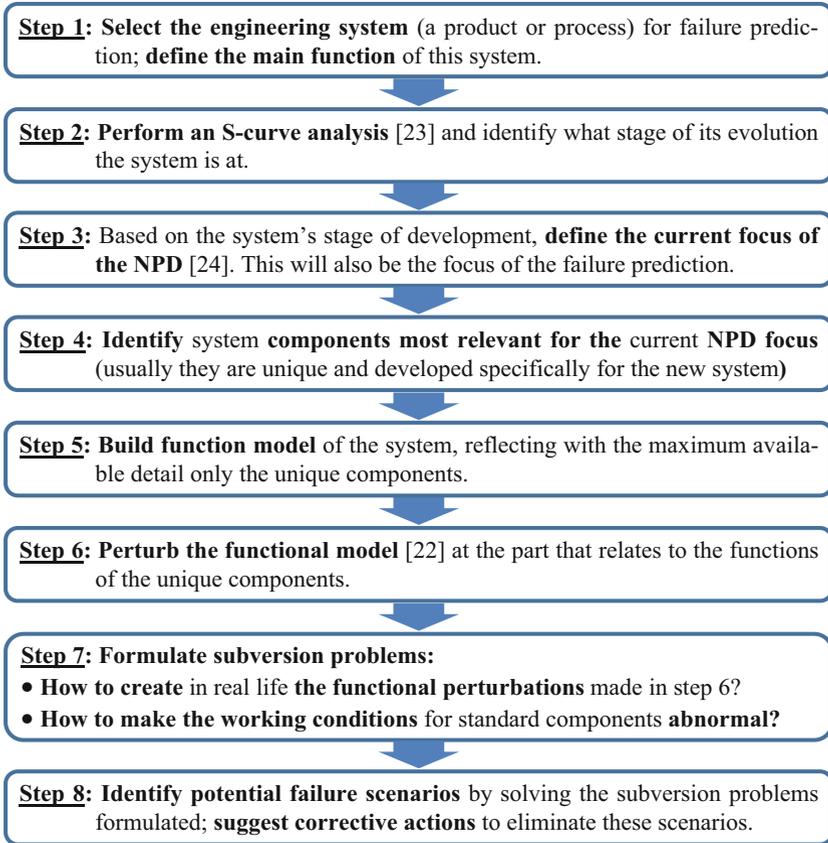


Fig. 1. Proposed algorithm for predicting and eliminating potential failures.

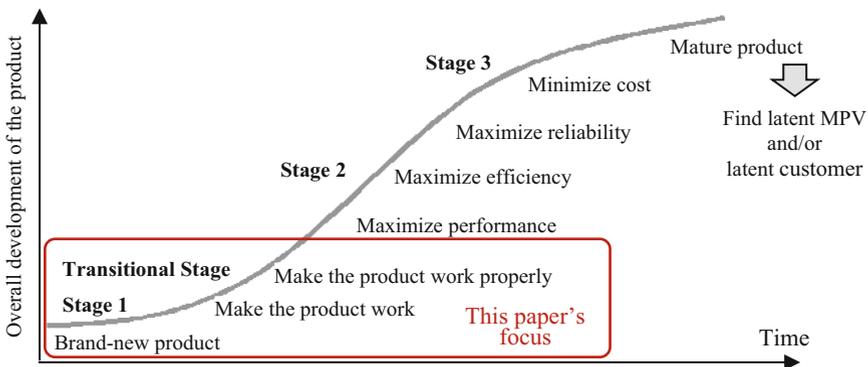


Fig. 2. Typical S-curve of the NPD focus [24].

transmission, control unit, operating unit and, sometimes, the power source. In this case, the focus of the NPD will be on the working unit and the control unit (if the product includes the latter).

In Step 5, the function model of the undeveloped product that is at Stage 1 on the S-curve should include all generic components of a complete engineering system: Engine, Transmission, Control Unit and Working Unit; sometimes Energy Source can be added to a generic function model (see Fig. 3). Note that the functions of some components in Fig. 3 could be performed by the consumer or by some components of the product's supersystem, which should be reflected in the model.

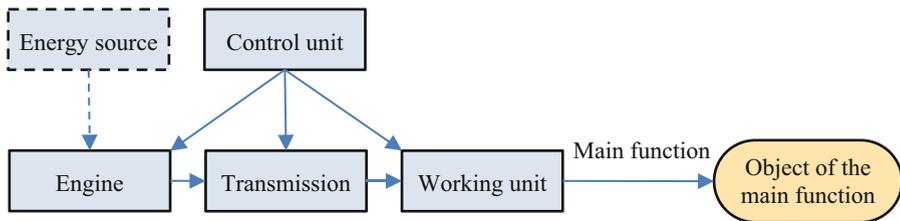


Fig. 3. Complete engineering system (generic function model).

For a product at the transition stage, when a product prototype has already been created or developed in detail, a more granular function model can be built. This model should include the actual components of the product prototype.

Since the most challenging failure scenarios to predict involve unique components designed specifically for a new product, these components should be represented in the model in as much detail as possible, with all their subcomponents, while other product components can be represented without detail.

In Step 6, the useful functions in the function model are perturbed using “noise factors” as suggested by Spreafico and Russo [22]. However, it is not necessary to perturb all useful functions, only those relating to the unique components of the product.

When the product has not yet been developed in detail, and, therefore, we have to use a generic function model, shown in Fig. 3, only the main function of the working unit (i.e. the main function of the product) can be perturbed by changing the parameters of this function so as to make it insufficient or excessive [25]. Another way to perturb the main function of the product and convert it into a harmful function is to redirect it to some other object. This new object must be close to the object for which the function was originally intended.

An example of a perturbed generic function model is shown in Fig. 4.

In Step 7, consider all the perturbations introduced into the function model as useful and formulate subversion problems to make each of these functional perturbations happen using only the resources that are already in the product.

Note: standard general-purpose components used in the product should provide their certified functionality if their operating conditions (temperature, humidity, voltage, etc.) are within specifications. Therefore, subversion problems for these components should be how to make their operating conditions abnormal to cause them to fail.

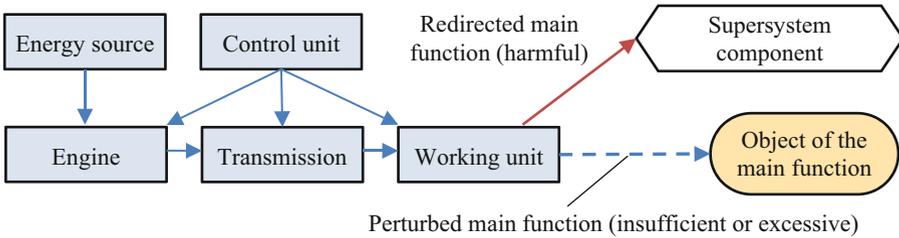


Fig. 4. Perturbed generic function model of a complete engineering system.

4 Case Study: Hydrokeratome

This case study relates to a real failure prediction project [26] relating to a novel keratome, which is a device used in LASIK surgery to create a thin flap on the patient's eye cornea prior to doing laser ablation.

The new keratome used a high-velocity water jet to create the flap and was therefore named Hydrokeratome [27, 28]. Compared to the usual microkeratomers that use tiny blades for this purpose, the Hydrokeratome offered a higher quality flap and cleaner cut.

The working prototype of the device consisted of the following parts (Fig. 5):

- Electric system, including a controller and standard drivers for all electromechanical components of the Hydrokeratome
- Pneumatic and hydraulic system to provide high-pressure water to the hand piece in which the high-velocity water jet was formed
- Vacuum and aspiration system providing vacuum to hold the hand piece on the patient's eye and to remove debris during the operation
- The hand piece performing the main function of the Hydrokeratome (i.e., to create a flap on the patient's eye cornea)

The prototype had been successfully tested in the laboratory and was being prepared for clinical trials. Thus, the goal of the project was to predict all potential failure scenarios that could occur in clinical practice.

Below are the most interesting steps of this project (refer to Fig. 1).

Step 2. The Hydrokeratome was in the transitional stage on the S-curve because it was not on the market but already functioned as a working prototype.

Step 3. Therefore, the main goal of the Hydrokeratome development was to make it work properly to facilitate its commercialization.

Step 4. The components responsible for the Hydrokeratome functionality were the hand piece, which was designed for this device from scratch, and the controller, which controlled all the other units. Although the controller hardware was standard, it ran a unique algorithm designed specifically for the Hydrokeratome. The hand piece included:

- A 30-micron precision sapphire orifice forming a high-velocity water jet
- Two filters: a ceramic 0.2-micron filter and a 20-micron metal filter, which were placed just before the orifice so that no debris particles could enter and block it
- A linear electromechanical drive that moved the water jet to create a flap
- Transparent applanator with suction ring to hold the patient's eye during surgery

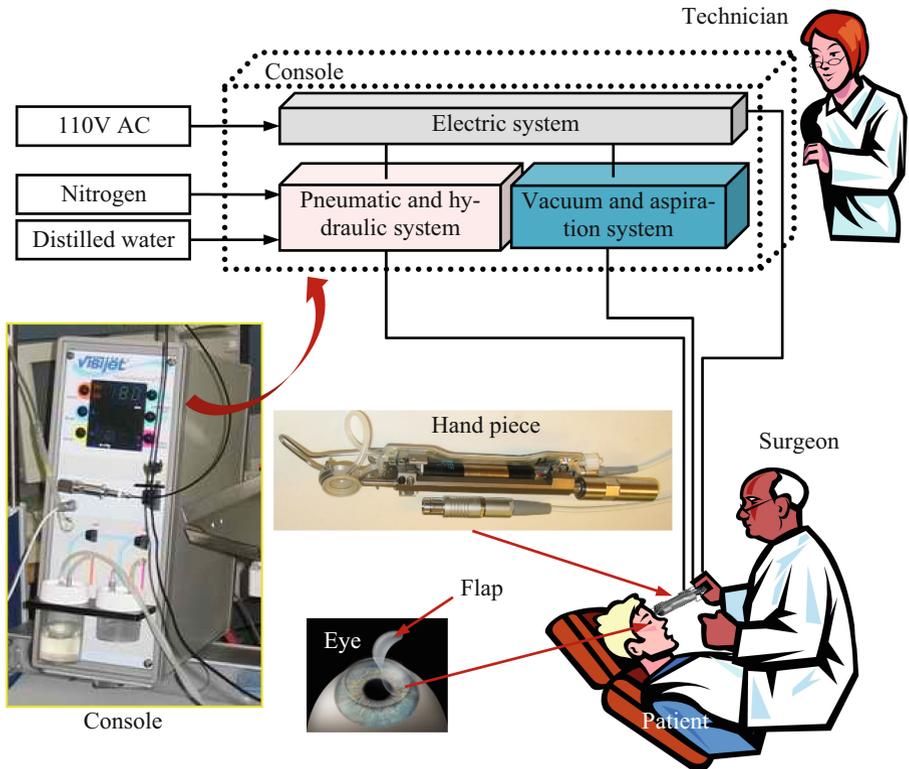


Fig. 5. The main parts of the Hydrokeratome.

Step 5. A simplified function model of the Hydrokeratome is shown in Fig. 6. The model reflects the operation of the apparatus, which is as follows:

- The surgeon places the suction ring on the patient's eye and tells the technician the diameter of the flap to be created for this patient.
- The technician sets this diameter on the seven-segment display on the console using the buttons.
- The controller adjusts the vacuum in the suction ring according to these settings.
- The surgeon visually verifies that (1) the diameter of the part of the cornea flattened to the applanator is correct and (2) the handpiece is correctly centered on the eye, and then presses the foot pedal, activating the cut.
- High-pressure water enters the hand piece and a water jet is formed.
- A linear electromagnetic drive is then activated and the water jet moves along the applanator until the flap is fully formed.

Note that over a half of the components in Fig. 6 are elements of the hand piece.

Step 6. The perturbed function model of the Hydrokeratome is shown in Fig. 7. Perturbations made to the function model built in Step 5 include the following:

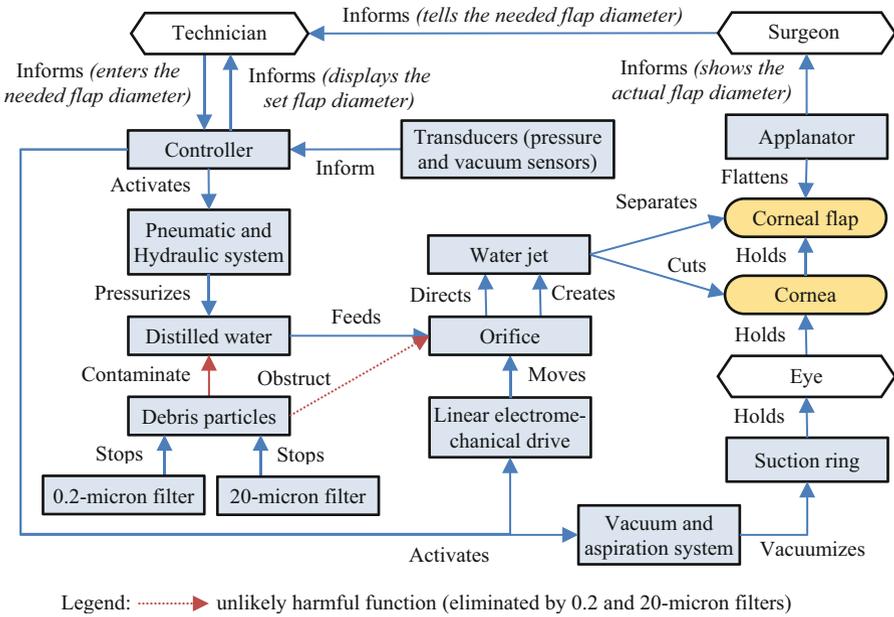


Fig. 6. Step 5: The function model of the Hydrokeratome.

- Useful functions of the controller and hand piece elements were made inadequate (either insufficient or excessive).
- Useful function of the water jet “to cut cornea” was redirected to the eye, which could represent a catastrophic risk as the water jet could seriously injure the eye.
- Harmful function of debris particles “to obstruct orifice” was introduced. This function was considered very unlikely in the original function model (Fig. 6) because of the presence of two fine filters that trap particles, but in the perturbed model the filters are considered inefficient, and this harmful function was included.

Step 7. Following the logic of Subversion Analysis, the perturbed functions in Fig. 7, which are in fact potential failures, are at this point seen as useful, and the subversion problems are how to make these perturbations happen, for example:

- How to deflect the water jet to cut the eye?
- How to make the 0.2-micron and 20-micron filters not stop debris particles larger than 30 microns? (Large particles can stick in the orifice and deflect the water jet.)
- How to make the water jet separate the flap only partially or fully?
- How to make the controller misinform the technician about the flap diameter that was set?

The subversion problems for all standard parts and assemblies whose functions are not perturbed in the functional model (see Fig. 7) are about how to make the operating conditions of these components (humidity, temperature, load, etc.) non-conform to specification, for example:

- How to increase the humidity or temperature in the controller compartment?

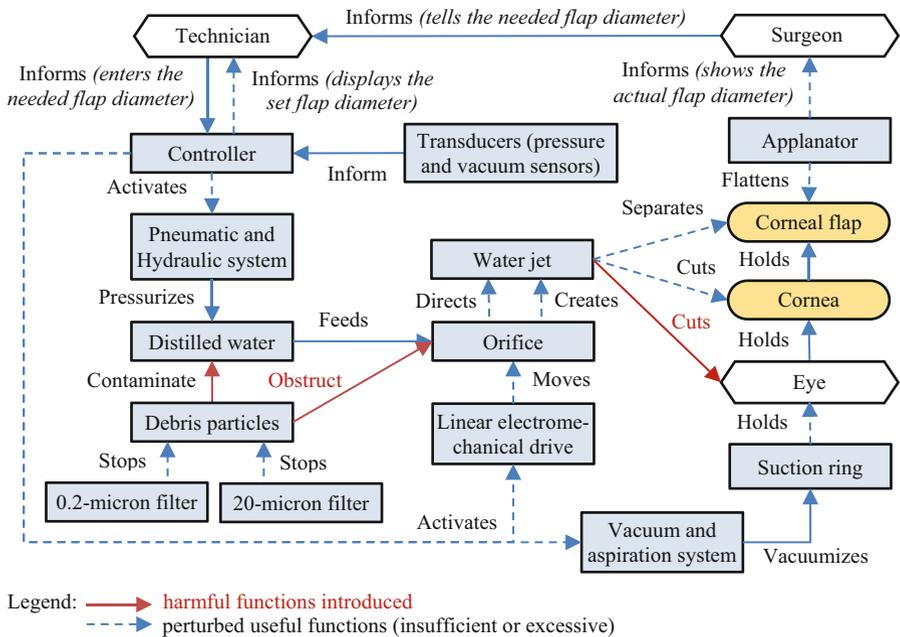


Fig. 7. Step 6: the perturbed function model of the Hydrokeratome.

- How to overload the pressure intensifier (a part of the hydraulic system that provides high-pressure water)?

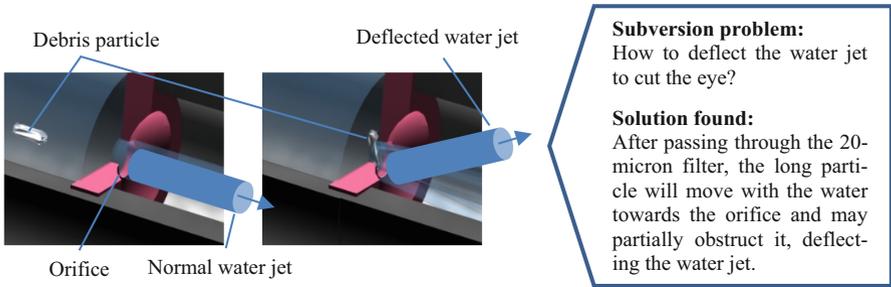
Altogether, 25 subversion problems were formulated.

Step 8. Subversion problems were then analyzed more deeply using CECA, and solved using TRIZ problem solving tools such as ARIZ, Resource Analysis, etc. A total of 36 solutions were found, each representing a potential failure scenario.

As in FMEA and AFD, failure scenarios were analyzed in terms of their risk and severity of consequences. Nineteen scenarios were found to be probable, while three of them were deemed inevitable. These three are:

- The orifice would eventually be obstructed by a large debris particle that could deflect the water jet into the eye, which could cause serious eye injury or loss.
- The transducer in the vacuum and aspiration system is designed to work only with dry air, but in fact works with wet air, causing it to fail much sooner than expected.
- The pressure intensifier is forced to provide 30% more pressure than the maximum pressure indicated in its specification, which could cause it to fail at any time.

Unfortunately, the first (and most catastrophic) scenario occurred during the clinical trial right on the day the results of the failure prediction project were given to the client (fortunately, the surgery was done on the volunteer’s blind eye that time). Examples of subversion problems associated with this failure scenario and the solutions found to these problems are shown in Fig. 8.



Subversion problem:
 How to make a 20-micron filter not stop debris particles larger than 30 microns?

Solution found:
 If the particle is non-spherical (as most particles are), it will penetrate a 20-micron filter even if its length significantly exceeds 30 microns.

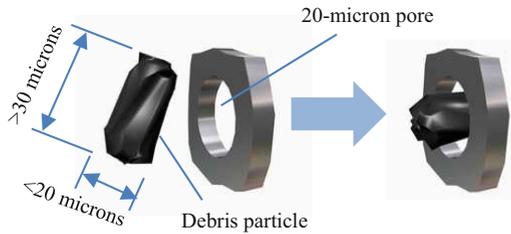


Fig. 8. Step 8: examples of subversion problems associated with the most critical failure and solutions found to these problems.

5 Discussion

Although the approach described in this paper has so far been applied only to brand-new products, for which failure prediction is most important, it could potentially be extended to more mature new products and used, for example, in product improvement or cost reduction projects.

In this case, the focus will not necessarily be on the control and working units, as in the example given here, but on other unique components designed or deeply modified specifically for the new product. However, specific recommendations on which components to focus on in mature products have not yet been developed.

It must be noted that the proposed approach, just like AFD, is focused on the technical failures in the new product, although even a technically perfect product can fail on the market due to a business failure (inability of the company to monetize the product).

Many business failures can be avoided by using a QEA-based screening tool [29], which allows a company to select only those new products that it can potentially monetize; however, this tool does not address failures associated with the wrong business model chosen by the company.

Recent research shows that business models can be innovated using TRIZ tools [30], giving the author of this paper hope that a TRIZ-based algorithm for predicting business model failures, like the algorithm for predicting new product failures presented in this paper, will eventually be developed.

One of the drawbacks of existing failure prediction tools, such as AFD and FMEA, is that they are difficult or impossible to automate because they are subjective and rely heavily on the expertise of the professionals involved in the analysis. The algorithm proposed here, although not yet automated, is more objective since it is based on the function analysis and TESE. Moreover, as shown in a recent paper [31], the use of TESE can be automated and integrated into CAD, which means that the algorithm proposed in this paper can potentially be automated using artificial intelligence (AI).

6 Conclusions

The proposed approach significantly speeds up failure prediction during NPD by focusing the analysis on unique components/units that have been designed specifically for the new product being analyzed and on the functionality of these components.

The algorithm described here can be applied even at a very early stage of NPD, when only a raw idea or product concept has been developed.

Further development of the proposed algorithm could include:

- Extension to products in stages 2 and 3 on the S-curve to make the algorithm applicable to product improvement and cost reduction
- Integration with CAD tools
- Adaptation for use with AI for fully automatic failure prediction.

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Impact of Theory of Inventive Problem Solving (TRIZ) on Innovation Portfolio Development

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Abstract. Innovation portfolio management (IPM) is a critical planning phase for organisations to visualise all possible growth opportunities and strategically allocate resources. However, to maximise the probability of business growth, it is necessary to follow a robust structured portfolio process. This paper analyses research and highlights several success dimensions of innovation product portfolios by a systematic literature review and outlines nine success criteria. Additionally, it examines all the portfolio methods that significantly influence the portfolio’s “innovation” aspect. Secondly, we evaluate and discuss the impact of TRIZ tools and approaches on innovation portfolios and explore their relationships with business growth. Thirdly, the research presents modern TRIZ approaches, and the types of TRIZ-based innovation projects organisations can execute to build robust, innovative product portfolios. Finally, the article summarises critical information on the different types of innovation projects and TRIZ tools utilised for these projects.

Keywords: Product Portfolio · Innovation Portfolio · Business Growth Strategy · TRIZ

1 Introduction

Today, an emerging technology in an area far from a firm’s business may threaten its market despite not being a direct competitor. Moreover, rapid technological breakthroughs pressurise the innovation portfolio planning phases, making it a critical inflexion point that could seal a company’s fate. The uncertainty of future business drivers poses a complex challenge for individuals and organisations, where innovation managers place their bets on potential market winners in the short, mid and long terms with maximal reliability and accurate forecasts. Furthermore, they have a herculean responsibility to distribute and allocate scarce resources to their innovation portfolios [1–4]. The analytical phase before the actual distribution of resources, with weak strategic intent and high uncertainty conditions, is known as Innovation portfolio planning or Innovation portfolio analysis [1, 4, 5]. On the other hand, firms that correctly utilise the synergies of their product portfolios represent their investment strategies and provide the organisation with increased benefits above and beyond those gained from projects run independently [6]. However, despite extensive research, there has not been a clear consensus on the

success criteria of innovation portfolios. Therefore, this paper focused on the success criteria insights from literature for defining successful innovation portfolios in organisations. Additionally, scarce research compares the various portfolio creation and selection techniques that influence portfolio success criteria.

On the other hand, Theory of Inventive Problem Solving (TRIZ) continues to be strong in its applicability to technical systems. Moreover, it expands its capabilities to business and management, i.e. non-technical areas [7–16]. However, a survey conducted in 2013 reveals that TRIZ was rarely applied to technology strategy, forecasting or business and management areas [16, 17]. We theorise that the findings in this study may have changed as of 2023, mainly because most modern TRIZ approaches for business needs developed from 2016 onwards and, therefore, can be applied to strategic business management. In addition, several TRIZ tools, while being the same, were formalised in the form of step-by-step approaches for innovation-related applications [7, 18–26]. However, despite the methodical developments mentioned above, relatively low TRIZ studies outline and describe the relevance of TRIZ in Innovation management, and even fewer studies are explicitly directed towards innovation portfolio analysis [17, 23, 27, 28]. Phadnis [28] provides some evidence and outlines the applicability of TRIZ tools to create better Innovation portfolios; however, the research needs to go deeper into the potential impact of Modern TRIZ on innovation portfolios [5]. Therefore, this paper explains the influence of modern TRIZ on product portfolios.

This paper adds novelty by attempting to identify the success dimensions of product portfolios, the impact of various methods on these success dimensions, and how TRIZ can impact a portfolio's success dimensions. Consequently, we answer the following research questions:

1. What are the success dimensions of robust innovative portfolios?
2. Which methods in the literature appear to be the most influential on the success dimensions of portfolios
3. What impact do Modern TRIZ approaches have on the success dimensions of portfolios?

2 Methodology

This research is divided into two sections: Sect. 1 analyses IPM success dimensions and sub-dimensions. Section 2 of the report illustrates different methodologies utilised for innovation portfolios and their impacts on the success dimensions mentioned in Sect. 1.

For Sect. 1, we conduct a systematic critical literature review as an explorative study with a deductive approach to identify the characteristics and traits that define innovation portfolios. We utilise the Web of Science and Scopus as databases to collect and analyse secondary data. The initial search string includes “innovation portfolio characteristics, innovation portfolio traits and innovation portfolio success” without the exact search function focusing on peer-reviewed articles and publications yielded 563 papers. The Web of Science collection papers ensures that they contain de-duplicated records. We decided to focus on research papers in the past ten years and therefore added a date range between 2013–2023, producing 377 articles. The paper investigates research and extracts success dimensions of innovation portfolios, and therefore we decided to exclude

mathematical and computer science-related studies that were irrelevant to the objective. Next, the papers were filtered based on top-quality peer-reviewed publishers, including Elsevier, Wiley, IEEE, Springer Nature and Emerald publications, to yield 309 relevant studies. Lastly, the papers were filtered based on title and abstracts, making 48 relevant publications available to the authors for analysis and synthesis. Figure 1 illustrates the systematic review literature review process and showcases the filtering mechanisms, number of hits(n), and studies excluded and included for the analysis.

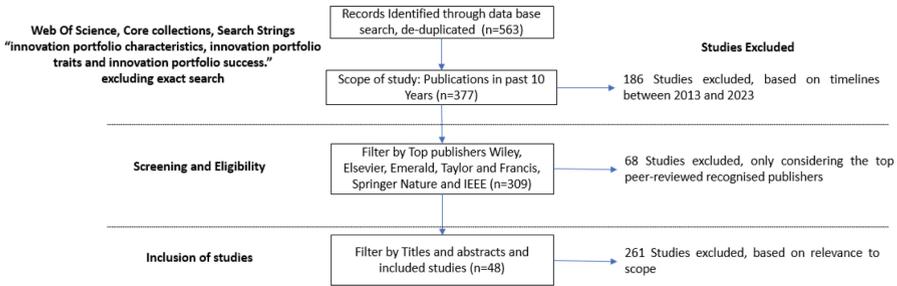


Fig. 1. Literature search process.

For Sect. 2, we use an integrative literature review to study all known methods utilised for IPM and evaluate them based on the success dimensions found in Sect. 1. This step allows us to assess the level of impact that known techniques make on the portfolio. Secondly, we use an integrative literature review to study known TRIZ impacts on IPM and the success criteria of portfolios. For this task, the study includes most modern TRIZ tools that are a part of the official body of knowledge. Lastly, we map several types of innovation projects with business growth strategies to enable the creation of IPM.

3 Literature Review Results

This paper focuses on IPM and considers it a pre-phase to PPM. However, some of the characteristics outlined for project portfolio management apply to innovation portfolio management and, therefore, will be a part of the analysis. The operational definition of a project portfolio considered for this paper is “maximising the contribution of projects to the overall welfare and success of the enterprise” [6, 29–31].

The resulting forty-eight papers are examined in-depth for portfolio success dimensions. In several cases, the articles needed to define portfolio success clearly. Instead, there were indirect success dimensions for portfolios referenced in other studies. The researchers, therefore, decided to trace the original references from the 48 papers to empirical studies that mention the success dimensions of innovation portfolios. Surprisingly, only three studies provide precise portfolio success dimensions, the measures of success, metrics of management, sub-dimensions and time dynamics [4, 29, 31, 32]. The following section briefly describes the ten success dimensions of innovation product portfolios.

3.1 Dimensions of Innovation Portfolio Success

Project Efficiency. Project efficiency is a function of project execution of governance of an organisation. This dimension is perceived as the least important to short-term success and relates to project management. Strong product portfolios meet their resource constraints within the given time. Project efficiency also correlates with a lean organisation with less hierarchical structures and governance mechanisms that lead to faster product development cycles. However, research implies that a successful implementation of a project does not necessarily produce commercial success and therefore has relatively low importance for an overall innovation portfolio success [32].

Impact on the Customer. This dimension relates to the market and the ability of the product to meet customer needs. It consists of sub-measures like meeting functional performance, fulfilling customer needs, overall impact during the product use and value created by the offering. It is a market-driven dimension and explains how well the product gets the “job” done, identifying and fulfilling current as well as future customer needs, the ability of the product to retain the customer for future generations, and the overall value created including the ecosystem of offerings with the product [33]. Therefore, customer impact is among the most critical innovation-related success dimensions [32].

Business Success. This dimension relates to financial returns and performance, often considered unimportant for long-term projects since we cannot measure it for at least one to two years post-product launch. All financial measurement metrics apply to this criteria, including return on investment, internal rate of return, net present values, et cetera. However, research suggests that this criterion is used in low levels of market uncertainty and is typically suited for incremental, iterative innovations [31, 34, 35].

Future Preparedness. This criterion is relevant to the organisational and technological infrastructure built for the future and is often considered critical for long-term portfolio planning. It explores opportunities for new markets, ideas, innovations, unexpected developments from technologies, and disruption of business models. Some of its sub-dimensions are exploring adjacent markets, opportunity exploration, development of core competencies and countering future threats from competitors or other threatening supersystem technologies [36–38]. It is a critical aspect and contributes to the “innovation” part of portfolio planning.

Strategic Alignment. This criterion primarily relates to the governance and execution of projects and the ability of projects to meet the business vision and missions of their respective corporate strategies. Phadnis [44] outlines two processes to align projects to their corporate strategy, namely emergent or deliberate innovation portfolios, and research recommends using both approaches in appropriate balance for sustainable portfolio success [39].

Portfolio Balance. Portfolio balance deals with interrelationships, dependencies of one product on the others and technical synergies of the portfolio. Portfolio balancing is also a function of the resource-based view wherein resources in the organisation are appropriately allocated and reorganised for the development of technologies based on the prioritisation of projects. It optimises the entire portfolio for maximal benefit. Some of its sub-dimensions revealed longitudinal interdependencies, technical synergies, and

vertical interdependencies of projects. Longitudinal interdependencies are when one product family improvement benefits some other product category. Whereas vertical interdependencies typically refer to manufacturing processes, wherein the impact of the process innovation can be realised at a broader scale across multiple product families, thereby impacting the organisation's operational efficiency [39, 40].

Value Maximization. This criterion has no measurable metric since it can only be realised strategically. We cannot measure the absolute value of a potential project before its execution and cannot account for intangibles, resources, and competencies it creates for the organisation. Therefore, from a mathematical perspective, it is less important as a success criterion for innovation portfolio management. However, its success is a direct function of all other criteria mentioned above, i.e. project efficiency, impact on the customer, business success, future preparedness, strategic alignment and portfolio balance [2, 32].

Systematic Decision-Making. This criterion refers to the overall decision-making structures of the organisation. Research suggests that a formalised IPM structure, with clear stage gates, go-no-go interventions, and methodological knowledge of the innovation process, leads to higher probabilities of success of product portfolios. Therefore, while the criterion is a function of organisation management systems, it is crucial for appropriately implementing IPM.

Resource Management and Information Availability. These two dimensions are positioned at a higher hierarchy than other criteria since all other success measures depend on accurate information and resources. Therefore, they are not considered in further analysis, and we assume that resource management and information availability are constants throughout the innovation portfolio development process.

3.2 Success Dimensions Synthesis

All forty-eight studies examined in this research demonstrated the abovementioned dimensions of portfolios either directly or indirectly. Our research results suggest that the abovementioned dimensions are good general indicators for organisations to focus on. Furthermore, these dimensions can help achieve a higher probability of success for growth. Therefore, to summarise the findings, a company must excel in each dimension to increase its chances of commercial success. Figure 2 illustrates the success dimensions and subdimensions and traces their sources to the original authors.

3.3 The “Innovation” in Innovation Portfolio Management

Unsurprisingly, academia and practitioners consider innovation the most critical driver that defines the long-term sustainability of an organisation. Additionally, research also suggests that the maximum probability of commercial innovation failure is associated with the fuzzy front end of product development, thereby recommending that organisations focus their efforts on more robust methodologies and approaches that do not rely on “guesswork” for decision-making [41]–[43]. But, unfortunately, the word “innovation”

		Project Portfolio Success dimensions					
		Success Dimensions	Measures	Metrics	Sub-dimensions	Importance of dimensions based on time dynamics	Original References
Resource management	Information availability	Project Efficiency	Meeting schedule goal	All project management metrics are applicable	1. Efficiency of management of a project wrt constraints and resources 2. Estimated Time to market to until commercial success	Important for Short term during project execution	(Lehtonen and 2007),(Shenhar et al., 2001), Cooper, and Edgett, and Kleinschmidt, 2002.
			Meeting budget goal				
		Impact on the customer	Meeting Functional performance	Expected level of performance vs actual delivered performance	1. How well does the product get the "job" done 2. Fulfilling current customer needs 3. Fulfilling future customer needs 4. Customer perception of the brand, and willingness to pay for a future development of the product 5. Overall satisfaction including the ecosystem of services before, during and after the products lifecycle	Important for Short term after-project execution and sales, since assessment can be done few months after product launch	(Shenhar et al. , 2001), Cooper, and Edgett, and Kleinschmidt, 2002.
			Fulfilling customer needs	Voice of the customer and satisfaction metrics applicable			
			overall impact during product use	ability of the product to retain the customer and gaining loyalty			
			Customer value creation	all customer related Satisfaction and value creation metrics			
		Business success	Commercial success	All traditional financial metrics apply	1. Estimated Time to market to until commercial success 2. Estimated return on investments	Direct success measurement possible only 1-2 years post product launch ,Mid to long term	(Shenhar et al., 2001), Cooper, and Edgett, and Kleinschmidt, 2002.
			Creating a large market share				
		Preparing for the future	Creating a new market	Market analysis, customer profiles and substantiation for the selected target market	1. Creating a new market for the same product or its components. 2. Exploration of new ideas, innovations, and technologies. 3. Developing core competencies and skills. 4. Countering future threats from competitors or other technologies	Long term , can only be assessed after 2, 3 or 5 years	(Shenhar et al., 2001) Cooper, and Edgett, and Kleinschmidt, 2002.
			Creating a new product line				
			Developing a new technology				
		Strategic alignment	Alignment of the projects and its ability to meet business visions and missions		Prioritization of projects and aligning projects to corporate strategies		Cooper, and Edgett, and Kleinschmidt, 2002.
Portfolio balance	Interrelationships, dependencies and technical synergies of the portfolio		1. Longitudinal interdependencies and technical synergies of projects 2. Vertical interdependencies and technical synergies of projects		Cooper, and Edgett, and Kleinschmidt, 2002.		
Value maximization	Maximising overall value of the portfolio complimentary to each other	No direct measurement			Cooper, and Edgett, and Kleinschmidt, 2002.		
Systematic Decision making	Risk analysis, project prioritization and governance of the portfolio process				(Martinsuo and Lehtonen, 2007), Cooper, and Edgett, and Kleinschmidt, 2002.		

Fig. 2. Innovation Portfolio success dimensions.

in innovation portfolio management is subject to the same uncertainty as commercial success.

Research suggests that the four types of uncertainty faced in the fuzzy front end are market, technological, environmental, and resource allocation uncertainty [44]. These uncertainties are also faced during innovation portfolio development. However, if we map all the above uncertainty types to the extracted success dimensions, only three relate and are a function of innovation. Those are (2) impact on the customer, (4) future

preparedness and (6) portfolio balance. All three innovation-related success dimensions exist in the most critical phases of IPM process: the ideation phase, often associated with opportunity recognition, and the selection phase, which is associated with evaluation and synergy. First, the ideation phase aims to generate concepts that match the future market needs, explore technological developments and create product concepts that could be injected into the portfolio for further analysis and substantiation. Secondly, a selection phase which acts as a screening mechanism to achieve portfolio balance either eliminates, merges, recombines, or diverges projects strategically to yield maximal value [2, 3, 5, 44, 44, 45].

Since categories 2, 4 and 6 were the most critical innovation-related dimensions, we decided to investigate if all known methods used to develop innovation portfolios impact these dimensions equally. This step examines which existing techniques influence innovation-related dimensions of the portfolio and whether a best-suited approach exists amongst them. The most common methods related to the ideation phase were technological road mapping, scenario planning, forecasting and backcasting techniques, and market /technology trend analysis [36]. On a broader perspective, these methods are categorised into a cluster of strategic or scenario-based plans, wherein an end visual scenario is simulated. Then, firms work backwards to determine which technologies, product features, and improvements could make to realise the vision. On the other hand, project selection methods comprise several mathematical models, financial techniques, and behavioural and probabilistic models to find synergies and maximise the portfolio's value.

Flechas et al., 2019 provide an in-depth review of more than 140 methods potentially utilised in IPM since 1974 to study their evolution and cluster them into 12 taxonomies. These 12 taxonomies of IPM methods are mapped to the success dimensions found in Sect. 1 to identify methods that potentially impact the innovation aspect of IPM. Table 1 illustrates the clusters/taxonomies of various methods that influence the dimensions of a successful innovation portfolio. The columns indicate the success dimensions in a numerical form, as seen in Sect. 3.1. The "x" indicates a significant impact, and a bold "x" indicates an impact on the "innovation" aspect of IPM [46].

Table 1 illustrates that only four clustered portfolio taxonomies, integrated methods, information gap theory, mapping and scenario-based approaches impact the IPM's most critical innovation-related dimensions. The following section provides a deeper examination of these methods to explain their impact on innovation portfolios.

Scenario-Based Planning. Scenario-based planning methods have multiple techniques for visualising end conditions or future use cases and creating a roadmap to achieve the perceived vision. Several approaches, such as technological road mapping, forecasting, backcasting and similar techniques, are utilized [37]. Scenario-based planning is best used in the ideation phases of the innovation portfolio since it gives direct input on potential product features that can meet future customer needs and technological developments associated with meeting future requirements and guiding decision-makers to decide which products and possible features they should invest in. However, all scenario-based planning approaches are highly dependent on the creative potential of an individual or team. Therefore, while the industry utilises structured or guided brainstorming techniques such as design thinking, concept boards, scenario envisioning techniques,

Table 1. Impact of Portfolio Methods on Portfolio Success Dimensions.

Portfolio success dimensions								
Portfolio method clusters	1	2	3	4	5	6	7	8
Financial methods			x		x		x	x
Probabilistic models			x		x		x	x
Option pricing theory	x		x		x		x	x
Strategic methods	x		x		x		x	x
Scoring models	x		x		x		x	x
Combinatorial optimisation	x		x		x		x	x
Behavioural models	x		x		x		x	x
Mapping approaches			x		x	x		x
Real options	x		x		x		x	x
Integrated methods	x	x	x	x	x	x	x	x
Information gap theory		x	x			x	x	x
Scenario-based approach		x	x	x		x		x

et cetera, consistently delivering relevant and innovative ideas takes time and effort. However, these methods fail to provide a detailed perspective, especially while ideating disruptive innovations, due to the irrelevance and uncertainty of historical market data [44, 47, 48]. Therefore it is challenging for organisations to account for and visualise all possible market-winning landscapes.

Mapping Approaches. Research suggests that plotted visual data against various parameters in a matrix, bubble plots or diagrammatic illustrations allow organisations to visualise their strategic position and help decision-making. Additionally, these methods are prevalent among multinational organisations and widely used in the industry. Several specific techniques are used under mapping approaches. However, the most common ones include the BCG matrix, McKinsey matrix, bubble plots, project sequence charts or risk versus reward plots [32, 49]. While these methods demonstrate strong capabilities in project selection and prioritisation phases, they mainly depend on financial data, customer data, technical data, scoring criteria and project-related variables. As a result, these approaches fall apart and must be adapted for their application in the ideation phases [46].

Integrated Methods and Information Gap Theory. The information gap theory model is an intriguing method of balancing immunity to uncertainty and goals. This method relies on identifying information gaps, uncertainties, and risks to assess the tolerance for bad outcomes. It works with a mathematical process model, performance requirement and uncertainty model. The information gap approach enables the evaluation of robustness (identifying potential negative consequences) and opportunity (windfall opportunities) by allowing analysts to determine what they consider valid and essential regarding the analysed system. While this approach helps determine probabilities of

success, it cannot be used during the ideation phases of the innovation product portfolio. Due to its mathematical nature, it utilises existing measurable and tangible metric data, but its accuracy is subject to error regarding radical innovations.

Furthermore, the lack of market data regarding radical breakthroughs can limit its application severely. Lastly, Integrated approaches use two or more separate taxonomies to direct the project selection process. It is the best compromise between mathematical project selection approaches and strategic mapping approaches that provide a more or less balanced portfolio with a better chance of success.

Upon closer inspection of all methods, the integrated approaches that use multiple techniques to narrow down and increase the probability of portfolio success are the most effective and significantly influence all success dimensions. Integrated methods operate throughout the innovation portfolio development process and utilise a combination of ideation and portfolio selection techniques. But where does the TRIZ approach position itself among these techniques impacting the portfolios?

4 Discussion

The discussions section describes where and how TRIZ fits into the picture and how it can impact the innovation portfolio outcomes. First, we provide reasons why TRIZ is considered an integrative method among the abovementioned types. Second, to justify the impact of TRIZ, we demonstrate the relationship between TRIZ tools and business growth. Finally, we propose different innovation projects that help obtain more robust and innovative product portfolios.

4.1 TRIZ as Integrated Method

When we consider the ideation phase of innovation portfolios, unsurprisingly, TRIZ is known to tackle psychological inertia and reduces the dependence on the creative genius of a person to generate better ideas. Extensive research has already proven the effectiveness of the approach on ideation. Firstly, TRIZ approaches such as main parameters of value analysis (MPV), S-curve analysis, and trends of engineering systems evolution (TESE) can be utilised for each product family. MPV analysis is typically a pre-step to S-curve analysis comprising function analysis (FA) and cause and effect chain analysis (CECA) for MPV candidates. In practice, it guides decision-makers in selecting the features to improve and setting realistic product development goals. Several papers outline the method and provide enough evidence of its success [18, 19, 21, 24, 26, 50, 51] In principle, TRIZ-based tools support the existing scenario-based planning methods through a functional and customer-oriented lens. Pragmatic S-curve analysis, TESE and MPV analysis enable engineers to set realistic parameters for improvement and facilitate appropriate resource allocation to achieve the required specifications in innovation portfolio outcomes [5].

Secondly, it is necessary to screen projects strategically for maximal portfolio value in the selection and project prioritisation phases. It identifies synergies between projects and guides decision-makers to allocate appropriate resources to a small project group

that maximally impacts the portfolio. Research suggests that quantum economic analysis (QEA) screening and contradiction analysis help to identify technical synergies between potential products and technologies, dependent on the framework for synergies as provided by Verbitsky and Casey 2008 [5, 20, 44, 50, 51].

Therefore, TRIZ can be considered an integrated method since it utilises more than two taxonomies in its project execution phases. Furthermore, while the TRIZ method is primarily qualitative, its combination with other mathematical techniques listed in Table 1 further improves the chances of portfolio success, especially considering the recent interest in artificial intelligence-integrated mathematical methods for predicting innovation success.

4.2 Impact of TRIZ on Innovation Portfolios

The main driver of why innovation portfolios exist in the first place is to achieve sustained business growth. According to Treacy and Sims [52], there are only five distinct sources of business growth. They are as follows: base retention, gross share gain, market positioning, adjacent markets and new lines of business. Table 2 below provides a summarised explanation of the different sources of growth. Three of these sources stem from a company's core business: continuing sales to established customers (base retention), sales won from the competition (share gain), and new sales in an expanding market (market positioning). The other two lie outside the core: move into adjacent markets where core capabilities can be leveraged and entirely new lines of business unrelated to the core are exploited, i.e. adjacent markets and acquisitions [52]. The resulting portfolio must provide input to all sources of growth.

Consider a hypothetical scenario and view the innovation product portfolio as a single project. In that case, its end product is an "innovation agenda/landscape" of existing, new and future-oriented projects assigned to each source of growth, as mentioned above. To do that, organisations must execute several exploratory innovation projects to build an innovation portfolio landscape. Consequently, think of them as a series of mini-projects that do not directly impact business growth but involve exploring ideas, detailed analytics, and the type of project to be performed for each product family, aligned to the sources of growth. This innovation agenda can allow decision-makers to gather information on what to improve and whether the improvements are practically feasible. Naturally, treating the IPM as a product, all product-related success criteria also apply [45, 52]. To summarise, decision-makers require a clear innovation agenda of all types of innovation projects from the portfolio that can be strategically aligned with the sources of growth. Table 2 summarises the sources of growth, their descriptions and critical understandings.

4.3 Typical Innovation Projects that Relate to Business Growth

Following the five growth sources mentioned in Table 2, we study the various innovation projects organisations can execute using TRIZ-based approaches that directly impact IPM. Finally, the typical innovation project types targeted towards their suitable growth strategies are studied and summarised below [9–16].

Table 2. Adapted summary of the five sources of growth [52].

Sources of business growth	Description
Base Retention	Keep existing customers from switching to competitors
Share Gain	Induce customers to switch from competitors
Market Positioning	Predict and show up where growth is expected to take place
Exploiting Adjacencies	Apply existing capabilities and technology to other related market opportunities
New lines of business and acquisitions	Create a new, unrelated business line by strategically buying out other entities

New Product Development (NPD) Projects. This type of project is typically executed in all organisations to stay competitive. It involves a new product, process, service or business model developed from scratch that addresses futuristic market needs. Several academic research articles outline that it is one of the riskiest projects for innovation with a shallow success rate [16]. However, they also imply that successful NPD creates significant growth for organisations and can be a primary source of revenue [21, 53–55]. NPD projects can impact base retention, and adjacent markets, used to gain market share or position the product carefully for growth. For base retention, NPD projects could have an ecosystem designed to lock in the customer and increase his switching costs.

On the other hand, NPD projects are also used to explore adjacent markets, i.e. ancillary markets where similar functionality is required. It also impacts product positioning, wherein developing products placed in a niche segment and appropriately priced can attract new customers and create a temporary monopoly. NPD projects apply to all sources of growth for firms.

Product/Process/Service Improvement Projects. These projects are typically about improving the existing offering without introducing radically new functions. Such projects aim to improve at least one MPV to outperform the competitor's product. Therefore, improvement-related projects are typically incremental that optimise products, thereby leading to several product iterations [46, 56, 57]. In addition, product improvement types of projects impact base retention and share again since they typically do not require radical changes or bring new novel functionalities.

Cost Reduction Projects. Cost reduction projects are the bread and butter of engineering teams worldwide as technology becomes cheaper and more accessible over time. Therefore, organisations must invest in continual improvement and cost reduction of their offerings. This type of project is well exhibited for creating impacts to capture market share, retain customers or position the product appropriately. Cost reduction projects can also be exploratory, leading to new products altogether. For example, if a technology reaches stage III on the S curve, one possible way to add value to the product is to switch the action principle of the product, which in turn may lead to NPD [58]. The other technique to add value would be cost reduction on the product or its manufacturing

process. Ideally, innovation portfolio landscapes should provide information on product families that have reached close to their developmental limits and require cost-reduction strategies to be applied for businesses to stay competitive in the market [58].

Intellectual Property (IP) Strategy Projects. Literature provides a variety of strategic methods, including typical strategies for marketing, R&D, sourcing, and innovation. An IP strategy is a part of this pool of underlying strategies, each of which serves as a building block for creating and executing the firm's overall business plan. IP may be included in the strategic planning process on several levels. "Organisations recognise that a well-crafted patent portfolio may be used for a variety of objectives, such as bolstering market position, protecting research and development efforts, generating revenue, and encouraging favourable cross-licensing or settlement agreements" [59]. TRIZ applications to IP strategy are well-researched, documented and applied in the industry. IP strategy-related projects impact base retention, adjacent markets, gaining market share, positioning, adjacent markets and new lines of business.

Main Parameters of Value Discovery Projects. This process aims to uncover the customer's latent needs and provides direct input to the portfolio of new products. It also helps uncover the voice of the product, meaning it allows us to assess the achievable level of performance of a product concerning the future market need [18, 19, 26, 50]. MPVs impact base retention, adjacent markets, market share again, positioning and acquisitions since they provide market -needs that drive all sources of revenue. Extensive research indicates the usage of MPV analysis and provides evidence of its success [19–21, 24, 26, 50, 51, 60].

Technology Mining and Technology due Diligence Projects. These projects typically relate to technology roadmaps to forecast critical developments in technical systems to gain competitive intelligence. It provides navigational assistance in an unknown territory that informs decision-makers to inform on product strategies. Technology roadmaps link commercial and technological perspectives in the firm and are used aggressively to align the company's innovation strategy. It involves scouting key emerging technologies, benchmarking existing technologies, valuation, and acquisition for strategy purposes. Research papers already provide the effectiveness of TRIZ on technology road mapping through case studies and provide an algorithm for the same [58, 61–63]. These types of projects impact adjacent markets and new lines of business.

Failure Anticipation Projects. There can be two distinct types of projects within failure anticipation, failure analysis and failure prediction. Failure analysis is a systematic procedure for identifying the root causes of failure or other undesired phenomena occurring in a system, allowing decision-makers to correct it promptly. On the other hand, failure prediction is a process for identifying and preventing all dangerous or harmful events associated with the engineering system - both types of projects can be used for innovation portfolios [64]. In addition, failure anticipation projects impact base retention, share gain and new lines of business.

Adjacent Market Identification (AMI). AMI is a type of project category that is executed to either (1) find new markets for a product /applications for a technology or equipment for a product other than the one currently produced, (2) to find applications

for a product that acts as a component for another product. Typically these projects are widely applied for products in the 3rd stage of the S-curve and are nearing their developmental limitations. Therefore, organisations can run AMI projects and identify adjacent markets that leverage existing competencies [24]. Table 3 summarises the types of projects, their alignment with the source of growth and the most common TRIZ tools used in the projects.

Table 3. Types of innovation projects and their relationship with growth strategies.

Types of Innovation Projects	Sources of growth					Key TRIZ tools utilised
	<i>Base retention</i>	<i>Share-gain</i>	<i>Positioning</i>	<i>Adjacent markets</i>	<i>New lines of business</i>	
New Product Development	x	x	x	x	x	FA, MPV analysis, FOS, Trimming, Contradiction resolution, TESE, S-curve analysis, QEA [18, 21, 26, 51, 58, 65]
Product Improvement	x	x				CECA analysis FA, Flow analysis, Trimming, FOS [21, 22]
Cost reduction	x	x	x			Trimming, FOS and contradiction resolution [73]
IP strategy	x	x	x	x	x	Trimming, FOS, TESE
MPV discovery	x	x	x	x	x	MPV analysis, FA, CECA, benchmarking, IP strategy, TESE [18, 58]
Technology mining and due diligence				x	x	Benchmarking, FOS, S-curve analysis, PEL
Failure analysis and prediction	x	x			x	CECA, resource analysis
Adjacent market identification				x		RFOS, FA, MPV analysis, QEA [44, 50, 51], [73]

5 Conclusions and Future Scope of Work

A successful innovation portfolio is critical for sustained business growth. However, the potential means of measurement of a successful innovation portfolio still need to exist clearly. We successfully answer the first research question by analysing the IPM process to find nine criteria defining portfolio success in the studied literature. If organisations focus on these factors, the chances of commercial success could improve. Moreover, we also qualitatively measured the impact of various existing IPM methods against the identified criteria. For the second research question, we found that integrative approaches used in IPM can create maximum impact on the success of innovation portfolios. We discussed why TRIZ falls into the criteria of integrated methods. Additionally, we provide a link between IPM, business growth and TRIZ projects.

Our literature review of the IPM process indicates the absence of a structured algorithm to execute IPM as a project.

Answering the third research question, the impact of modern TRIZ on IPM is showcased by providing a relationship between sources of growth, outcomes of innovation portfolios, types of projects that can be executed and their association with TRIZ approaches used within those projects. While independent TRIZ algorithms exist for all the abovementioned project types, we still lack roadmaps to execute IPM as a project.

The literature review provides insights about the success dimensions for product portfolio, while during this research the focus was more on physical products but given the type of criteria that emerged from the research, it might be applicable and generalisable to all industries alike. Non-physical product offerings may have additional criteria that physical products lack. However, this must be investigated and verified for other industries for additional reliability and validity of the research.

While modern TRIZ and its applicability are expanding to the innovation management domains, there needs to be more evidence of successful case studies to substantiate the claims. However, due to the nature and sensitivity of product portfolios, it is challenging for researchers to collect data from organisations. Currently, literature primarily studies the generalised portfolio approach, technology road mapping and IPM methods; however, some variations of brainstorming (such as scenario planning) still appear to be a popular method used to shape portfolios in the fuzzy front end of innovation that addresses opportunity recognition. This research provides ample evidence of potential modern TRIZ tools, types of innovation projects that can be executed with them and how they can help the business growth. This research currently explains the use of TRIZ for better product portfolios but lacks the algorithm to construct and execute IPM-type projects. It also paves the way for future studies for building, testing, refining and proposing a method for IPM-type projects using TRIZ.

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Determination of Optimal Functionality

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Abstract. There are several tools in TRIZ and in system design for finding new functions for engineering systems. Increasing functionality is often taken as a synonym for increasing value. The continuing existence of simple tools like hammers and pencils, though, proves this assumption to be wrong. We are researching ways to determine the optimal amount of functionality integrated in an engineering system, which will correspond to maximal value. According to the current state, a value benefit analysis can provide helpful means for decision of the optimal functionality. There are, however, less common cost factors which must be considered. Moreover, we suggest to consider not only a specific engineering system, but an extended system comprising the whole set of tools required by the user to perform a specific task.

Keywords: Function · Engineering System · Integration · Functionality · FAST

1 Introduction

In the process of methodic product definition, we have always been using to search for ways to increase the functionality of products (i.e. the whole functional range or the complete multitude of functions a system performs). We implicitly used to assume that higher functionality was generally better, i.e. more valuable. This also seemed to result from the goal of "improving" a product and the "Laws" [1] or "Trends of Engineering System Evolution" [2], especially

- The Trend of Increasing Value
- Trend of Transition to the Supersystem
- Trend of Increasing System Completeness

Basically, a product should serve as large a number of users as possible. Since their wishes differ, a higher level of functionality than required for a single user seems plausible as long as it is not associated with an excessive increase in product costs.

However, there are systems that remain at comparatively primitive levels and do not evolve, e.g. fork, pencil, and eraser. Obviously, the value or customer benefit V in the sense of

$$V = N/R \tag{1}$$

with satisfaction of needs N related to consumption of resources R (money, material, time, etc.) [3] – would not increase with further development, but decrease. The increase in functionality would therefore be overcompensated by an increase in resource consumption. The example of the evolution of mobile phones, which first showed a strong increase in their functionality and then branched off into low-functional devices, so-called senior phones, also showed that an increase in functionality does not always mean an increase in utility [4]. This raises the question “*what scope of functionality of a technical system is optimal?*”

Goldenberg [5] mentions the term of “feature creep”: functionality-driven product development may increase complexity until it eventually outweighs any benefits that additional functions may create. A striking example of this effect is the Swiss Army Knife: While the one on the left in Fig. 1 is obviously less functional than the other two, the one on the right, which is highly integrated, offers the most functions but has little utility:



Fig. 1. Left: Victorinox knife “Escort”, center: “Work Champ” [6], right: Wenger “Giant Knife” [7].

The high functionality of the large pocket knives results from the number of tools that can fulfill these functions. But is it necessary for all of them to be built into a single device? As individual components or in smaller groups, they would enable the same applications and would be easier to manage. Figure 2 shows this using a cutlery set for camping purposes.

This leads to the second question which is “*what degree of integration of functions is optimal for engineering systems?*”.

2 System Integration and TRIZ

TRIZ sees an object that people use to influence things in their environment as a *system*, i.e. as “a [...] interdependent group of items forming a unified whole” [8]. The system aspect makes it possible to consider the components of the object and their interrelations separately, as well as to differentiate between hierarchical levels and to examine and use the dynamics of system development. A *technical* or „*engineering system*” is a system that meets a purpose [1]. Systems use to be described in hierarchical levels and as such may be regarded as components (elements) of respective *super systems*, i.e. higher-order systems.



Fig. 2. Cutlery set for camping (left) vs. “spork”, a highly integrated set.

System elements interact with each other or with external objects, thus influencing each other’s properties or parameters. Interactions of this kind are called *functions* [1].

The system aspect is omnipresent in TRIZ and is expressed in most tools of the methodology. The concept of ideality is of particular interest here [9, p. 228ff]. The *Trend of Increasing Value* states that over time, the ratio of total functionality of an engineering system (i.e. not an individual system but a certain type of systems, e.g. pocket knives) over costs will increase [10, p. 38], Fig. 3. If functionality does not increase, required resources must go down.

Secondary to this trend are the *Trend of Increasing System Completeness* and the *Trend of Transition to the Supersystem*. The first one refers to Altshuller’s definition of a working system that must comprise an operating component, a transmission, an energy source, and a control system [9, p. 223f]. Lyubomirskiy et al. propose a certain order in which these subsystems use to be integrated into the system. The authors verify their theory with examples, but do not mention causes. It is to be noticed, though, that these subsystems on the one hand are required for a working system but on the other usually are not part of it. To our view, this contradiction is produced by a fuzziness of terms: The “*Complete System*” must be able to work, not the engineering system in focus and neither the mentioned components. The Complete System – which may include the user – collects these components from the supersystem and connects them in a more or less tightly integrated compound. In this interpretation, the trend demands that the integration of these components become tighter, preferably in the order Lyubomirskiy [2, p. 39] indicates.

The second, the transition to the supersystem, states that an engineering system tends to merge with other systems, thus forming an integrated hybrid system [2, p. 47ff]. Lyubomirskiy et al. mention increasing access to resources and decreasing consumption of resources as the drivers to this trend. The trend is detailed by four subrends:

- *Increasing Differentiation of Parameters*: The system gets more versatile in adapting itself to the object it is used on.
- *Increasing Differentiation Between Main Functions*: Incorporation of “allied systems” that use to be employed together with the system, or synergetic systems.

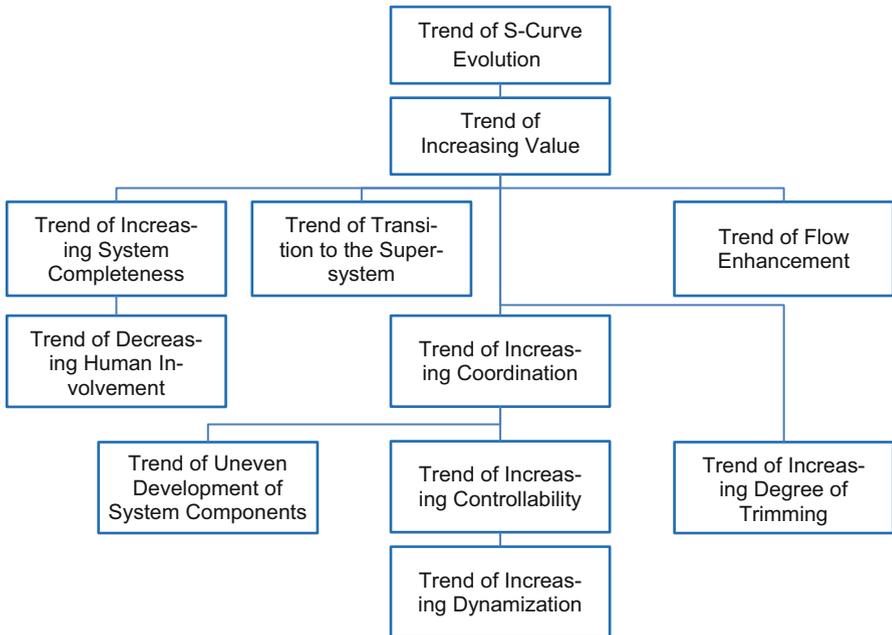


Fig. 3. Hierarchy of Trends of Engineering System Evolution [after 10 and 2].

- *Deeper Integration*: The degree of integration increases. The authors suggest a sequence “Unlinked – Sequentially linked – Partially trimmed – Completely trimmed engineering system”. Trimming in this sense means reduction of the number of individual components of the system, down to one or even zero.
- *Increased Integrated Systems* – the number of systems merged increases.

Lyubomirskiy’s scheme obviously describes the examples given above: The pocket knife contains screw drivers of different sizes (differentiation of parameters), tools that are useful in similar situations (differentiation between main functions), and the three variants reflect an increase in the number if integrated tools. The cutlery sets demonstrate the degree of integration.

The optimal degree of integration however has not been determined yet.

3 Integrated Systems in Other Areas

3.1 Engineering

The mechanical designer distinguishes *integral design* from *differential design* [11, p. 338ff]. The former integrates or merges a multitude of functional elements into one component, in order to

- Remove interfaces between parts → weight, stiffness, robustness may improve.
- Decrease number of components → assembly labour and possibly manufacture steps are diminished, and part management reduced.

Differential design aims at assembling a system from specialized elements which are each optimized to perform a single function or can be better manufactured individually [12, p. 450f]. This can

- Improve system performance due to usage of optimized components
- Reduce cost by using standardized parts or specialized processes

The authors recommend differential design for low and integral design for high production numbers.

The two terms of integral and differential design however use to be interpreted not as the functionality of a system, but mainly in the sense of how many machined components a system should consist of [13, p.468f].

Krause [14, p.129ff] compares both strategies as condensed in the following Tables 1 and 2.

The term of *modularization* mainly relates to efficient management of variants of a product family. It is regarded as a technique to provide a diverse product portfolio with little diversity of components [11, p. 340].

The sources cited evidently accentuate the manufacturing aspect of integration and focus on the functional structure secondary to the main function (sub or secondary functions). They do not examine the question of how many main or basic functions a system should perform.

Table 1. Pros and cons of functional integration, after Krause [14].

Advantages or benefits	Disadvantages or costs
reduction in the number of components	Partial functions can affect each other negatively (e.g. heat changes a bearing gap)
Simplification of the product structure	Compromises → no optimization for individual sub-functions possible
Miniaturization (lower masses, lower dynamic forces, lower volume)	more complex function structure → harder to calculate
Less assembly effort	Production sometimes more complex
more intensive material utilization	Partial functions difficult to adjust

3.2 More Areas

Besides engineering, the subject of an optimal degree of integration of functionality is widespread:

- In business administration, products are to be placed on the market in optimal configuration.
- Strategic management researches the optimal structure of a company, bundling resources in business units, acquiring new and selling unneeded units as well as managing portfolios of products (*horizontal integration* or *diversification*) [15, p. 412ff],

Table 2. Pros and cons of functional separation.

Advantages or benefits	Disadvantages or costs
Uncompromising optimization of the respective functional elements	Synergy effects (joint use of space and materials) are not used
Product structure very modular	Large number of units
system easier to calculate	
Good reparability	High assembly effort
high accuracy, high material utilization through optimization	

resources, and of competences. Criteria here are costs and returns of units, but also risks, information, flexibility, and other [16, p.239ff; 17, p.375ff].

- Product manufacturers and sellers have to decide on their product program
- Organisms are composed of modular subsystems and interact in symbiosis with other organisms. A symbiotic system can be regarded as a more functional one. The symbiosis is maintained as long as it is profitable, at least for the stronger partner [18].
- Societies organize themselves into sub-units which interact. This proves more profitable that interaction on individual basis only.

In these areas, the topic of modularization includes not only the physical delimitation but also the question of the optimal assignment of functions to a module. We have summarized the found pro and contra criteria in the following Tables 3 and 4.

Comparison of engineering systems like a milling center or an assembly line to the organization of a business company or a social structure points out certain problems of understanding: What exactly are the alternatives to be compared? Is the low-functional spoon to be compared with the spork, the kitchen knife with the Swiss Army Knife, the milling center with a chisel, or the married couple with a single person?

Evidently, the alternative to a spork is a set of comparable functionality, i.e. a set of cutleries, the alternative to a Swiss Army Knife some useful a set of tools. In order to be able to formulate comparable alternatives, it is not sufficient to consider a single “Technical System” as the designer uses to do, but we must consider a complete situation, a “Job” [19]. It takes a variety of functions to perform the job and a variety of tools. We accordingly suggest to define an “*Extended Technical System*” (ETS) which comprises the complete set of tools the user requires to perform the job, if they are connected in any way, or not. To be able to compare the suitable degree of integration, we thus have to compare one or more extended technical systems as alternatives, some of which contain integrated components and some a more or less uncoordinated (or “unlinked” in Lyubomirskiy’s words) set, but with the same overall functionality.

To identify the complete set of required functions, we recommend employing a FAST diagram as we presented in [20], Fig. 4:

Table 3. Pros of functional integration; MFS means “multifunctional system”, UCS “uncoordinated (‘unlinked’) systems.”

Criterion	Vertical Integration in Business [17, p. 375ff]	Swiss Army Knife	Marriage	Symbiotic System: Ants and Aphids [18]
Control			Intimate relation is well-controlled	
Benefit	MFS more efficient than UCS and therefore superior to the competition; business activity in integrated area can generally be worthwhile	MFS provides the entire required pool of skills		One partners resources spare expensive ones of the other
Risk/Safety	Savings from stable business relationships; external partners can be unsafe, too expensive or in the hands of competitors		Long-term adaptation; guaranteed availability of partner’s resources; short term availability	
Adequacy		MFS allows safer work → useful side effects result from integration	Partners complement the common pool of skills	
Flexibility	Hybrid models	MFS may be adjustable (in limits)	Hybrid models	
Synergy	Cost savings by connecting suitable processes and by avoiding external transactions	Use of existing resources allows cost savings	Partner provides excess resources	

(continued)

Table 3. (continued)

Criterion	Vertical Integration in Business [17, p. 375ff]	Swiss Army Knife	Marriage	Symbiotic System: Ants and Aphids [18]
Differentiation	Access to more stages in the production process → opportunities to influence the product			
Information gain	Gaining knowledge about upstream and downstream processes		Partner shares his information	

4 Cost of Functions

The “trends” listed above all point to the direction of increasing functionality in engineering systems. Nevertheless, there are systems that do not seem to have changed much since their invention like knives, spoons, and forks, hammers or wrenches. In fact, there do exist higher developed variants, but the basic model is still in use somehow. Why is this so? Evidently, there must be drawbacks associated with higher functionality that prevent further development or even make a product evolve back from an elaborated to a primitive form. Together with many students, we have been trying to collect examples for cost factors for (generally useful) functions. The procedure was not systematic and the list thus is not exclusive. We complement the collection with observations from the comparisons with other systems shown in the Tables 3 and 4:

4.1 Additional Functions Consume Resources (Generalized Function Costs)

The required resources for higher functionality may be resources of the system, the super system, or the user’s. We suppose that available unused resources foster higher functionality whereas excessive consumption of resources impedes it.

- *Space* → system will get bigger. The Swiss super pocket knife excessively demands user’s hand or pocket space which the additional benefit from additional tools does not counterweigh. The minimal pocket knife as well as customer cards with 4% discount on the other hand demand little space but their benefit is so small that space use is not worthwhile.

The shell-type handle of the pocket knife, however, offers unused system space, Fig. 5. Even though the benefit from a toothpick and a simple pair of tweezers is low, they come at no cost and are willingly accepted.

- *Substance* → system may become heavier – or lighter. Both the knife-spoon-fork “Spork” and the Swiss-Army knife are lighter than the respective unlinked tool sets.

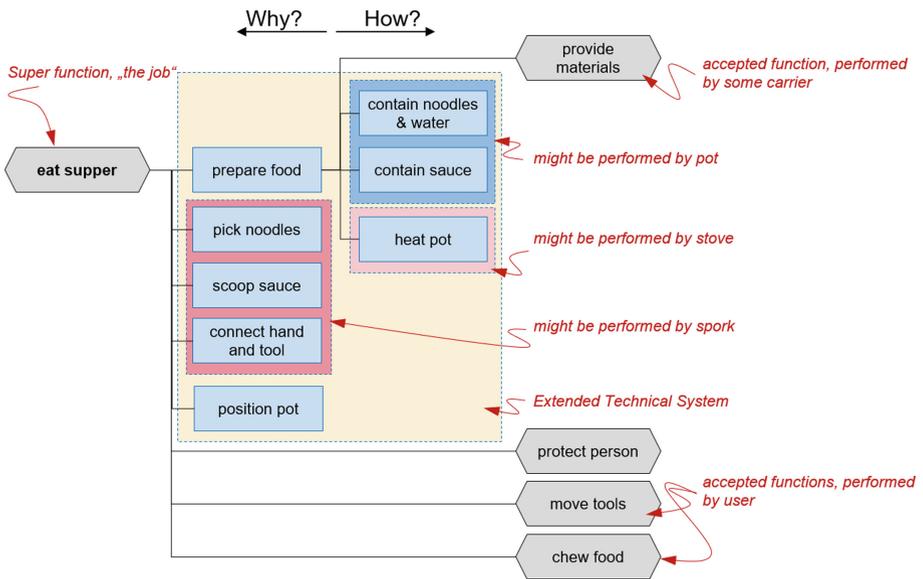
Table 4. Cons of functional integration, see text.

Criterion	Vertical Integration in Business [17, p. 375ff]	Swiss Army Knife	Marriage	Symb. System: Ants and Aphids [18]
Control	Resource utilization must be balanced across the entire production chain Ways of control maybe incompatible between units	Complex systems difficult to understand and to maintain; MFS specifies structures of use	Loss of self-determination possible; partner may act too autonomously; restriction of one's own life according to the possibilities of partner	Partner may get out of control
Cost	Investment in processes, management more expensive	Cost of integration of components; consumption of user resources	Investment in change of lifestyle and common goods	Labor and material costs in the care of the partner
Risk/Safety	Risk capital required; risk of business spreads to other units	Failure of one function causes failure of all functions. Risk of rising costs of maintenance or replacement	Risk of losing the partner and thus many competencies; risk of increasing partner demands; partner's loyalty may decrease	Risk of losing partner and according resources; risk of increasing partner demands; Partner may produce toxins
Adequacy	Quantity of goods to be processed must be large enough	Large and heavy; complete set of functions included; functions interfere with each other	Tuning is only temporarily optimal; partner is competent in selected areas only	
Flexibility	Reduced flexibility due to fixed cost, compulsion to equalize capacities	Fixed functionality, adapted to specific job; conversion from one function to another tedious	Demands on the partner can change → fixed partner inflexible	Cooperation with aphids is only worthwhile under certain conditions

(continued)

Table 4. (continued)

Criterion	Vertical Integration in Business [17, p. 375ff]	Swiss Army Knife	Marriage	Symb. System: Ants and Aphids [18]
Exit barriers	More difficult to change partners	Investment must pay for itself	Divorce: material and emotional	Adaptation to one species hinders switching to another
Information gain	Cooperation with externs may produce more information			



Ambient (Super System)

Fig. 4. Simple FAST diagram for the situation or "job" of eating supper.

- *Geometry* → system functions may jeopardize each other by requiring the same geometric structures. In the case of the Spork, the knife uses up the left side of the fork, so it is easier to cut yourself when using the fork. The spoon and fork share the handle and overly exploit the resource so both functions do not work simultaneously.

- In the same way, the aesthetic appearance of a simple and clear geometry may be affected by introducing additional elements, so a designer's coffee mug may be more appealing without a handle, Fig. 6¹.



Fig. 5. Tweezers and toothpick (rear side) in handle of Victorinox Classic SD [6].



Fig. 6. Coffee mug: Design without (left) and with handle (right) [21, 22].

- *Time of the system* → processes on a computer will take longer if many applications are active. Resources required by various functions in common may be available for only one function at a time. The Swiss Army Knife offers many functions but only one at a time can be used – which the knife permits. In contrast to this, the spork does not permit the user to pick one function after another, but all three are always active. This is a general disadvantage compared to a (“sequentially linked”) set of cutlery.
- *Time of the user* →
 - time required for management of the functions,
 - time required to control the system,
 - time spent on maintaining the system,

¹ Side note: The designer, A. Häberli, obviously preferred the version without the handle. In the other one, he solved the physical contradiction to provide a handle for its function, but not to provide one for aesthetics. To our view, he used separation according to Karasik [23]: The mug appears in the aspects of colour and of shape. The shape provides the handle, the colour does not.

- Time required to learn
- Time and risk of making the wrong decision when choosing between alternatives
- *Attention or brain capacity* → Passwords, IDs or consumer cards must be remembered and stored by the user. If the operation of a device is not self-evident, it must be understood and remembered by the user.
- *Money* → Manufacturing and operating costs tend to increase with higher functionality.
- *Control or communication* → Communication with an integrated system may get simpler on the one hand because of the reduction of user interfaces (in fact, reducing interfaces is one of the main methods of modularization [13]). On the other hand, the relations between components inside the system may be very complex and difficult to understand and to maintain.
- *Risk / safety* → Failure of an integrated system may cause the complete functionality to fail. Limited understanding of the functionality increases the likeliness of misuse and eventual accidents. The user may not be able to maintain a complex system by himself and thus becomes dependent on service suppliers. Dangerous functions may be hidden in the system. Finally, the user may become dependent on the system and risks losing it together with its benefits.
- *Adequacy of the functionality* → Jobs to be done change over time, so the functionality aggregated in the system will soon not be adequate to the job any more. The system will cooperate with a varied set of tools and functions will then be redundant or missing, or their parameters will no more match the situation.
- *Flexibility* → the user is restricted by the system and have to live with what he is offered, thus he is no more free to use whatever tool seems suitable.
- *Exit barriers* → Giving up an integrated system may come with high cost, thus keeping the user from moving to a more suitable one.
- *Information gain* → a desired function from some systems is gaining information. As was seen, this happens to be performed better by uncoordinated systems instead.

4.2 Optimization Always has Disadvantages

Optimization in general – i.e. introducing new or improving existing functions – means using resources of the system, the super system, or the user's in a more targeted manner, so they are withdrawn from other features and their corresponding functions. Optimizing or creating one function therefore in general means deterioration in certain others, even though this may not have any impact in practice: the resource of space required by the toothpick is not demanded otherwise, but it is no more available. Universality suffers through specialization.

Examples: Sharpening of knives improves the functions of cutting, safety, and reduces weight. However, it damages the function of smoothing surfaces and stability and generates maintenance costs. Evolving a hammer into an ax boosts the cutting function (impulse very concentrated → destroys wood), but harms the hammer function (impulse too concentrated → also destroys ax when hitting steel, and will no longer be good for driving nails).

4.3 Useful Effects Can Be Harmful, Too

The effect of a given system (subject) upon another (object) can be harmful depending on the situation: A sharp knife is positive for an adult but dangerous for a child. Garden gnomes delight philistines but annoy people with decent taste. Medicine may save one but kill the other. The effect, i.e. the function, thus not only depends on the subject but also on the reaction of the object under the existing circumstances. As a hypothesis, we claim that every function has malicious variants. It will depend on the functional environment as well as on the object itself whether these harmful effects can be compensated or become effective².

This means that the functionality of a system is not a characteristic of the system alone: It acts on an object with its features and the function is produced in the interaction of the “conflicting pair” [24, p. 26]. If functionality is not an objective set of functions, the opening question will be undecidable, though. We therefore must reformulate it into “what scope of *intended* functionality of a technical system is optimal?”.

5 Determination of Optimal Functionality

Evidently, one plausible way to determine the optimal intended functionality of a technical system (or to determine the optimal modularization of the extended system) is to compare alternatives. A common calculus for this task is utility analysis [25] (another is Pugh’s decision matrix). In utility analysis, criteria for comparison are collected and weighed, then the alternatives are rated against these criteria and the weighted assessments are summed up. In the example of “eating supper”, Fig. 4, alternatives for the

Table 5. Criteria and their assumed weights in three situations.

Criterion	Candlelight dinner	Picnic	Outdoor camping
Pick food	1	0,9	0,7
Transport food to mouth	1	0,9	0,7
Elegant use	1	0,5	0,2
Clean hands	1	0,75	0,3
Compliance with rites	1	0,5	0
Low weight	0	0,5	1
Low volume	0	1	1
Little cleansing effort	0	0,3	1
Cost	0	0,3	0,5
Low risk of losing tool	0	0,3	1

² If an effect turns into a useful or a harmful function seems to underlie similar aspects as physical contradictions in TRIZ which can be separated in respect of space, time, object, external condition and system level [24,p.21f].

functions “pick noodles”, “scoop sauce”, and “connect hand and tool” shall be sought. Criteria for evaluation are given in Table 5 and estimated degrees of criteria fulfillment in Table 6:

Table 6. Criteria and their estimated fulfillment by three system variants.

Criterion	Steel set of cutleries	Camping set of cutleries	Spork
Pick food	100	100	100
Transport food to mouth	100	100	50
Elegant use	100	50	30
Clean hands	100	100	50
Compliance with rites	100	50	20
Low weight	0	70	100
Low volume	0	70	100
Little cleansing effort	20	20	100
Cost	0	0,3	0,5
Low risk of losing tool	0	0,3	1

Multiplication of the degree of criteria fulfillment with the respective weights of the criteria in the considered situations will then yield a statement about the suitability of the various alternatives for each situation, Fig. 7. The results meet the expectations and recommend the steel set for the situation of a candlelight dinner, the camping set for a picnic, and the spork for a hiking trip.

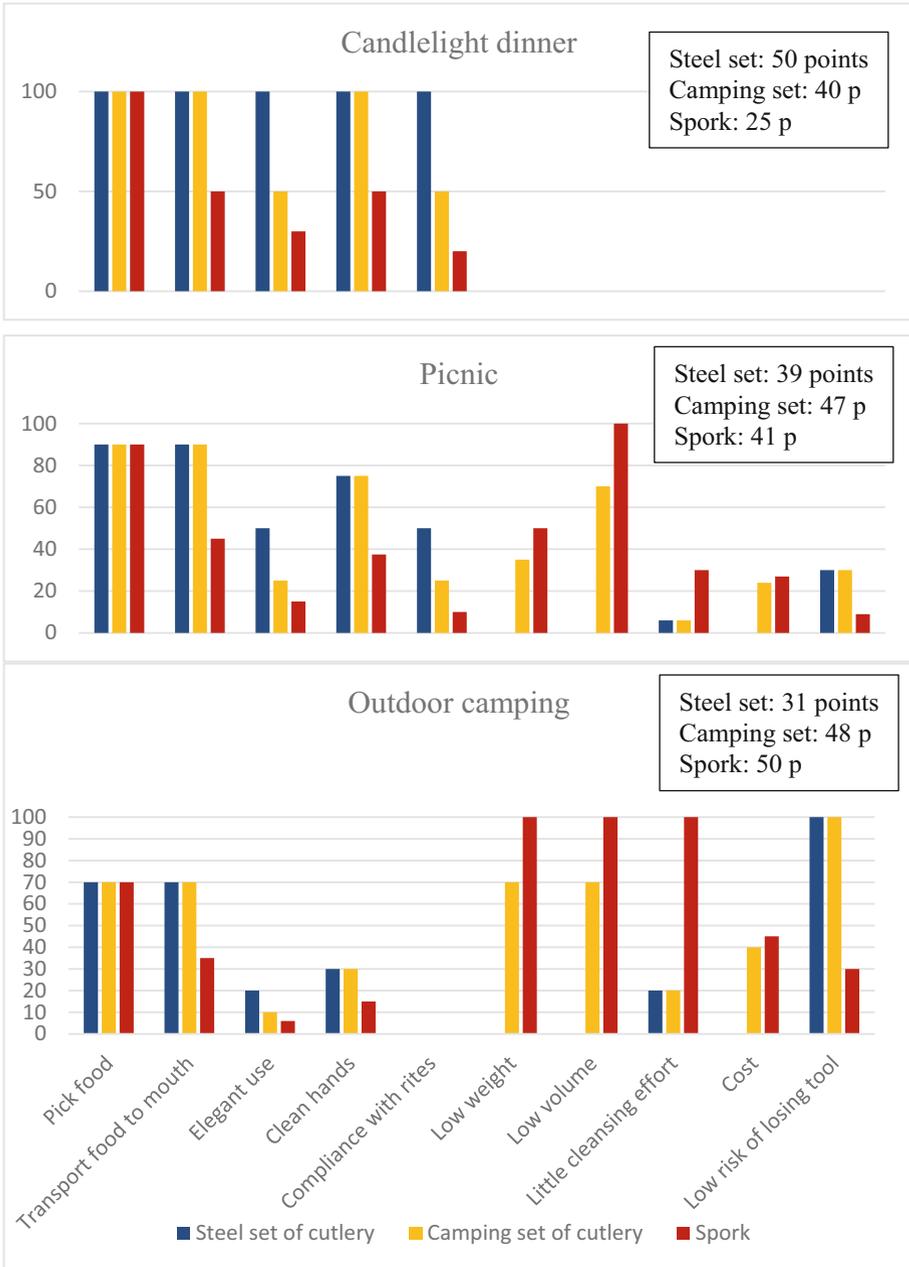


Fig. 7. Value contour (weight x fulfillment) of the three alternatives in the situations “formal dinner”, “picnic”, and “outdoor camping”. Evidently, the weights attributed to the conditions of the situation decide on the suitability of the alternatives.

6 Conclusions

After learning that a higher degree of functionality integrated in a single product is not always better, we have been searching for a way to determine the optimal amount of functions a product or technical / engineering system should incorporate. Since a user typically employs several systems to accomplish his task, it is not sufficient to consider just one engineering system, but we suggest to regard an “extended technical system” which includes all the tools and their functions required for the respective task. The multitude of functions that is then to be combined into modules can be suitably structured by means of a FAST diagram. The optimal modularization of the extended system may then be found by comparing alternatives. This does not prove that a method to calculate an absolute optimum of functional integration was impossible but this will be a future task of research.

7 Outlook

The work presented here is a first attempt to access the formulated question “*what scope of intended functionality of a technical system is optimal?*”. Since it is a rather basic one we expect that more knowledge on this subject is existing than we have discovered. References on this matter will be highly appreciated.

To compare and evaluate alternatives, Bauer [26] suggests to use a two-dimensional diagram that shall be rated according to two or more criterial dimensions. Meerkamm et al. [12] also recommends the work of Adunka [27] on decision methods. These works have not yet been considered and will be left for future work.

One of the aspects we have not considered yet is the “Trend of Increasing Degree of Trimming” in Fig. 3. It states that the number of components of a system decreases, although its functionality remains constant. When applied to an extended technical system, this seems to suggest higher degrees of integration of the individual technical systems. Another aspect are the various hierarchical levels that systems consist of. On each of these, modularity can be optimized. The topic of modularity in general will be taken into account in the future.

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TRIZ in Marketing Management: Study of Current Situation

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Abstract. The issue addressed in this paper refers to the improvement of methods and tools for systematic innovation in the field of marketing management. The first part of the work defines a set of current and significant problems of marketing management, including a set of contradictions emerging in the management of Digital Marketing. The second part of the work, as a result of a systematic review of the literature, identifies the current state in the use of methods and tools of Theory of Inventive Problem Solving (TRIZ) and General Theory of Powerful Thinking (OTSM) in marketing management. There are four basic categories of problems in solving of which the TRIZ and OTSM tools specified in the work apply, i.e., problems related to the implementation of the concept of quality management in marketing, the implementation of green marketing (including eco-design, eco-innovation), marketing product management (including product design and improvement) and the issues of sustainable marketing management of enterprise. The last part of the paper indicates the directions of further research work for the improvement of methods and tools for systematic innovation in the field of marketing management.

Keywords: Marketing Management · Digital Marketing · Artificial Intelligence · TRIZ · OTSM

1 Introduction

The popularization of personal computers, as well as a widespread access to the Internet, were the catalysts for changes in marketing. Błażewicz (2021) specifies two marketing revolutions: (1) relating to process improvement and knowledge codification, (2) relating to Big Data, Machine Learning, and Artificial Intelligence applications in marketing. In 1936, in the United States, Arthur C. Nielsen recognized the need to study who and when watches specific television programs – he then invested in telemetry measurement technologies, which became the foundation of the company that today has a 40% market share. In the 1980s of the 20th century, a couple of statisticians, Robert and Kate Kestnbaum, initiated another trend. They used statistical modelling to analyze customer data and develop personalized communication with the potential customers. Customer Management Software (CMS), a precursor of modern Customer Relationship Management (CRM) systems, was introduced to the market. CRM systems, which developed

on the basis of the market needs, collected large databases. Additional Sales Force Automation modules were introduced, which, on the basis of simple rules, began to relieve marketers of repetitive, mechanical tasks. The natural direction of the development in marketing became investment in activities and channels that brought the biggest benefits. Database Marketing, which began to develop in the early 1980s, forced the need for a new type of business talent – an analyst who will be able to make use of the collected data. The next stage is new technologies in marketing of Big Data, Machine Learning, and Artificial Intelligence (Błażewicz, 2021). New categories in marketing developed on the Internet in order to understand and persuade users to buy a product or service (Avery, 2012).

As a result of changes in marketing activities, resulting, among others, from the application of new technologies to specific marketing functions, new problems arise in marketing management, including (Mantura, 2015): (1) How to ensure the harmonious development of marketing science in the following aspects: descriptive and explanatory (marketing theory) and normative (marketing engineering); (2) How to investigate pathologies in marketing practice and what preventive and corrective solutions to propose, taking into account social responsibility in marketing activities and the use of technology in the service of humanity (Kotler et al., 2021); (3) How to ensure more pro-social orientation, ethics, partnership, cooperation and harmonious and sustainable development, and less consumerism in marketing practice; (4) How to improve the social image of marketing. This paper indicates the importance of searching for new methods and tools to support an innovative solution to current and significant problems of marketing management. Creative thinking is particularly important in areas such as advertising, new product design, logo design, service design, sales and promotions, marketing strategy implementation, and in the Internet/digital marketing (Ameen et al., 2022).

The paper presents the results of a systematic review of the literature relating to methods and tools for systematic innovation in the field of marketing. The aim of the study is to check the state of knowledge in the field of application of specific methods and tools of the Theory of Inventive Problem Solving (TRIZ) and the General Theory of Powerful Thinking (OTSM) in solving marketing management problems. The work is carried out in accordance with the procedure of systematic literature review, consisting of four basic phases, i.e.,: (1) determining the purpose of the study, (2) selecting the literature on the subject, (3) bibliometric analysis and content analysis, (4) drafting the report (Czakon, 2016).

2 Determining the Purpose and Significance of the Research

In the first stage of the research work, an analysis of current and significant publications related to considerations on problems, directions of development and the future of marketing was carried out. Numerous works indicate the most commonly used methods and models of Data Science, Machine Learning and Artificial Intelligence supporting marketing management. The areas of marketing in which the use of new technologies becomes particularly important are also specified (Syam and Sharma, 2018; Davenport et al., 2020; Saura, 2021; Huang and Rust, 2021; Ameen et al., 2022).

Data Science in Digital Marketing strategies supports in particular: analyzing User Generated Content (UGC), optimizing Customer Preferences, tracking Customer Behavior Online, tracking Social Media Commentary/Interactions, optimizing Stock Levels in e-Commerce Websites, analyzing Online Sales Data, introducing New Products, analyzing Social Media Trends, analyzing Product Recommendations and Reviews, personalizing Customer's Online Experience, building Recommender Systems; measuring and predicting Clicks Online (Social and Paid Ads), measuring and predicting User Behavior, improving User Experience (UX), analyzing Real-Time Data, identifying Online Communities, identifying Fake News (Saura, 2021). With reference to Strategic Framework for Artificial Intelligence in marketing (Huang, Rust, 2021), AI is particularly useful within Marketing Research, formulating Market Strategy and shaping Marketing Action. AI driven processes are likely to transform marketing processes, e.g., providing AI powered websites, enhanced shopper experience, providing product recommendations and product purchase suggestions in real time. As the result of applying the above analysis of the current state of new technologies (in particular, Data Science, Machine Learning and Artificial Intelligence) in the field of marketing management, the list of search terms was selected (see Table 2).

At the next stage of the research, the current benefits and challenges of digital technology in marketing were formulated. The aim of the considerations in this research paper was to check whether the future of marketing based on new and developing Data Science, Machine Learning, and Artificial Intelligence models may lead to problems requiring systematic methods of solving innovative problems, i.e., TRIZ and OTSM TRIZ. At this stage, the insight from several leading experts on issues related to digital marketing was referred to. When considering the possible scenarios of the future of digital marketing, problems arise, the solution of which requires the ability to model and solve contradictions. This is a prerequisite for pointing out the need and importance of developing the application of TRIZ methods and tools in contemporary marketing. When defining the most important directions of marketing development, it is indicated, among others, to such areas as (Dwivedi et al., 2021), e.g.:

- (1) Digital marketing and humanity (form individuals to societies and from consuming to creation);
- (2) How to improve metrics and scales for digital content marketing that aims to foster customer experience and customer journey;
- (3) How to coordinate the Electronic Word of Mouth (eWOM);
- (4) How the new technologies impact the Social Media Marketing research;
- (5) How to provide responsible Artificial Intelligence (AI), considering ethical AI design and governance, risk control by human and AI coordination, ethical AI mindset and culture;
- (6) How AI would affect digital marketing, including the issues, such as, e.g., the appearance of innovative advertising, AI power websites, enhanced shopping experience, genuine product recommendations, chatbots;
- (7) Ethical issues in digital and social media marketing.

The introduction of new solutions in marketing means that it is already possible to observe the occurrence of numerous problems of contradictions emerging at the level of marketing management, among others in areas such as:

- Advertising: Customer attitudes towards social media can in turn influence attitudes towards brand (e.g., the Customer Experience using Instagram advertising (Gaber et al., 2019), i.e., the customer attitudes are influenced by customer perception of

content usefulness, entertainment, credibility and lack of irritation form the Instagram advertisement itself). But, the emerging trend of targeted personal advertising has led to an increase in privacy concerned from customers.

- **Electronic Word of Mouth (eWOM):** Customer voices have become more powerful due to the advancement of social media and are heard by many people. eWOM communication can have a significant effect on information adoption, consumer attitude, purchase intention, brand loyalty and trust (Filieri and McLeay, 2014; Ismagilova et al., 2020 in: Dwivedi et al., 2021). However, negative eWOM communication can lead to dire consequences for companies resulting in damaged reputation, negative customer attitudes and resulting reduction in sales (Lappenman et al., 2018 in: Dwivedi et al., 2021).
- **Social Media:** Individuals spend much of their time-consuming information, social and cultural capital. As seekers of social and cultural capital, consumers participate in multiple forms of social media. Ideally, this could lead to a lived experience of mindfulness, happiness and belonging. But, paradoxically, digital marketing simultaneously enables negative mental health issues (e.g., loneliness, Berezan et al., 2020: in Dwivedi et al., 2021).
- **New social media platforms:** New social media platforms are introduced and begin to grow in popularity and gain new followers. That brings diverse opportunities for brands to interact with individuals. However, marketing managers must learn to adapt to using the platform effectively to reach customers.

The selected problem of Technical Contradictions related with Social Media Usage are presented, as an example, in Table 1 using the structure of generic table of a contradiction, from the TRIZ point of view (Cavallucci and Eltzer, 2007; Cavallucci et al., 2008; Zanni-Merk et al., 2009).

Table 1. Selected problem of contradiction in marketing management.

TC_n	AP_n	
	Va	$V\bar{a}$
TC_1 : Social Media Usage (SMU)	<i>High Intensity of SMU</i>	<i>Low Intensity of SMU</i>
$EP_{1,2}$: Consumption of Information, Social and Cultural Capital	☺	☹
$EP_{1,2}$: Mental Health Issues (e.g., loneliness, Berezan et al., 2020: in Dwivedi et al., 2021)	☹	☺

Source: own study based on (Dwivedi et al., 2021).

Referring to the results of analyses in the field of development stages, current problems and possible directions of marketing development, the need to introduce new methods and solutions aimed at improving the solution of complex contradictions emerging in marketing management was recognized. The aim of the systematic literature review is to identify current areas of application of the Theory of Inventive Problem Solving (TRIZ)

and the General Theory of Powerful Thinking (OTSM) in marketing, in particular within those functions where Digital Marketing solutions are used.

3 Selection and Analysis of Literature on the Subject

Current development of the Theory of Inventive Problem Solving (TRIZ) establishes the prerequisites for treating it as an applied scientific theory, with a defined key problem to be solved by TRIZ, Fundamental Postulates and Fundamental Models of TRIZ and the System of Instruments (see: Khomenko and Ashtiani, 2007). There are three Fundamental Postulates of Classical TRIZ, i.e., (1) the Postulate of Existing Objective Laws that drive the evolution of engineering systems, (2) the Postulate of the Evolution of an Engineering System as a sequence of contradictions and their resolutions (Altshuller, 1996), and (3) the Postulate of a specific situation, i.e., the peculiarities of a given situation should be taken into account in the course of the problem solving process (see: Khomenko and Ashtiani, 2007).

Classical TRIZ and new branches of Classical TRIZ, such as General Theory of Powerful Thinking (OTSM), are manifested in the use of specific methods and tools supporting the evolution of systems and solving contradictions. OTSM developers Classical TRIZ ideas further to propose approaches and instruments to deal with non-typical complex interdisciplinary problem situations. TRIZ tools for creativity and clever solutions include, among others, 8 Laws of Engineering System Evolution (8 Trends of Technical Evolution), the TRIZ System of Standard Solutions for Inventive Problem Solving (39 Engineering Parameters, Contradiction Matrix, 40 Inventive Principles, 76 Standard Solutions), Substance-Field Analysis (Su-Field), Smart Little People Modeling (SLPM) and other concepts such as Hill Model of the TRIZ Problem Solving Process (Cascini et al., 2009), Tongs Model of the TRIZ Problem Solving Process (Khomenko in: Cascini et al., 2009), Funnel Model of the TRIZ Problem Solving Process (Khomenko in Cascini et al., 2009), ENV Model (Element, Name of the property, Value of the property), OTSM model of TRIZ Contradiction, Thinking in Time and Scale model (System Operator, also called 9-Windows, 9-Boxes) and Algorithm of Inventive Problem Solving (ARIZ85C) - a meta-method using most of the basic TRIZ instruments, and OTSM Problem Flow Networks approach (PFN), including four types of networks: Network of Problems, Contradiction Network, Parameter Network (Specific) and Parameter Network (Khomenko and De Guio, 2007; Khomenko and Ashtiani, 2007; Gadd, 2011; Cascini, 2012).

The above set of TRIZ and OTSM TRIZ methods and tools is the basis for the creation of a set of search terms indicating the publication using the basics of systematic innovation in marketing management. This study took into account articles published and indexed in Web of Science database. The list of search terms is presented in Table 2. The search terms were searched for in the Title, Abstract and Keywords. As a result, 1113 publications were identified. In the next stage, the so-called database cleaning was carried out, consisting in the application of the exclusion and deletion criteria of publications classified into groups, i.e., Book Chapters, Early Access, Retracted Publication. Therefore, in further analysis 1099 publications from the group, i.e., Proceeding Paper, Article, Review Article are taken into account. The VOSviewer visualizing scientific

software was applied for scientometric analysis. This method is based on mathematical and statistical bibliometric analysis (Mongeon and Paul-Hus, 2015). The main premise of this type of analysis is the use of content and data contained in publications (Diodato and Gellatly 2013).

Table 2. Search terms used at the publication selection stage.

Search Terms related to Marketing Management

“Digital Marketing*” OR “Online Marketing*” OR “Internet Marketing*” OR “Market*” OR “Advertise*” OR “Sale*” OR “Service*” OR “Brand*” OR “Product*” OR “Search Engine Optimization” OR “Search Engine Marketing” OR “Programming Advertising” OR “Social Media Marketing” OR “Digital Content Marketing” OR “User Generated Content” OR “Customers’ Preferences*” OR “Customer Online Behavior*” OR “Social Media Commentary*” OR “Social Media Interactions” OR “Online Sales Data” OR “New Products” OR “Social Media Trends” OR “Product Recommendations” OR “Product Reviews” OR “Customer’s Online Experience” OR “Recommender Systems” OR “Measure Clicks Online” OR “Predict Clicks Online” OR “User’s Behavior” OR “User Experience” OR “Marketing Research” OR “Customer Understanding” OR “Market Strategy” OR “Market Segmentation” OR “Marketing Action” OR “4Ps” OR “Product” OR “Promotion” OR “Place” OR “Price” OR “Customer Needs” OR “Customer Wants” OR “Personalize Product” OR “Customer Preferences” OR “Customer Emotional Needs” OR “Communication with Customers” OR “Promotional Content” OR “Personal Communication” OR “Customer Preferences” OR “Customer Reactions” OR “Advertisements” OR “New Product Design” OR “Logo Design” OR “Services Design” OR “Sales” OR “Promotions” OR “Marketing Strategy*” OR “Market Intelligence” OR “Personalized Recommendations” OR “Programmatic Advertising” OR “Price Management” OR “Place Management” OR “Customer Service” OR “Experiential Marketing” OR “Branding” OR “Sales Forecasting” OR “Market Research”

AND Search Terms related to TRIZ and OTSM TRIZ

“Theory of Inventive Problem Solving” OR “TRIZ” OR “OTSM” OR “8 Laws of Engineering System Evolution” OR “8 Trends of Technical Evolution” OR “TRIZ System of Standard Solutions” OR “TRIZ Inventive Problem Solving” OR “Hill Model of the TRIZ Problem Solving Process” OR “Tongs Model of the TRIZ Problem Solving Process” OR “Funnel Model of the TRIZ Problem Solving Process” OR “OTSM model of TRIZ Contradiction” OR “OTSM Problem Flow Networks approach (PFN)” OR “OTSM Network of Problems” OR “OTSM Contradiction Network”

Source: own study based on (Khomenko and De Guio, 2007; Khomenko and Ashtiani, 2007; Cascini et al., 2009; Gadd, 2011; Avery, 2012; Cascini, 2012; Syam and Sharma, 2018; Davenport et al., 2020; Błażewicz, 2021; Dwivedi et al., 2021; Huang and Rust, 2021; Saura, 2021; Ameen et al., 2022)

Figure 1 shows the distribution of the number of publications and the analysis of the number of citations. This allows us to assess the changing size of the collection of publications and its importance on the map of science. The analysis of publications in the following years allows to assess the stage of development of a given research area. Assuming that the number of publications is subject to lifecycle regularities: after birth there is a slow growth that accelerates, then stabilizes at a given level to finally decrease.

Referring to the results obtained, it can be noted that the research area in the scope of TRIZ application in marketing management is in the second phase of growth. This means that the first results of research in this area have already been implemented and their results constituted a prerequisite for further research work.

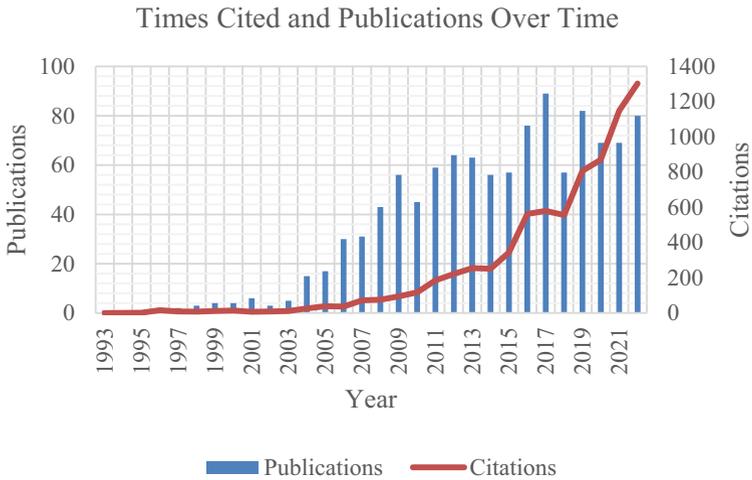


Fig. 1. Analysis of the number of publications and citations over the years (Source: own study with an application of VOSviewer software).

The analysis of the number of citations reflects, relatively to the number of publications, the significant impact of the obtained results, measured by the number of works that use them. At the next stage, the analysis of content, the so-called keyword frequency survey, was conducted. Table 3 shows a set of words ordered against the occurrence of the keywords and the strength of interdependencies with other significant terms in a separate publication database.

Subsequently, the distinguished 80 keywords with the highest level of occurrence were classified. A specific set of keywords was extracted after the adoption of the so-called minimum number of keyword repetitions. The larger the database, i.e. the number of analyzed publications, the greater the number of keywords occurring and recognized by VOSviewer software. In order to separate the crucial keywords in the analyzed data set ($n = 1099$), after initial verification of the number of repetitions based on the graphical presentation of the results, a minimum number of keywords repetitions amounting to five was adopted. In the next step, in order to increase the reliability of the results, the keywords with the lowest correlation value, i.e., the value of the Total Link Strength indicator calculated by VOSviewer, were removed from the data set. Having the created set of keywords, the VOSviewer software algorithm was used, which classifies keywords by taking into account thematically and meaningfully similar areas in which the words occurred. As a result, six clusters were isolated, as shown in Fig. 2.

Table 3. A set of important keywords.

Keyword	Occurrences	Total Link Strength
TRIZ	645	1113
Design	108	315
Innovation	107	308
QFD	83	224
Conceptual Design	70	170
Model	47	178
Product Design	44	129
Product Development	43	124
Quality Function Deployment	39	145
Eco-Design	27	71
(...)	(...)	(...)
Technology Evolution	8	16

Source: own study with an application of VOSviewer software

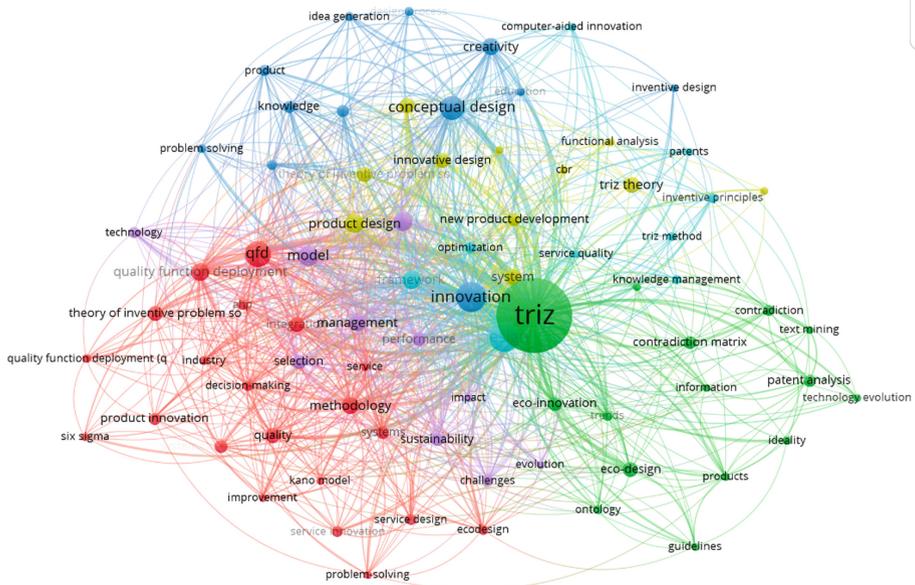


Fig. 2. Map of six clusters of the keywords related to the domain (Source: own study with an application of VOSviewer software).

Taking into account the significance expressed in terms of the number of repetitions of individual words in a given cluster, four categories of research areas related to the

subject of research in question were identified, i.e., marketing management using TRIZ and OTSM methods and tools. When describing the words assigned to a given cluster, the number of repetitions recognized for a given word was indicated, and the TRIZ and OTSM methods and tools used in a given category of problems were highlighted in italics.

1. Category referring to the integration of TRIZ with methods supporting quality management, in particular those methods that relate to the areas connected with marketing (i.e. QFD, Kano Model):
 - Cluster 1 (highlighted in red color): {Quality Function Deployment (QFD), 132; Methodology, 34; Integration, 27; Theory of Inventive Problem Solving (TRIZ), 27; Quality, 26; Systematic Innovation, 21; Systems, 21; Product Innovation, 19; Service Design, 15; Service Innovation, 14; Analytic Hierarchy Process (AHP), 13; Decision-Making, 13; Eco-design, 13; Industry, 11; Improvement, 8; Kano Model, 8; Problem-Solving, 8; Service, 8; Six Sigma, 8}.
2. The category referring to green marketing and shaping of ecological products:
 - Cluster 2 (highlighted in green color): {TRIZ, 645; Eco-Design, 27; Eco-Innovation, 23; Contradiction Matrix, 20; Patent Analysis, 17; Products, 16; Contradiction, 15; Trends, 12; Ideality, 10; Ontology, 10; Guidelines, 9; Text Mining, 9; TRIZ Methodology, 9; Information, 8; Technology Evolution, 8}.
3. The category referring to the marketing management of a product, including the shaping and design of a new product or the improvement of a product:
 - Cluster 3 (highlighted in dark blue color): {Innovation, 107; Conceptual Design, 70; Creativity, 33; Inventive Design, 29; Knowledge, 18; Engineering Design, 17; Product, 16; Design Methodology, 13; Idea Generation, 11; Problem Solving, 11; Design Process, 10; Education, 9}.
 - Cluster 4 (highlighted in yellow color): {Product Design, 44; System, 32; TRIZ Theory, 30; Innovative Design, 29; Axiomatic Design, 27; Theory of Inventive Problem Solving, 26; New Product Development, 20; Contradictions, 8; Functional Analysis, 8; Innovation Design, 8}.
 - Cluster 6 (highlighted in light blue color): {Design, 108; Framework, 38; Optimization, 15; Inventive Principles, 12; TRIZ Method, 11; Knowledge Management, 10; Patents, 9; Service Quality, 9; Computer-Aided Innovation, 8}.
4. The category referring to the issue of sustainable marketing product management:
 - Cluster 5 (highlighted in purple color): {Model, 47; Product Development, 43; Management, 33; Selection, 24; Sustainability, 22; Performance, 21; Challenges, 15; Technology, 14; Evolution, 9; Impact, 9}.

At the first stage of research, marketing functions in which the application of new technologies becomes particularly important are indicated. Based on the analysis of a set of publications presenting the results of research related to the application of TRIZ in the area of marketing, the use of TRIZ methods and tools as part of functions related to product quality management, including green marketing and taking into account sustainable development in the marketing strategy related to product improvement were

indicated. These studies use such TRIZ methods and tools as: the Golden Rule of TRIZ (i.e., improving Ideality is the aim of all problem solving); 8 Trends of System Evolution; Functional Analysis; Contradiction modeling; Patent Database Analysis; Inventive Principles and Computer-Aided Innovation.

4 Conclusion

The aim of the work was to identify the current state of application of the Theory of Inventive Problem Solving (TRIZ) and the General Theory of Powerful Thinking (OTSM) in marketing management, in particular within those functions in which Digital Marketing solutions are used. As a result of the implementation of individual stages of research works:

1. Particularly important areas of application of new technologies were identified, i.e., application of Data Science, Machine Learning, Artificial Intelligence in marketing (see Sect. 2).
2. Current and significant problems of digital marketing management were identified, including problems of contradictions in marketing management. The validity of improving methods and tools for systematic innovation in the field of marketing management was indicated (see Sect. 2).
3. On the basis of a systematic review of the literature the current areas of application of TRIZ and OTSM methods and tools in marketing management were identified, among others (see Sect. 3):
 - Category 1: as tools supporting quality management in marketing (TRIZ integration in the implementation of the Six Sigma, QFD, Kano Model concepts);
 - Category 2: as part of the implementation of the green marketing concept (using, among others, *Contradiction Modeling - Contradiction Matrix, Inventive Principles; Patent Database Analysis; 8 Trends of System Evolution*);
 - Category 3: as part of marketing product management, including shaping and designing a new product or improving a product (when using, among others, *Functional Analysis, Contradiction Modeling - Inventive Principles; Patent Database Analysis; Computer-Aided Innovation*);
 - Category 4: as part of the issue of sustainable marketing product management (application of, among others *8 Trends of System Evolution*).

Creating new knowledge requires recognizing its existing state. In this work, the first stage of research activities related to the resolution of the research problem regarding the suitability of TRIZ methods and tools in solving current and significant problems of marketing management was carried out. In this work, the analysis of scientific publications using bibliographic techniques, i.e. the analysis of the number of publications and citations over the years, as well as identification of the set of crucial keywords, and the classification of the keywords was carried out. In the next stage of research activities, it is planned to verify the correctness of the publication database by reviewing abstracts, which will allow for further narrowing of the developed database. The crucial problem will be to isolate the so-called publication layers, i.e., those directly related to the studied issue, partly related to the studied issue, and poorly related to the studied

issue (Czakon, 2011). The analysis of the most frequently cited papers within scientific production/output; the analysis of the most influential and productive authors; the analysis of the joint co-authorship for scientific production; the analysis of science journals that generate scientific publications related with the domain, etc., are also pointed as the direction for future studies. It is indicated that the direction of further research may be the use of TRIZ in solving current digital marketing problems. Firstly, as part of solving problems identified in the paper, emerging along with the use of Data Science, Machine Learning or Artificial Intelligence in marketing. Secondly, the application of new technologies along with the use of TRIZ tools in marketing management. In addition, there are still few works referring to the application of TRIZ and OTSM in the area of research, evaluation and improvement of marketing communication, and the study, understanding and anticipation of customer needs, requirements and changing behaviors.

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TRIZ Impact in Society



Using TRIZ to Write a Good Thesis on Time

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Abstract. Millions of students worldwide face the challenge of developing a graduate thesis on time every year. Most of them approach such a task for the first or second time, so they can hardly rely on their experience. Working at the university for over 35 years, the author supervised and reviewed numerous theses and observed similar shortcomings appearing again and again. Many requirements constrain the development of a thesis, and some compete with others. The most fundamental issue is that a thesis must be delivered on time and provide good content and adequate quality to earn a degree. This paper briefly introduces the TRIZ approach and uses the thesis writing process to demonstrate how TRIZ tools may help solve problems in a non-technical area. The outcome is intended to serve as a collection of student guidelines and recommendations.

Keywords: TRIZ · Inventive Principles · Function-Oriented Search · Trimming · Feature Transfer · Super-effect Analysis · Thesis writing · Contradictions

1 Introduction

1.1 About the Problem

Writing a thesis is a well-established task in the academic world, repeated for ages by countless students. Nevertheless, it is still challenging for newcomers, as different students seem to make the same or similar reappearing errors. The reason is that students usually write a graduate thesis for the first (BSc) or second (MSc) time in their lives, so they cannot rely much on their own experience in this area.

Moreover, in the last decades, students increasingly communicate through social media and instant messengers. Consequently, they spend less time reading large, structured documents, adversely affecting their abilities to develop such documents. Indeed, the observed average size and overall quality of the theses seem to decrease continually.

Due to the lack of experience, the students look for help, and there is much to choose from. Searching books on amazon.com with the “how to write a thesis” query yielded over 400 hits, while the same query on google.com returned over 400 million hits. Many universities and publishers also provide in-house writing guides.

Consequently, multiple sources supporting thesis development are available in different formats, styles and sizes, ranging from a few pages [1] to a few hundred pages

[2], including general writing guides [2, 3], research writing guides [4–6], thesis writing guides [1, 7, 8] and guides for writing and defending a thesis [9].

A diploma thesis is demanded to fulfill many requirements, which makes the task yet more challenging, and some of them compete or directly conflict with others:

- easy and sophisticated – a thesis should be easy to read, and it should present non-trivial content to earn a degree,
- short and long – a thesis should be concise for comfortable reading and elaborated to provide necessary details,
- theoretical and practical – a thesis should provide a sound conceptual justification of the approach, and it should demonstrate the usability of the developed solution,
- generic and specific – a thesis should indicate possible applications of the solution, and it should show concrete outcomes confirming claimed properties or benefits,
- closed and open – a thesis should demonstrate achieving declared goals and should indicate directions for further work to prove the ability to see the “big picture”,
- written on time and of high quality – a thesis is usually developed under time pressure and is expected to present the content correctly and clearly.

This paper analyzes these requirements and proposes recommendations on designing thesis structure and content and organizing the thesis development process by solving presented conflicts with TRIZ tools. Because the paper is primarily targeted at a TRIZ-unaware audience, we will start with a brief introduction to this methodology.

1.2 About TRIZ

TRIZ is a systematic approach to innovation devised by Genrich Altshuller in the 1950s, which spread out worldwide. The acronym comes from the original Russian name of the methodology, usually translated as *Theory of Inventive Problem Solving*. TRIZ offers concepts and tools supporting identifying and solving problems [10, 11]. Contrary to other solution generation methods, which typically use a trial-and-error formula, TRIZ employs a structured and often algorithmic approach directly aimed at the required outcome.

In the beginning, TRIZ addressed mainly mechanical design. Later, it was successfully introduced to other technical areas, including IT [12, 13], business and management [14, 15], social sciences and art. TRIZ was also adopted by many global corporations and contributed to their development through innovations, with General Electric, Philips, Samsung, and Siemens constituting well-known examples.

One of the fundamental findings of TRIZ is that all solutions utilize a small set of generic solution models called *40 Inventive Principles* (many of them appear below). There are also statistically confirmed mappings between different models (types) of problems and models of successful solutions. Hence the usual TRIZ way of conduct is to extract the problem model, identify an appropriate solution model, and adjust it to a specific problem situation. Another outcome, often indicated as the most important, is that the developments of different systems follow common patterns, known as *Trends of Engineering Systems Evolution*. Therefore, the innovation potential of existing and future solutions may be forecasted and explored systematically.

In contrast to other methods, where coming to conflicting demands often leads to confusion, we appreciate contradictions in TRIZ as the symptoms of inventive situations. When we can formulate justified demands requiring the same system characteristics to take two different values – e.g., short and long – it is called a *Physical Contradiction*. TRIZ offers several strategies for resolving problems defined in this way:

- *separating contradictory demands* is the most straightforward approach, and it relies on investigating if the conflicting values may be attributed to different locations or moments or to different components or system hierarchy levels or directions (which is called separation in space, time, relation, system level and direction, respectively);
- *satisfying contradictory demands* is tried in the next step when separation attempts do not yield satisfactory results, and it usually introduces more profound changes to the system;
- *bypassing contradictory demands* is the most disruptive variant consisting in redesigning the system to such an extent that the conflicting requirements become irrelevant, e.g., due to a new operation principle.

A short list of Inventive Principles (statistically proven to be the most successful) is provided for each strategy. Moreover, if none of the recommended principles leads to a promising solution idea, one should check all the remaining Inventive Principles for inspiration.

2 Analyzing Problem Situation

Writing a thesis may be considered one stage in the much broader process, starting with topic formulation and ending with conferring a degree. While the TRIZ tools may be applied in every stage of this process, we will mainly address thesis writing, as stated in the title.

2.1 Mapping the Process

Since the TRIZ approach requires analyzing the problem before turning to solution generation, we will describe the process to identify its structure and entities involved. The outline below refers to the context of the Faculty of Electronics and Information Technology, Warsaw University of Technology, where the graduate theses are related to technical systems or processes. It is supposedly adequate for other technical universities and differs mainly by the nature of the independent work performed by students concerning other types of universities.

1. Formulating thesis topic – this is typically done by a supervisor, but sometimes the subject may also be proposed by a student or a third party interested in solving a specific problem, verifying a hypothesis, etc.
2. Defining thesis scope – the scope is usually determined or proposed by the party formulating the topic, and it implies the boundaries or constraints of the task (e.g., using a particular approach, tool or technology).

3. Assigning the topic to a student – this stage may employ written descriptions or presentations performed by the supervisors; if there are several candidates, the topic or scope may be adjusted for co-authoring or launching more than one thesis.
4. Researching and developing – this is independent student work being evaluated; it usually includes a literature overview, formulation of requirements and assumptions, developing a solution or performing experiments, and validating the outcomes.
5. Writing thesis text – the thesis should describe what the student’s task was, how it was completed (domain overview, analysis of existing solutions, design, implementation, verification), and what outcomes were obtained.
6. Reviewing thesis text – this is done by reviewers who prepare written reports constituting the basis for grading the thesis; reviewers’ activities may also include verification of the outcomes (e.g., testing a developed model, device or application).
7. Preparing thesis presentation – the thesis is to be orally presented by the student to the examination committee members; this short speech (ca. 10 min) is usually supported using slides or by demonstrating the technical outcomes.
8. Defending thesis – the committee members ask questions related to the thesis or any course attended by the student during their university education path; the quality and completeness of the answers affect the final committee verdict.
9. Conferring a degree – the committee decides about the grade of the thesis and exam and confers a respective degree; in case of discrepancies, the thesis grade is agreed upon between reviewers or determined by the examination committee chair.

Some stages of this process may overlap, disappear or start in a different order. For instance, the scope may be articulated before devising the title, and explicit assignment is not required if the student proposes the thesis. Despite possible variations, the key participants, objects and parameters appearing in the process description are as follows:

- Participants: student, supervisor, reviewer, examination committee member, examination committee chair.
- Objects: thesis text, thesis outcomes, thesis presentation, thesis review.
- Parameters: thesis title, thesis scope, thesis size, thesis grade.

There may be some unusual cases resulting in an increased number of reviewers and other participants, like co-authoring or co-supervising, especially if the thesis is multidisciplinary or launched at the request of a third party. Such modifications make the interactions more complicated but do not require significant changes in the described model.

2.2 Functions in TRIZ

In TRIZ’s perspective, people create technical systems to deliver benefits provided through specific functions. Among TRIZ tools, we have *Function Analysis for Devices* and *Function Analysis for Processes*, supporting the structural and behavioral analysis of the problem situations. They allow for describing the interactions between system components or process operations and assessing their relative values by estimating how much they contribute to the functionality and cost.

Distinguishing useful and harmful functions (or operations) and assessing the performance levels support the identification of functional disadvantages. Knowing these

disadvantages, we may consider reasonable improvements such as removing components providing harmful functions (or those too expensive regarding their functionality) and distributing their useful functions among other components or operations, which is called *Trimming*. We will not go that far in Function Analysis, sticking to the problems initially described by the contradictory demands in Sect. 1.1.

3 Identifying and Solving Problems

The following sections address particular contradictions. The key assumption is that the reviewers are the crucial participants whose sensations and reactions impact further process steps the most. We also assume that a reviewer does not have to be an expert in all the subject areas covered in the thesis, and – consequently – the thesis should also be understandable to non-expert readers (including other students).

We will analyze each contradiction to identify the expected benefits hidden behind required characteristics and then look for feasible solutions derived using the Inventive Principles and other TRIZ tools. Because the names of the principles vary among literature sources, they are accompanied below by numeric identifiers for disambiguation.

3.1 Easy and Sophisticated

Easy and sophisticated means that a thesis should be easy to read and comprehend, and its content should be sufficiently complex and correct to earn a degree. Therefore, *easy* is about effortless perception (and may be understood as *comfortable*), and *sophisticated* is about significant intellectual content (and may be understood as *valuable*). In other words, the thesis should be advanced enough yet understandable.

Despite personal differences in perception, making the text appear differently to various people, a straightforward structure, consistent terminology and convenient navigation significantly increase the chances for comfortable reading. These commonly known recommendations are directly justified by respective Inventive Principles:

- *Segmentation* (#1) – decomposing the thesis into chapters, sections and paragraphs in a logical way to ease the perception.
- *Homogeneity* (#33) – using consistent terminology and narrative style to avoid distracting readers with unimportant stimuli.
- *Partial or excessive action* (#16) – describing the broad perspective briefly and focusing on specific areas or aspects within the thesis scope.

Separation in space may be applied to describe the same issues using various styles or notations, considering the different expectations of expert and non-expert readers. For instance, we may describe an algorithm or its fragments with free text, structured text, a flowchart, pseudocode, or actual program code in a specific programming language. This approach follows the principle of *Local quality* (#3) by adjusting local characteristics to meet specific requirements or needs.

We may also use the principles of *Merging* (#5) and *Universality* (#6) and present the same data as tables and graphs, provide different units (e.g., centimeters and inches)

or different parameters (e.g., wavelength and frequency), or plot diagram markers using different shapes and colors. Such enhancements may significantly increase the readers' comfort due to meeting their individual preferences.

The smoother the reviewers' journey through the thesis, the more focused attention they may pay to the merit. Hence, it is worth using the principle of *Prior action* (#10) to announce the contents of the following sections in advance, explain new terms upon first use and, generally, make all intellectual maneuvers as effortless as possible. Other examples of using this principle are thesis templates (with predefined structure, styling, logotypes, etc.) and writing guides offered to students by universities.

Sometimes tables may be substantially compacted and made much more readable by transposing or regrouping their contents. The navigation among sections, figures, etc., may be supported with hyperlinks embedded in the text. The former reflects the principle of *Inversion* (#13), while the latter follows the principle of *Another dimension* (#17).

3.2 Short and Long

Short and long means a thesis should be concise enough for comfortable reading and elaborated enough to provide the required details. Therefore, *short* is about brevity (and may be understood as the requirement to provide *necessary* content), while *long* is about completeness (and may be understood as the requirement to provide *sufficient* content). This recommendation on simplicity may also be described using Einstein's words: *as simple as possible, but not simpler*. The former implies removing everything redundant, and the latter warns against the harm of oversimplification.

We may follow the principle of *Asymmetry* (#4) by sizing particular thesis sections to reflect their relative importance. A typical solution is to provide a brief yet complete description of the project in the main part of the thesis and present additional details (such as relevant schematics, code listings, test results, etc.) in the attachments so that interested readers will reach them easily.

Suppose some sections are mandatory, and we do not consider them essential. In that case, we may use the principle of *Rushing through* (#21) and reduce their sizes to the extreme, thus saving reviewers' attention for the crucial sections without violating formal requirements. Also, the principle of *Composite materials* (#40) may be used to decrease the thesis size while increasing its expressiveness by condensing and enriching the contents, e.g., combining plots representing the variability of different parameters in the same experiment on a single graph with two vertical axes.

The principle of *Nesting* (#7) may be used by describing the same topics with different levels of detail to allow readers for comfortable transitions. This approach is typical for research papers published in journals and conference proceedings. The abstract provides an overview of the problem, approach and results. The introduction prepares a non-expert reader for the main part of the publication, which typically describes the specific problem, literature overview, conceptual or experimental setup and the following project-specific stages, up to the result presentation and discussion. The last sections provide a summary and indicate directions for further research.

With minor publisher-specific variations, the described composition is a de facto standard for the research papers published in indexed sources, so the reviewers are supposed to expect a similar structure in a graduate thesis or at least to receive it well.

3.3 Theoretical and Practical

These adverbs may relate to the subject area of the thesis, distinguishing basic research from applied research, but we are more interested in describing thesis characteristics independently of its domain. *Theoretical and practical* means a thesis should provide a sound conceptual justification of the chosen approach and demonstrate the usability of the developed solution. Therefore, *theoretical* is about the justification of the paradigm or method (and may be understood as *correct and convincing*), while *practical* is about outcome validation (and may be understood as *credible*). In other words, the developed solution should be presented as properly designed and adequately validated.

The first reason to perform a thorough literature review is to identify the state of a subject domain, including existing solutions. The advantages of these solutions may support selecting a specific approach directed to the most prospective methods or technologies. The recognized shortcomings of such solutions may, in turn, support decisions regarding specific improvements. The second reason justifying a literature review is to identify the results achieved by the existing solutions, which are necessary to assess obtained results reliably. The ability to perform such a comparison is crucial for claiming the practical applicability of the new solution.

Finally, reviewing the literature allows identifying the resources available in the system or its environment (called *Supersystem* in TRIZ) that may help develop required improvements. Besides trimming components (due to their harmful functions or disproportionately high cost), we may enhance the system by intensifying existing useful functions performed insufficiently or adding new functions without worsening essential system characteristics.

3.4 Generic and Specific

Generic and specific means a thesis should indicate possible applications of the solution and show concrete outcomes confirming claimed properties. Therefore, *generic* is about broad applicability (and may be understood as *multipurpose*), while *specific* is about proven usability (and may be understood as *verified*). In other words, the developed solution should be described as *promising* by presenting its application potential and validation performed on representative samples or cases.

Function-Oriented Search (FOS) is a TRIZ tool developed for identifying existing solutions to the analyzed problem by describing the required system function in a possibly generic way. The recommendation is to look for solutions in application areas where this function is of primary importance, considering the high-budget markets (like military, aerospace, and medicine) and nature being a rich source of proven solutions. This approach is reasonably justified because acquiring and adjusting a tested solution will likely be easier, faster, cheaper and less risky than creating and developing a new solution from scratch.

While FOS is helpful for “importing” a solution from another market, there is also *Inverted Function-Oriented Search* (IFOS) tool aimed at discovering new markets where the product developed for a specific application may be “exported”. It also relies on describing the key characteristics of the new product using generalized functions. IFOS may be used to identify the potential adjacent markets (typically in the thesis summary).

Feature Transfer is yet another TRIZ tool worth mentioning here. It supports an algorithmic approach to “transplanting” required features – either as a specific implementation or just as a solution concept – from another system built for the same purpose to alleviate identified downsides of the developed system. This approach may be applied to technical or research tasks (e.g., by adopting experimental procedures) and the thesis text (by following document structure, graphical conventions, etc.).

3.5 Closed and Open

Closed and open means a thesis should demonstrate achieving declared goals and indicate directions for further work to prove the author’s ability to see a broader perspective. Therefore, *closed* is about project completeness (and may be understood as *finished*), while *open* is about the growth potential (and may be understood as *prospective*).

A TRIZ project typically consists of three stages: problem identification, problem solving and solution substantiation. Usually, several solutions ideas generated in the second stage are characterized and compared. Then the concept selected through a ranking as the most promising is developed into a prototype and final solution.

Introducing changes usually leads to secondary problems resulting from modified interactions between system components or subsystems (or between system and super-system) which must be identified and solved. On the other hand, the same changes may also create innovation opportunities, paving the way to additional benefits. *Super-effect Analysis* is a TRIZ tool aimed to support the systematic exploration of this potential by navigating the process of identifying new functions and resources and analyzing their applications. Concluding, a thesis should be *closed* by showing convincing evidence of the fitness of the developed solution for a specific purpose, and it should be *open* by showing how the system characteristics contribute to its further development.

3.6 Written on Time and of High Quality

A thesis is usually developed under time pressure and is expected to present the content correctly and clearly. In contrast to the other contradictions, these requirements refer to different characteristics, reflecting the interrelation between the writing speed and the thesis quality so that *written quickly and slowly* does not sound appropriate description. When improving one essential system parameter results in worsening another essential parameter, we call it in TRIZ a *Technical Contradiction* and usually describe such a situation using the IF-THEN-BUT format, like the following:

- *IF the author is fast, THEN writing takes less time, BUT the thesis quality is low.*
- *IF the author is diligent, THEN thesis quality is high, BUT writing takes more time.*

As can be seen, the IF clause indicates a specific condition implying a given situation, the THEN clause describes the benefit by indicating the improving parameter, and the BUT clause describes the interrelated drawback by indicating the worsening parameter. These complementary Technical Contradictions lead to valuable observations:

- A fast and diligent author will presumably write a high-quality thesis quickly, so students with both these capabilities may safely focus on other challenges.

- A fast and not diligent author will primarily benefit from supporting quality assurance in the writing process.
- A diligent and not fast author will primarily benefit from increasing the productivity of the writing process.

Quality assurance may involve self-reviewing or using automated tools to detect errors and suggest corrections or asking others to review the work. The former represents the principle of *Self-service* (#25), and the latter implements the *Intermediary* (#24) principle by putting another person as a proxy between the author and the official reviewer. Thesis supervisors may (and should) enter the proxy role, but their extensive knowledge about the subject area and project context may impede their ability to recognize deficiencies regarding smooth introduction, understandable terminology and overall logical consistency.

These deficiencies may be equally invisible to authors and supervisors, so it is highly advisable to ask a non-expert reader to validate the clarity of the thesis, which implements the principle of *Another dimension* (#17), as there is no such participant in the regular process. The quality improvements may come from correcting specific errors and the remarks from proxy reviewers, which directly implements the *Feedback* (#23) principle. Also, some advanced tools, such as Grammarly, provide extensive guidelines and suggestions on rephrasing questionable phrases, directly supporting the authors in enhancing their writing skills [16].

On the other hand, any attempt to increase productivity by using text fragments written by other people or generative AI-based software, such as GPT, would violate the requirement to develop the thesis independently. The only way of using the works of others accepted in the academic world is by references, with credits given to respective authors or publishers. Anything else might be reasonably considered plagiarism.

Despite these circumstances, the problem of low productivity may be handled using the concepts represented by the principles of *Counterweight* (#8), *Periodic action* (#19) or *Cushion in advance* (#11). The first approach may be to plan the writing in a realistic timeframe, considering the actual author's performance. As the academic calendar usually determines the submission deadline, this recommendation translates to starting the writing early enough to develop the thesis on time and monitoring the progress frequently enough to cope with detected delays.

The third approach is to define the thesis scope variants using priorities, as is often done in projects. Even the simple *must have - should have - could have* gradation clearly indicates what parts of research and writing are mandatory and must be handled first. Scheduling the optional items to the end of the available period assures that the possible harm of not addressing the full intended scope is effectively minimized, and the thesis may still be defended on time with a safely adjusted scope.

Unfortunately, sometimes applying these approaches may be insufficient to meet the deadline, so the thesis defense must be rescheduled for next semester. This additional time may be used to create missing fragments and review, rethink, and enhance the thesis. The *Trimming* approach may be particularly instrumental at this stage to simplify the structure and decrease the thesis size without degrading its intellectual content. Hence, the delay should be perceived as an opportunity to make the thesis inherently better, as it is suggested by the *Convert harm into benefit* (#22) principle.

A thesis developed in a local language typically provides the title and abstract in English for unified indexing in repositories, while some universities require full text to be provided in the local language and in English. In such a case, it looks advisable to follow the *Use a copy* (#26) principle and develop the thesis in the student's native language (or the one commanded better) and then obtain a reliable translation.

4 Novelty and Applicability of Results

The recommendations derived (or supported) by using the Inventive Principles and other TRIZ tools are summarized below.

- Segmentation (#1) – decompose and logically organize the thesis text,
- Local quality (#3) – let the form of specific fragments follow their functions,
- Asymmetry (#4) – let the sizes of particular sections reflect their importance,
- Merging (#5) – combine items or features to address various readers' preferences,
- Universality (#6) – combine modalities – e.g., by adding values to graphs,
- Nesting (#7) – describe important topics with different levels of detail,
- Counterweight (#8) – start writing early enough to finish on time,
- Prior action (#10) – prepare readers for the following sections in advance,
- Cushion in advance (#11) – prioritize topics to minimize writing delays harm,
- Inversion (#13) – consider transposing or reorganizing tables,
- Partial or excessive action (#16) – add detailed explanations where needed,
- Another dimension (#17) – ask non-experts to read your thesis,
- Periodic action (#19) – monitor work progress to handle delays effectively,
- Rushing through (#21) – make unimportant sections as short as possible,
- Convert harm into benefit (#22) – turn your enemies into allies whenever you can,
- Feedback (#23) – use the feedback from people and tools to enhance your thesis,
- Intermediary (#24) – ask other people to read your thesis before the official review,
- Self-service (#25) – verify the thesis yourself before passing it to others,
- Use a copy (#26) – write the thesis in a preferred language and translate it if required,
- Homogeneity (#33) – use consistent terminology and narrative style,
- Composite materials (#40) – enrich content to increase expressiveness,
- Trimming – remove or simplify a component/section retaining its useful functions,
- Function-Oriented Search – identify existing implementations of a required function,
- Inverted Function-Oriented Search – identify existing markets for a new function,
- Feature Transfer – transfer superior characteristics from one system to another,
- Super-effect Analysis – maximize benefits of the system modifications.

Although the recommendations substantially overlap with known best writing practices described in many guides, they are believed to feature two important advantages:

- They go beyond the writing, proposing some ideas regarding the graduation project planning, monitoring, managing and tooling, and handling specific thesis sections,
- The presented considerations, related to benefits, functions and resources, aim to instill a better understanding of the thesis development process and its interrelations.

Differences between BSc and MSc theses are reflected by their challenge ranks and evaluation criteria, which mainly pertain to *what* is expected inside. These criteria may vary among universities or faculties, but it seems reasonable to assume that each thesis should be written on the topic, thoroughly and comprehensibly, while the assessment focuses on the technological aspects of BSc theses and the methodological aspects of MSc theses. Most of the MSc criteria also pertain to a Ph.D. dissertation, where the specificity consists in developing an original solution to the problem stated and demonstrating the candidate's theoretical knowledge in a given scientific discipline and their ability to conduct scientific work independently.

The presented guidelines are primarily focused on *how* to organize the activities regarding the development of the thesis. In this perspective, BSc, MSc and Ph.D. theses seem similar enough to consider them jointly, as they share common characteristics regarding the generic goal (earn a degree), format (structured scientific publication) and project constraints (scope, time, effort, quality).

We may extend these recommendations to other types of publications, such as conference papers, with some differences between research-oriented *scientific papers* and application-oriented *practitioners' papers*. Moreover, some recommendations also appear directly applicable to business and general-audience writing (in particular, those related to diagrams may be used in presentations and infographics).

Using AI-boostered tools for searching relevant literature sources or checking and improving text created by the student does not raise any ethical doubts. Moreover, the language models open new possibilities, like balancing the sensory connotations in a thesis (visual, auditory, kinesthetic, etc.) to enhance the experiences of readers with various input preferences [17]. On the contrary, text created by generative AI tools must not be presented as independent students' or researchers' work and explicit regulations on this are urgently needed in the academic world [18].

5 Summary and Conclusions

We presented the thesis writing as a stage of a broader process, identified key entities appearing in this process and discussed essential constraints of the thesis writing described as conflicting requirements. Then we analyzed each contradiction to identify the specific goals or benefits hidden behind the required characteristics. Finally, we demonstrated how simple TRIZ tools might support a diploma project, with a particular focus on writing the thesis. The intended outcomes of this work include:

- presenting explanation and justification for particular requirements regarding theses,
- providing students with practical guidelines on meeting these requirements,
- popularizing TRIZ as a systematic approach to analyzing and solving problems,
- demonstrating how TRIZ may be used in a non-technical domain.

Even if many of the proposed recommendations appear in other writing guides, deriving them “anew” with TRIZ tools confirms their appropriateness. The presented approach and outcomes are deemed to help students write good theses on time and spark their curiosity about TRIZ as a robust methodology supporting systematic innovation.

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Improving Usability Services and User Experience of Online Museum Virtual Exhibition with TRIZ Theory

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Abstract. This study explores users' perceptions of a digital museum's online virtual exhibition. A survey and interviews have been conducted to collect data on user opinion and the ultimate objective was to determine what users think of the museum's online virtual exhibition services and what suggestions they provide for improvement and personalization. TRIZ theory contradiction matrix method was used to modify and improve the usability services and user experience of the Shaanxi History Museum's "World Heritage Photography Art Exhibition" virtual exhibition by analyzing data and identifying problems from a user-centered perspective. The results of this study recommend five TRIZ principles for the development of conceptual solutions for increased user engagement, improved usability services, and better user experience for the museum's online virtual exhibitions. These findings suggest that the successful application of TRIZ theory can enhance user experience as it helps to solve complex problems in an organized and systematic way.

Keywords: Usability Services · TRIZ Theory · TRIZ Contradiction Matrix Method · Virtual Exhibition · User Experience

1 Introduction

1.1 Online Virtual Exhibition: User's Perception and TRIZ Theory

The digitalization of museums has led to the emergence of online virtual exhibitions, which can be more interactive and immersive than traditional exhibitions. However, these digital experiences often suffer from issues such as low user impact, satisfaction, and engagement. This study examines users' perceptions of virtual exhibitions provided by the Shaanxi History Museum, focusing on interaction, enjoyment, usefulness, and satisfaction. Through surveys and interviews, data on user opinions were gathered to understand their perceptions and identify areas for improvement. The study applies the TRIZ theory contradiction matrix method to enhance virtual exhibition services and improve the user experience. The goal is to utilize TRIZ theory to create customized content that better meets users' needs in online museum digitalization services [1].

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1.2 Online Digital Museum Services

Digital transformation and the digitalization of museums have been receiving much scientific attention during the past few years, especially in light of the COVID-19 pandemic. Nevertheless, there are still challenges to face when it comes to controlling elements such as layout, navigation, content, interactivity, and customization that affect the user experience when it comes to online digital museum services [2]. With the help of a user-centered usability perspective, it is possible to create a better service system for the future. Although there are many theoretical and practical obstacles to overcome, digital transformation and the digitalization of museums have been the focus of intense scientific research in recent years, especially since the COVID-19 pandemic [3–6].

1.3 Research Questions

This research objective is to explore how TRIZ Theory can be applied to improve virtual exhibition usability services and better user experience. The research questions guiding the study are: RQ 1. What are the user perceptions from a user-centered perspective of the digital museum's online virtual exhibitions? RQ 2. Based on user perceptions of a museum's online virtual exhibition, what potential problems in a museum's virtual exhibition services can be suggested for improvement? RQ 3. How can TRIZ Theory be applied to improve usability services and better user experience of online virtual exhibition, once user perceptions of the virtual exhibition have been identified?

2 Literature Review

2.1 Virtual Museums and Exhibitions in China Through User-Centered Usability Evaluation

Virtual museums and exhibitions in China leverage emerging technologies like VR and AR to provide users with enhanced access to cultural heritage. Scholars found that participants learned and enjoyed their experiences through these technologies [7]. User-centered usability evaluation, employing scales such as SUS, SIST, TUS, VEQ, and NASA-TLX, helps investigate user perceptions and improve the user experience. Questionnaires, like SUS [8], are commonly used for assessing user perception. Analyzing the relationship between user experience and online museum services enables museums to create more engaging and personalized experiences for users. However, there is a need for more research in the context of museum visits [9].

2.2 TRIZ Theory Application in the Service Design and Public Service Innovation

In recent years, the growing application of TRIZ (Theory of Inventive Problem Solving) has become increasingly relevant in the design of services for the public. Initially developed by Russian researcher Altshuller in 1984, [10]. TRIZ is a systematic approach to problem-solving that has been applied in many industrial fields, including engineering and research and development (R&D) [11]. Recently, TRIZ has been used in the

design of services in many different areas, such as banking, marketing, management, education, healthcare, hospitality, and airline service [11, 12]. Furthermore, Lee et al., (2020) put forward a novel knowledge-centric innovative service design (KISD) model which combined the TRIZ method and CBR to generate great ideas for customized, innovative service design [13]. Chiou et al., (2012) used TRIZ in the convention and exhibition industry to carry out systematic innovation [14]. TRIZ is an increasingly useful tool for service design and public service innovation. Through its systematic approach to problem-solving and creative solutions, it has the potential to provide benefits in many different domains. Likewise, its application to the design of services for the public can help optimize resource allocation and create innovative, customized services [12]. Therefore, TRIZ is a powerful tool and should be given serious consideration by those researching and designing services for the public.

3 Research Framework

3.1 The TRIZ-Based Conceptual Research Framework of the Museum's Online Virtual Exhibition

The process of our research study consisting on four stages as described and shown in the Fig. 1.

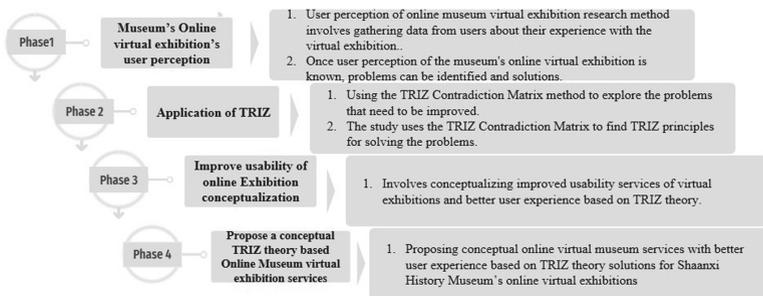


Fig. 1. A proposed conceptual framework for improving user experience in the museum's online virtual exhibition based on TRIZ theory.

TRIZ theory principles have been applied within this research framework in order to determine the best user experience and improved services for the virtual exhibition. The TRIZ theory principles include the following components: identifying inventive principles, researching the system, isolating the problem area, searching for an inventive solution, and implementing the solution [15]. We analyze the data after testing and propose improvement directions based on TRIZ theory. TRIZ (Theory of Inventive Problem Solving) is a process that helps to solve complex problems in an organized and systematic way. It has been widely used in the engineering field and has shown great promise in other fields. Recent research has shown that TRIZ theory can be successfully applied in usability engineering, providing a very suitable model for improving usability as well [16].

3.2 Users' Perception of Online Museum Virtual Exhibition Research Method

In this study, we have incorporated and adapted a conceptual and theoretical framework in alignment with user usability scales as suggested by [17]. Our survey questionnaire, designed to evaluate an online virtual exhibition from a user-centered usability perspective, utilized a five-point Likert scale for responses. Scale 1 comprised seven items/attributes, while Scales 2 to 5 consisted of four items/attributes each. To gather qualitative data, we conducted six interviews and employed thematic analysis as recommended by Braun and Clarke [18]. The interviews were recorded, transcribed, coded, and analyzed thematically. The survey was conducted during a two-week period, specifically from January 10, 2023, to January 24, 2023, focusing on the “World Heritage Photography Art Exhibition”. It is estimated that the total number of visitors to this online virtual exhibition during the specified time frame was a few hundred. The survey questionnaire was shared with participants via WhatsApp and WeChat. Respondents willingly participated in the survey without receiving any compensation. We employed a combination of convenience and snowball sampling to approach potential respondents from the networks of teachers, students, and researchers. Quantitative analysis was carried out using descriptive statistics and factor analysis, following the quantitative research method, to examine users' perceptions of the online virtual exhibitions at the digital museum. The survey was distributed to a sample size of 100 users for evaluation. Additionally, we conducted six online user interviews. According to Braun and Clarke (2013), a small research project typically requires 6–10 participants for interviews to ensure valid conclusions through thematic analysis. Considering time constraints, we interviewed six participants, with each interview lasting approximately 45 min.

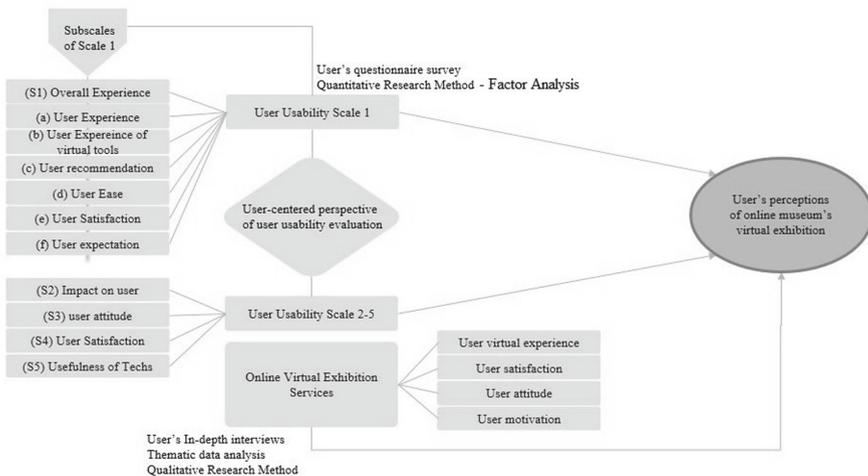


Fig. 2. Proposed conceptual & theoretical framework. We have adapted the user usability scales as advised by [17].

The distinction between item (e) User Satisfaction and (S4) User Satisfaction lies in their focus. Item (e) specifically pertains to the user's satisfaction with the virtual

exhibition being evaluated, whereas S4 represents a broader assessment of the user's satisfaction with the services offered by the digital museum as a whole.

4 Results

4.1 Descriptive Statistics of Item Responses

The survey's descriptive statistics results showed the highest percentage was students (52%) followed by researchers (29%), practitioners (17%), and others (2%). The majority of respondents were males (65%) followed by (35%) of females, and most reported using computer skills daily or almost daily (62%). (47%) of respondents reported intermediate-level skills, 31% reported advanced, and 22% reported expert, as shown in Fig. 3. Descriptive statistics of survey results also showed an overall mean of 3.1482 and a standard deviation of 0.28709. The distribution of the data was normal, with skewness and kurtosis values between -1 and 1 .

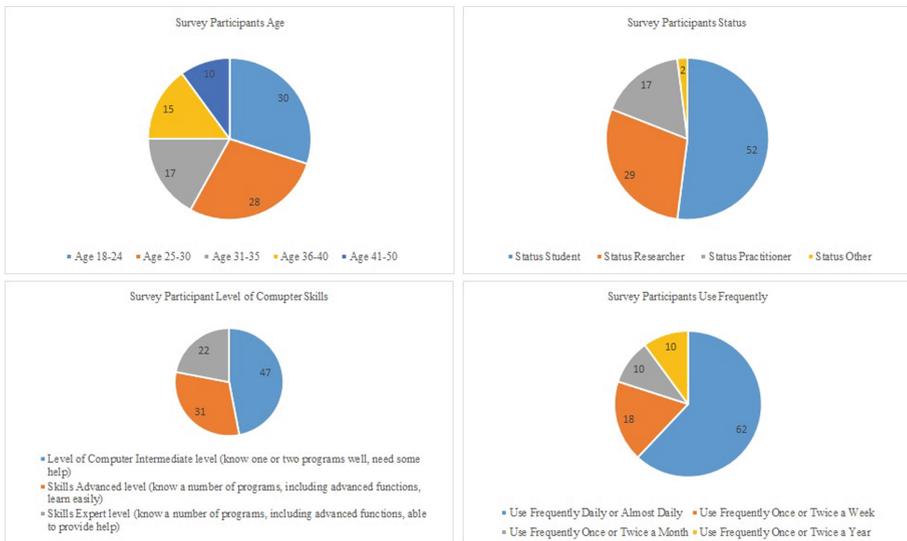


Fig. 3. Results of descriptive statistics.

4.2 Assessing Questionnaire Reliability

As shown in Fig. 4. The evaluation of items in Scale 1 (S1, a-f) and Scale 2–5 (S2-S5) demonstrated good reliability when assessing the reliability of each item across two different scales. The corrected item-total correlation and Cronbach's alpha were calculated for Scale 1 (S1, a-f) with a sample size (N) of 7 and for Scale 2–5 with $N = 4$. The correlations ranged from 0.500 to 0.821, and the alphas ranged from 0.825 to 0.880, indicating high reliability for the items across both scales. Overall, Cronbach's

alpha for items in Scale 1 (S1, a–f) was 0.851 with $N = 7$, while for Scale 2–5 (S2–S5), it was 0.885 with $N = 4$. These results suggest excellent reliability for the items at both scales [19].

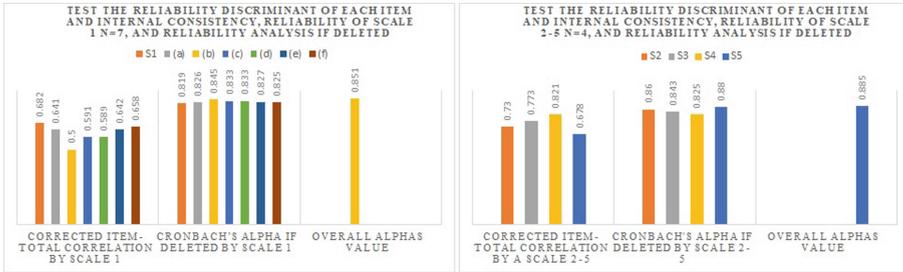


Fig. 4. Test each item’s internal consistency, scale reliability, and reliability analysis.

4.3 Thematic Analysis

We have conducted a thematic analysis on collected data from six interviews, first interviews were transcribed and coded and identified four themes: user virtual experience, user satisfaction, user attitude, and user motivation as also mentioned in Fig. 2. The interview participants generally had a positive virtual experience of the museum’s online exhibition services. While some felt that their satisfaction was partially met, most participants expressed the need for improved interactivity and responsiveness. Overall, all participants showed motivation to engage with virtual exhibitions in the future. Based on the thematic analysis of the six user interviews, users reported positive, engaging, and enriching experiences with online virtual exhibitions, but still valued the physical presence of a museum or gallery.

4.4 Construction of User’s Perception

Based on our conceptual and theoretical framework, we performed a factor analysis to investigate the construct validity of the instruments. We made an effort to determine if the eleven measurement items/attributes could adequately account for the study’s framework of user-centered usability viewpoint evaluation of the museum’s online virtual exhibition’s five usability scales. Two factors, F1 and F2, were found by factor analysis to account for 63.528% of the total variance and had an eigenvalue of 1.011. Additionally, Barlett’s test of approximated chi-square had a significance level of $p < 0.000$ and the Kaiser-Meyer-Olkin (KMO) measure of sample adequacy was 0.879 (Fig. 5).

The rotated component matrix from a factor analysis using principal component analysis factor loadings is shown in Table 1. Under the heading “User Perception of the Museum’s Online Virtual Exhibitions F1 and F2”. We looked at factor loadings with absolute values below 0.55 to assess the factor structure of user perceptions of the museum’s online virtual exhibition.

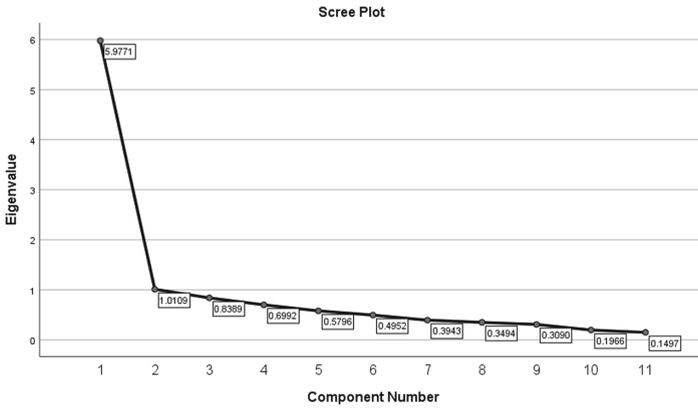


Fig. 5. Scree plot of user perception of online museum’s virtual exhibition, factor analysis.

Table 1. Rotated component matrix of factor analysis

Usability Scales	Items/attributes	F1 - User perception of the museum’s online virtual exhibition	F2 - User perception of the museum’s online virtual exhibition
Scale 1	S1 = Overall Experience		.657
	(a) = User Experience	.612	
	(b) = User Experience of virtual tools		.930
	(c) = User Recommendation		
	(d) = User Ease	.754	
	(e) = User Satisfaction	.580	
	(f) = User Expectation	.551	
Scale 2–5	S2 = Impact on User	-.881	
	S3 = User Attitude	-.732	
	S4 = User Satisfaction	-.881	
	S5 = Usefulness of Techs	-.634	

Factor F1, as assessed through a user-centered usability perspective evaluation (Scales 1–5), was primarily characterized by high loadings for User Experience (0.612), User Ease (0.754), User Satisfaction (0.580), and User Expectation (0.551). Additionally, an inverse relationship was observed such as the impact on the user $-.881$ (S2), user attitude $-.732$ (S3), user satisfaction $-.881$ (S4), and usefulness of techs $-.634$ (S5). Factor F2 was characterized by high loadings for the User Overall Experience (0.657)

and User Experience of Virtual Tools (0.930). Taken together, these findings suggest the relevance of assessing user perceptions of the museum's online virtual exhibition through a user-centered usability perspective evaluation. Overall, the results disclose that the scales 1–5 measurement items/attributes were appropriate in exploring users' perceptions of an online virtual exhibition. The factor analysis and interviews thematic analysis results of this user-centered usability study on the perception of the museum's online virtual exhibition answered RQ 1, by revealing that users' overall experience was strongly influenced by their experiences with virtual tools, ease of use, satisfaction, and expectations. Moreover, it was observed that there was an inverse correlation between users' perceptions of these virtual exhibitions and the impact on them, attitudes, satisfaction, and usefulness of technology.

5 Application of TRIZ Theory

5.1 Problems and Definitions

By addressing user perceptions of the Shaanxi History Museum's virtual exhibition, this study provided an answer to RQ 2 by identifying the major potential problems with the museum's virtual exhibition usability services.

Problem 1: Virtual Tool Frustration (P1)

Users often have an inverse or negative experience with the museum's online virtual exhibition tools due to difficulty in navigation, lack of intuitive design, and other issues.

Problem 2: Low Impact (P2)

Many users do not find museum online virtual exhibitions satisfying due to the low or inverse impact of interacting within the immersive experiences.

Problem 3: Prefer Physical (P3)

Despite the convenience of virtual experiences, many users still prefer the physical presence of a museum or gallery.

Problem 4: Immersion Challenges (P4)

It can be challenging to create an immersive virtual experience due to website design, features, and audio guidance.

5.2 Application of TRIZ Theory Contradiction Method

The TRIZ theory was applied in a flexible manner to improve user usability and deliver a better user experience for virtual exhibition services. The inventive principle numbers are obtained from Table 2.

TRIZ contradiction matrix. In order for the museum's online virtual exhibition services to deliver improved usability services and better user experience for online museum's virtual exhibition, we selected No. 8 (Volume and Stationary), No. 5 (Area of Moving Object), No. 11 (Stress or Pressure), and No. 10 (Force (intensity)) improving features lead to four worsening features: No. 13 (Stability of the Object), No 10.

Table 2. TRIZ contradiction matrix improving and worsening features.

Improving features	Worsening features			
	No. 13 Stability of the object	No. 10 Force (intensity)	No. 23 Loss of substance	No 4 length of stationary
No. 8 volume of stationary	34, 28, 35, 40	2, 18, 37	10, 39, 35, 34	35, 8, 2, 14
No. 5 area of moving object	11, 2, 13, 39	19, 30, 35, 2	10, 35, 2, 39	–
No. 11 Stress or pressure	35, 33, 2, 40	36, 35, 21	10, 36, 3, 37	35, 1, 14, 16
No. 10 Force (Intensity)	35, 10, 21	–	8, 35, 40, 5	28, 10

(Force), No 23. (Loss of Substance), and No. 4 (Length of Stationary). A TRIZ matrix was constructed with the deteriorated features and improved features that could help rectify the identified problems. As our study has identified the problems 1. Virtual tool frustration, 2. Low impact, 3. Prefer physical and 4. Immersion challenges from user's perception of the Shaanxi History Museum's recent virtual exhibition named "World Heritage Photography Art Exhibition". The selection of deteriorating parameters and improving parameters in this study was based on the application of the TRIZ contradiction matrix. The relationship between these problems and the deteriorating parameters and improving parameters can be understood by considering how the identified problems align with the features analyzed in the TRIZ contradiction matrix [20]. By using the TRIZ principles, the study aimed to address these problems by proposing conceptual solutions based on the identified improving parameters. The relationship between the parameters and problems suggests that improving the identified features could potentially alleviate the issues faced by users, leading to better usability and user experience in virtual exhibition services [21]. The final inventive principles selected from the TRIZ contradiction matrix included Transformation of Properties (35), Extraction (Extracting, Retrieving, Removing) (02), Prior Action (10), Flexible Membranes or Thin Films (30), and Local Quality (03).

5.3 TRIZ Principles to Develop Conceptual Solutions

This study has employed five TRIZ principles to develop conceptual solutions, the details of these solutions are discussed in the Fig. 6.

We identified four improving and worsening features from TRIZ contradiction matrix that require attention in order for the museum's online virtual exhibition services to deliver improved usability services and better user experience. Five TRIZ principles were then employed to develop conceptual solutions which included Transformation of properties, Extraction, Prior Action, Flexible Membranes or Thin Films, and Local Quality. Our proposed conceptual TRIZ theory based online museum virtual exhibition services are consisting on total three stages 1. Services diagnosis, 2. TRIZ solutions,

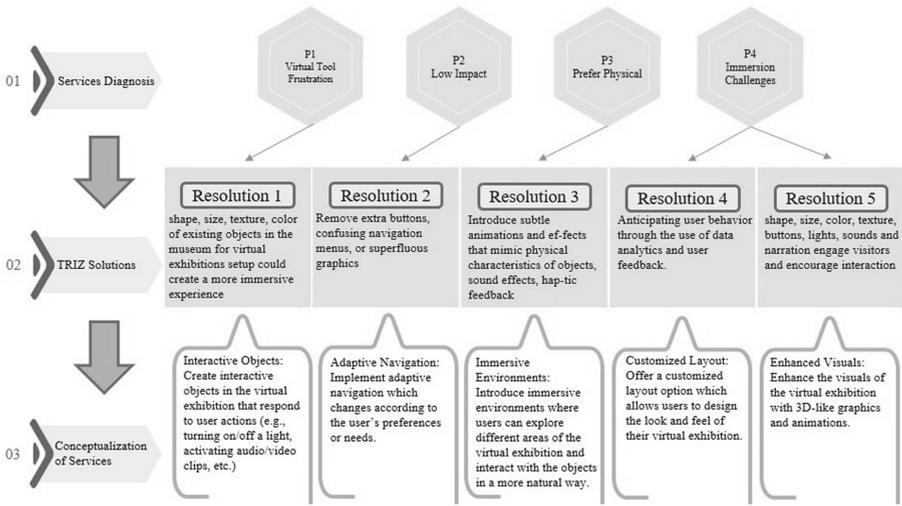


Fig. 6. Proposing a conceptual TRIZ theory based online museum virtual exhibition services.

3. Conceptualization of Services. As shown in the Fig. 6. These five TRIZ solutions (resolutions) are based on five TRIZ principles.

6 Discussion and Conclusion

This study applied TRIZ theory principles to address problems in the usability services and user experience of the Shaanxi History Museum's virtual exhibition services. The study proposed several solutions based on TRIZ principles:

1. Transformation of Properties: Changing the physical properties of objects in the virtual exhibition, such as shape, size, texture, and color, to create a more immersive and intuitive user experience.
2. Extraction: Removing unnecessary components from the virtual tool to simplify and enhance efficiency.
3. Flexible Membranes or Thin Films: Introducing tactile feedback and animations to simulate touch and texture, making the virtual experience more realistic and immersive.
4. Prior Action: Anticipating user behavior through data analytics and feedback to improve the design and functionality of the virtual tool.
5. Local Quality: Increasing the visual appeal and interactivity of stationary objects to engage users.

The proposed solutions aim to guide the Shaanxi History Museum in developing more intuitive features and audio guidance for an immersive virtual experience. Our conceptualization services as shown in the third stage of Fig. 6. After careful implementation could improve the usability of services and user experience of the online museum's virtual exhibitions. This study contributes to the application of TRIZ theory

in virtual exhibition services and provides insights into improving user experience and usability services. The findings of our study can be applied to other virtual exhibition scenarios, offering guidance to designers in this field. We recommend that in the future research should focus on analyzing user perceptions, demands, and immersive preferences through extensive data collection and exploring technical optimizations to enhance the design of virtual tools.

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An Experiment on the Impact of TRIZ-Inspired Thinking on Solving Insight Problems

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Abstract. Insight problems (problems requiring to restructure the mental representation of the problem in order to find a solution) are notoriously difficult to solve. Previous studies have used mostly problem-specific hints to improve problem solving performance. However, ideally a more general sort of training could be developed in order to increase solution rates. The present study tested whether a short intervention could be effective in facilitating problem solving performance for a battery of different problems. Specifically, it addressed the question whether referring to generic TRIZ concepts instead of problem-specific hints could support the problem solving process.

Two groups of participants were exposed to 16 video clips of magic tricks as problem solving tasks and had to find out how each trick was accomplished. The experimental group (19 students) had been taught about selected TRIZ techniques while a control group (25 students) attempted the problems without any training. Results showed that the experimental group solved more problems correctly than the control group, indicating the effectiveness of the intervention.

Keywords: insight problem solving · constraint relaxation · restructuring · TRIZ · smart little people · operational space

1 Introduction

1.1 Theory of Inventive Problem Solving (TRIZ)

Genrich Altshuller and his colleagues developed the Theory of Inventive Problem Solving (TRIZ) over the course of several decades. TRIZ can best be described as a set of tools for systematic creativity and problem solving. Many of those tools have been proven to be useful in practice [17]. However, in contrast to other techniques, in particular brainstorming (the best-known technique for creativity and problem solving), only few empirical studies have investigated the usefulness of TRIZ tools. Surveying the empirical literature, Meinel and Voigt [24] identified 31 articles on brainstorming, but only 6 on TRIZ.

A possible explanation for this observation is that techniques such as brainstorming can be applied after a rather short introduction. TRIZ, on the other hand, includes an extensive set of concepts and tools that cannot be explained in a few minutes.

However, while it seems to be very difficult to apply the complete TRIZ technique in an experimental setting, it is possible to select specific TRIZ concepts and tools that are rather easy to teach and to understand in a short time period [5]. Of course, students can then use only a very small fraction of TRIZ. In the present experiment, we wanted to find out whether any effects on the ability to solve insight problems could be observed under laboratory conditions.

Students were taught about two topics that are easy to understand: The first topic was the method of Smart Little People [1]. It was suggested as a means to overcome mental inertia and the reluctance to isolate parts from an intact object. The basic idea is to model a system as being made up from a group of collaborating little people. Those little people can have any desirable physical properties—they can be very heavy or very light, can grow or shrink, merge with others or separate into several little people, etc. Given such a mental model, the following question has to be answered: “Which steps would such a group of smart little people perform to reach a given goal?” The standard VDI-4521 [34] points out: “The playful approach of the small figures with all-encompassing abilities and characteristics overcomes barriers in formulating the problem and the goal, keeping in mind an ideal solution.”

The second topic we introduced serves as a guide to ask the right questions: the concept of the operational space (also called operational zone). The question has to be answered where exactly an effect takes place, with typical answers such as “at a surface of the object”, “at the boundary surface between two objects” or “only at the front side of the object”.

1.2 Testing Insight Problem Solving Skills

Insightful problem solving is characterized by the impossibility to derive solutions directly from past experiences. This stands in contrast to analytical problem solving where it is helpful to rely on prior knowledge and familiar solution steps. Classical theoretical accounts of insight such as Ohlsson’s Representational Change Theory [26] postulate that insight problems activate prior knowledge and assumptions that are not helpful and prevent the problem solver from finding the solution. Such prior knowledge needs to be overcome in a so-called “restructuring” process which yields a completely new perspective on the problem. Representing the problem in a more appropriate way enables the problem solver to eventually find the solution.

Traditionally, research on insight problem solving used classic puzzles such as Sam Lloyd’s Nine-Dot-Problem [23], matchstick arithmetic [18] or Duncker’s candle problem [14, p. 104] that are thought to require a fundamental change (restructuring) of the mental representation of the problem in order to become solvable. They can therefore not be solved by analytical thinking strategies that rely on well-known approaches.

Danek et al. [11] introduced a new type of problem solving task: Participants are presented with short video clips of magic tricks and asked to find the secret method behind the trick, i.e., how the trick is achieved. Magic tricks represent “non-typical” problems that cannot be solved by applying conventional, analytical thinking strategies.

The rationale to use magic tricks as insight problems is as follows: Similar to classic insight problems, the initial problem representation that is set up by problem solvers after seeing a magic trick is typically false and overly constrained by unwarranted assumptions (known as “mental inertia” in the terminology of TRIZ). In order to solve the problem, the initial problem representation needs to be fundamentally changed or restructured. This hypothetical restructuring process can be accomplished by different processes, for example constraint relaxation, re-encoding or elaboration [26, 27]. In the case of magic tricks, observers’ initial representation of the trick is almost always false—otherwise, the trick would not be surprising. This occurs because magicians systematically manipulate observers’ implicit assumptions about the objects used (for example, whether a box is empty or not, or assumptions about the actual weight or size of an object). Those false assumptions turn into constraints that prevent the observer from discovering the secret method of the trick. The problem can only be solved when those unwarranted constraints are overcome. The key question for the present paper is whether and how the restructuring process can be facilitated. It was hypothesized that TRIZ tools could be helpful in that regard.

The usefulness of TRIZ tools for removing constraints can be illustrated with an example: The magic effect of one trick used in our experiment was that a pen penetrates a 50-Euro bill which was shown to be intact afterwards. Thinking about the operational space forces the problem solver to think about what happens at the place where pen and bill come in contact with each other. In addition, the Smart Little People method would suggest to split either the bill or the pen temporarily into parts—the latter idea is already an important step towards the actual solution.

2 Related Work

2.1 Effects of TRIZ on Problem Solving Skills

Belski states in [5] that “there is lack of reporting on successful university TRIZ teaching that is based on actual improvement in student problem solving performance.” In a review on the 100 most cited publications on TRIZ, Chechurin [9] identified only two papers that deal with the quantitative evaluation of TRIZ trainings: [32] and [21]. Sokol et al. [32] performed an experiment in two secondary schools in Latvia. An experimental group that had been taught TRIZ-inspired creative thinking over the course of several weeks performed better in an inventive thinking test than a control group with no such training. [21] used a creativity test to compare the creativity of a group of students who had one semester of TRIZ training against a control group—without obtaining conclusive results.

Both experiments ([32] and [21]) measured the effect of training over longer periods of time. The same is true for most other such studies we are aware of.

Ogot and Gül [25] compared the creative output of 16 student teams that were educated on TRIZ for one semester with 24 teams that did not use TRIZ. All students worked on the same industry-sponsored design problem. The TRIZ teams provided on average 8.94 feasible solution ideas while non-TRIZ teams came up with 4.42 feasible solution ideas.

In [31], the creative output of 230 first-year undergraduate students was measured. So-called eco analysis scores were given to improvements in student projects after the application of various TRIZ tools. However, the results of this study are limited because they refer to a comparison between different groups of TRIZ tools, i.e. no group was tested that did not use TRIZ tools at all.

In Chang et al. [8], 121 students at National Taiwan Normal University were either taught TRIZ tools (experimental group) or problem-solving approaches (control group) for six weeks. While the two groups did not significantly differ with regard to identifying problems, the TRIZ group scored significantly better in a task to produce creative products in the area of engineering design (designing solar cars).

[16] challenged two groups (TRIZ and non-TRIZ) to redesign a traffic light and found that TRIZ improves the metrics for novelty and variety while it slightly reduced the quantity of ideas when compared to a control group using ad-hoc ideation methods.

All these experiments have in common that they investigated the impact of TRIZ education lasting several weeks at least. We are aware of only two experiments that investigated the influence of a short intervention (referring to a TRIZ concept) on idea generation.

Belski et al. [4, 6] confronted three groups of students with the same problem (to clean a tube). Two of these groups received training on Su-Field analysis. During the problem-solving phase, two of the groups were exposed to Powerpoint slides showing either random words or the names of the eight types of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, Biological) fields. It turned out that the group that was educated in Su-Field analysis and exposed to words for the types of fields produced significantly more ideas than the control group without Su-Field training. They also surpassed students who were trained in Su-Field analysis, but exposed to random words during the experiment. This experiment demonstrated that certain TRIZ tools can be applied successfully by students after a few hours of training.

In [7], a problem related to the analysis of two black boxes with electric circuits [22] was given to 42 students. After 41 of them failed to come up with the correct solution, the concept of resources was explained for a period of 5 min with an example not directly relevant to the electric circuit problem. After this intervention, 17 students provided the correct solution. Unfortunately, the validity of the results is restricted due to the fact that there was no control group.

In the present paper, we describe an experiment that investigates the influence of raising awareness of two rather easy to understand TRIZ concepts on solving insight problems. Related work on this type of problems will be discussed in the following subsection.

2.2 Effects of Hints on Insight Problem Solving

Most insight problems are notoriously difficult to solve. Many studies have therefore used cues and hints to increase solving rates. Of course, the hints must be carefully selected in order not to give away the entire solution. The underlying idea is that by giving hints that are perfectly tailored to the problem at hand, a restructuring process can be triggered that eventually leads to a solution. Often, hints are designed with the aim of relaxing unwarranted constraints, helping problem solvers to overcome their false

initial representation of the problem [28]. Both overt, i.e., hints that were clearly apparent to the solver [15] and covert, i.e., incidental [33] hints were shown to be effective.

Typically, the given hints are problem-specific, and provided along with the corresponding problem, or shortly before. This applies both to studies using magic tricks ([10, 11, 30]) as well as studies with other task domains (e.g., [2, 3]). For example, it was shown that both pictorial and verbal hints aimed at relaxing self-imposed constraints resulted in higher solution rates for a set of magic tricks [30]. However, in this experiment, the hints were problem-specific, designed by a person who already knew the solution of each trick. It seems desirable to develop hints that are more general and could be helpful for a number of different problems. Only few studies have attempted to do so. One notable example is a study by Patrick et al. [29] that implemented an unspecific training aimed towards identifying inconsistencies in problem representations. This study succeeded in facilitating the solution of seven different insight problems. The aim of the present experiment is to test whether an unspecific training of TRIZ concepts could have a similar effect on solution performance in 16 different magic tricks.

3 Experiment

3.1 Participants

Forty-four healthy adults participated voluntarily in this experiment. All participants gave written informed consent to participate in the study, according to the Declaration of Helsinki.

In the experimental group, the answers of three participants had to be excluded (the reasons will be explained in Sect. 4.1). So we considered the answers of forty-one participants (mean age: 23.3 years, range 19–35 years; 11 male, 27 female, 3 did not disclose gender).

3.2 Procedure

A battery of 16 video clips of magic tricks (previously used in experiments at the University of Munich [11] and the University of Illinois, Chicago [12]) was shown to a group of 19 students at the University of Zwickau (experimental group) and to a group of 25 students at the University of Heidelberg (control group), asking them to provide a solution how the trick was accomplished.

Before the experiment, two concepts from TRIZ were explained to the students of the experimental group: the concept of operational space and the method of “Smart Little People”. The latter was explained using a textbook example (to empty a water gutter) from [19]. The concept of operational space was explained by two examples ((1) preventing rice from burning at the bottom of a pot and (2) showing only one side of perimeter advertising at a sports event in TV, thus allowing different advertising to be shown in two different countries by filming from two views). It is easy to see that example (2) includes the idea of a separation principle, but this was not explicitly discussed.

Participants were informed that taking part in the experiment is voluntarily. After providing informed consent, participants were orally instructed to watch the magic tricks

that were presented via video projection in a classroom. After a practice trial, each of the 16 magic tricks was shown three times. After each of the three presentations, students were given 45 s of thinking time. For the experimental group, after the first viewing the following question was shown: “Does thinking about the operational space help to solve the trick?” After the second presentation, another question was shown: “Provided that the system consists of smart little people—how could they achieve the magic effect?”. The control group did not receive any hints, but had also 45 s of thinking time after each viewing.

After the third viewing, students were asked to type in their solution ideas for that trick using an online survey. In addition to providing an answer, they should check “I already knew the secret behind the trick” if they happened to know the trick and the corresponding solution before watching the video. In this case, answers were discarded and excluded from the analysis. In addition, the experimental group could check none, one or both of the statements “Thinking about the operational space helped me to find a solution.” and “Using the method of Smart Little People helped me to find a solution.”

4 Results

4.1 Coding of Solutions and Data Analysis

In the experimental group, the answers of three participants had to be excluded. One of them completed the electronic form before all tricks even have been shown, another one turned out to be unable to describe the solution in readable German or English language. A third person had to be excluded for mixing up the order of the tricks (i. e. giving the solution for trick 5 at form 6, etc.) which made it impossible to assign the empty solutions to the corresponding tricks.

Participants’ solutions were coded as correct (methods that the magician actually used or alternative methods verified as plausible) or incorrect (no solution, partial solutions, implausible methods, or impossible solutions with respect to the conditions seen in the video clip) by two independent raters. They used a coding manual that had been compiled with the help of the magician who performed the tricks in the video clips. The two-way random intraclass correlation coefficient (absolute agreement), ICC (2, 2) was 0.88 with a 95% confidence interval of [0.85;0.90] indicating a good level of agreement according to the conventions set out in [20]. Conflicting cases were resolved by a third rater. Data was analyzed using the IBM SPSS Statistics Software, Version 29.

4.2 Results

Using a two-sided t-test for independent samples, the main hypothesis that the TRIZ group would show better problem solving performance than the control group was tested. On average, participants in the TRIZ group had a higher solution rate ($M = 43.3$, $SD = 17.6$) than the control group ($M = 30.4$, $SD = 15.9$). This difference was significant, $t(39) = 2.43$, $p = 0.02$, representing a small effect size of Cohen’s $d = .17$.

Figure 1 shows mean solution rates, averaged across all 16 tricks, of the TRIZ group and the control group. The mean solution rate from a previous, unrelated study (published in [12] using the same 16 tricks, without any hints) is also shown for comparison. This dataset is available at the open repository PsychArchives [13].

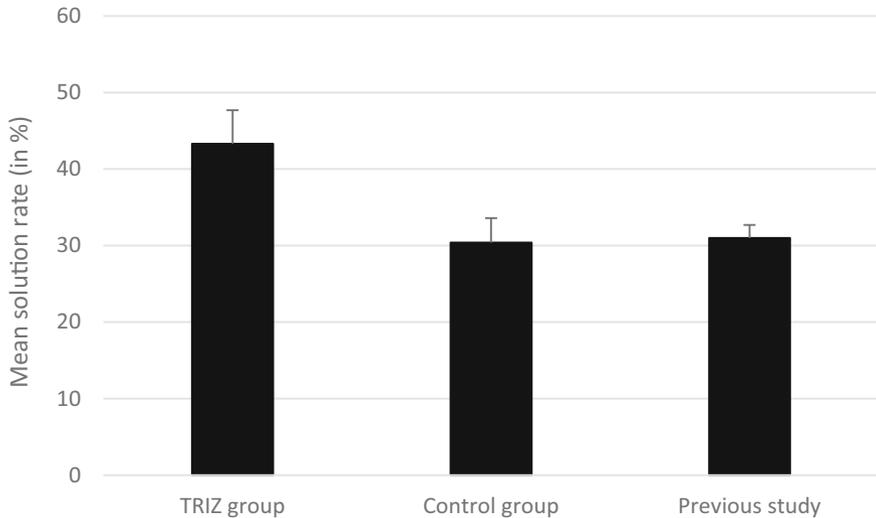


Fig. 1. Mean solution rate (in %) for the two groups of the present study (TRIZ and controls), together with a comparison group from a previous study ($n = 70$). Error bars denote standard error of the mean.

5 Discussion

The present study demonstrated beneficial effects of a short, non-specific training intervention on solving a set of 16 different problems. On average, the TRIZ group solved 13% more magic tricks than the control group. One interpretation of this finding is that the trained TRIZ techniques helped problem solvers to overcome self-imposed constraints that prevented a solution, and to set up a new, restructured problem representation which included a possible solution. While the underlying restructuring process was not directly measured, it seems likely that it was triggered by thinking about the TRIZ concepts. This work therefore represents a successful implementation of a non-specific training that facilitated restructuring across different problems.

Altogether, 243 answers (including empty ones) had been collected in the experimental group. In those answers, participants mentioned 94 times that thinking about the operational space was helpful and 31 times that the Smart Little People method was helpful. It has to be noted that the above numbers cannot be used to conclude that the operational space was more helpful than the Smart Little People method; the reason for referring to the operational space more often could simply be that it was provided as the first hint. An interesting observation was that the largest difference between the results of the experimental group and the results of the control group was found for a trick where an object apparently changes but actually only a cover at the surface of the object is removed. This is a good example for the value of thinking about the operational space: *Where* does the transformation take place? At the surface of the object!

A possible limitation could be differences in background between the experimental group (mainly computer science students) and the control group (psychology students). Therefore, it is desirable to repeat the experiment with participants from the same field

of study. In addition, it will be interesting to include more TRIZ concepts (such as separation principles) into the experiments.

A conclusion from the present experiment is that a group discussion on problem solving can benefit from a short intervention, for example on the basic concept of operational space (a fact that should already be intuitively well-known to many TRIZ trainers).

An interesting side-result of our work is that teaching about selected (and easy-to-understand) ideas of TRIZ in no more than 10 min already leads to remarkable results. Such “low-hanging fruits” could help to convince skeptics of the usefulness of TRIZ education, even if such a short introduction cannot be regarded as a replacement for rigorous TRIZ training.

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Bringing Back a Source–TRIZ in Social Science

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Abstract. Dialectic played an important role in the transformation of TRIZ as a problem and as a methodological aim. It is argued that this source can be fruitful for the field of social sciences. As a systematic and theoretical topic, TRIZ offers new impulses for further research and for the development of teaching. We will demonstrate that TRIZ in social science can not only serve purposes of social science, but also help to create a different understanding of the role of the social scientist. This new role offers new perspectives for further development in science, but also for project work of a digitally enhanced market economy. The development of AI requires a systematic design and a methodical survey of the requirements of its respective target group. Bringing back a source of TRIZ means remembering the possibilities of dialectic in theory and practice.

Keywords: Dialectic · Infradisciplinarity · Human-Machine-Interaction · Methodological Pluralism · User-centered Design

1 Introduction

In view of the complex development processes, systematic innovation approaches are becoming indispensable. The role of AI as a key technology in this area is undisputed. It is often overlooked that very different types of artificial intelligence are used depending on the task. And they all differ in their architecture, in their adaptation to their environment and its requirements. For example, chatbots, facial recognition systems, search engines and driving assistants are used.

Accordingly, not only ethical issues are of interest to developers, but also the understanding and design of human-machine interaction, which focuses on the user both as consumer and producer [1, 15]. To include such a prosumer as much as possible, understanding and implementation processes are therefore systematically interwoven and require the identification of risks and the subsequent management of practical adaptation.

Interdisciplinarity becomes both a theoretical prerequisite for context setting and a practical basis for project development. Both theories and methods of the social sciences and humanities increasingly play a role, as tools and as new methodological perspectives on the processes themselves.

Model development and adaptation is no longer important only for scientists, but the developer and programmer are also dependent on such representations and simulations. The complex design of the knowledge base as well as the sociologically based construction of the user-centered designs are crucial.

Methods are used and are the basic prerequisite to make the connections visible. The sociological framework is both the site of emergence and the arena of systematic innovation. Humanities and more over social science are interesting for methods and procedures. However, this new role in contemporary social science has gone rather unnoticed or even still trapped in its self-imposed methodological restrictions.

In this paper, we will first address the phenomenon of socio-technological complexity in Sect. 2, which is fundamental for the methodological approach and the development of new applications. This leads to the main problems that will be discussed in Sect. 3.

Complex systematic contexts are usually themselves subjected to argumentative analysis, and in the process the contradictions that are so crucial to the contexts are ignored as method. Yet such strategies have not been unknown in the past. The connection between contextual model development and comprehensive contradiction analysis can already be found in Altshullers work and has been tested and applied as TRIZ in many fields as we will show in Sect. 4. The aim of this study is to make TRIZ fruitful for the field of social sciences by having social scientists themselves reflect on their own methodological foundations. Therefore, we are looking closely on the historical development of dialectic as contradiction method, which is not linear in the sense of argumentation. Social science for that reason is the focus of this paper which does not mean that humanities cannot benefit from these experiences.

Furthermore, the social scientists themselves should participate in the development process to not only analyze, but to actively shape the development process with the help of the complex methodology and in anticipation of various user requirements.

As we will demonstrate in Sect. 5, there are various fields of application for this complex methodology. For example, in teaching, in research and in the formation of a sustainable reflexive awareness of the context of one's own methodological approach.

In these areas, the various insights of TRIZ into dialectics are shaped differently according to the respective objects and circumstances, yet they are united by non-linearity with comprehensive contextualization of contradictions. Following this insight, in Sect. 6 we will look ahead to what is feasible in the exploitation of these approaches beyond academia and outline opportunities that can be crucial for today's digitization and the responsible development of smart AI applications.

Dialectic consequently serves as a motor, method and foundation. While our consideration remains a speculative discussion of the possibilities, it nevertheless demonstrates both the existing conditions and the different facets to make contradictions methodologically fruitful in a comprehensive contextualization. Remembering TRIZ's own theoretical basis of development is thus not solely a topic for the social sciences, but itself a comprehensive utilization of social science procedures, insights and ultimately an attitude in a social development that impresses both by its complexity and its speed.

2 Socio-Technological Complexity

Technological developments are embedded in a socio-technological framework. Accordingly, the interdisciplinary composition of development teams is a natural prerequisite.

This also means that the observer and actor perspectives are mixed. The complexity of the environment and the actors lead on the one hand to an interweaving of theories as well as perspectives. On the other hand, linkages are also a personal concern of the actors, because their theoretical description as well as representation of the subject matter is itself part of the process in which the actors cooperatively participate. Today's development of technology and its socio-economic conjunctions point to a more complex context: the socio-technological frame is the basic condition and place of the changes that keep the world in suspense.

Against this background, the legitimate question of who can meet these challenges becomes complex itself and refers to the complexity of socio-technological development.

Even today, technical applications are by no means the simple implementation of a black-box solution but require comprehensive project management as well as the intensive elaboration of user demands. Project managers are already dependent on participant observation and a mixed-method approach to combine customer wishes and applicability into a satisfactory application. Social scientists play an increasingly important role in such a collaboration both with respect to their profound professional training and their methodological knowledge, which is of interest for practice recognition as well as design. The prosumer, as consumer and producer, will not be found alone in the intended target group; rather, developers in today's interdisciplinary teams are relied upon to contribute their methodological experience and to be involved as a potential target group. Thus, the analysis of ongoing development as process is a theoretical and practical problem that poses new challenges, especially for the social sciences.

Accordingly, the focus of the present paper is twofold. On the one hand, TRIZ is of interest as an extension and inspiration for social science methodology and reasoning itself. TRIZ presents a long lasting and methodical possibility to meet these complex demands of socio-technological development in the social sciences themselves. On the other hand, it is of interest how such a trained social scientist can work in heterogeneous development teams and make the complexity of the socio-technical development manageable there. Her knowledge of methods, her involvement as an actress in development, and her view of the contexts and conditions of possibility of such processes make the social scientist, as well as her methods themselves, the object of interest in being able to responsibly design sustainable human-machine interaction. The methods themselves thus become the central object for the skilled person.

3 Problem: Argumentation and Contradictions

Analysis of basic conditions and requirements has become an elementary task of project design in the field of modern applications of the socio-technological framework. Analyses themselves are accordingly both the basis and representing determinations of the needs of the architecture and the possible customer of an application. Nowadays it appears as normality that customer requirements, but also technical possibilities are

more and more aligned during the concretization of a project. Remarkably, social science standards and considerations are exported and made fruitful, but unfortunately mostly without a reflection on the conditions of the social science perspective itself.

The analysis of the social sciences is itself a problem that is almost blind to the challenges and possible applications of the complexity of its objects. One does indeed develop a critical attitude and sensitivity towards the problems of the use of terms and the transition from adaptation to practical action. But the problem of argumentative leadership itself is rarely considered.

Social science methods, for all their critical awareness of the problems of definitions, axioms and basic concepts, are basically built up argumentatively linear. This leads, on the one hand, to the typical sequence of stages as a representation of development in the social sciences and, on the other hand, to the content-poor trap of brainstorming in the context of the practical application of methods in the field of direct project work. [15].

Analytical reasoning as a linear explanation and representation thus falls short in the social sciences, but also in its practical application to product development.[16] Contexts are addressed as a background assumption rather than being used seriously in theory. Contexts, in turn, are the condition and object of consideration as well as practical guideposts for the modification of social science methods. Linear argumentation and the non-interwoven adaptation of context form the core of the application of social science methods both in science and the market economy.

There is an internal contradiction: the context itself should come into play as a modeled representation and as a field of application but cannot be captured because of the linearity of the argumentation; the black box does not become a white box. The context as field of application and as modeled representation are not interwoven but are demanded to interact. Linearity keeps them separate and prevents the view of complexity. Real contradictions that would become visible in the interaction of need, environment and circumstances remain invisible in this representation. Internal contradictions are thus not identified and certainly do not become the theoretical building block or even fulcrum for getting a sustainable theory adaptation for iterative evaluation and development. Internal contradictions, however, are the driving forces for the development of the theory as well as a user-friendly application. Accordingly, the central problem is the underestimation of contradictions both in the methods of social science and in the application of these methods in practical projects outside the scientific enterprise. [13, 14].

The possibility to make contradictions useful as a method and as a frame of reference in problem solving is thus a requirement for the systematic evaluation of conditions as well as for the fruitfulness of sustainable as well as innovative solutions. The social scientist both as theorist and developer is challenged.

TRIZ provides both theoretical and practical experience of mediating sociological analysis of contradiction and innovative practice design as well as a theory-immanent basis on the problem of contradiction itself. The basis of the decades-long differentiation of the most diverse TRIZ tools, applications and utilizations in many fields is itself the problem of dialectics.

Bringing back a source of TRIZ now also means remembering a source of social science work itself: Dialectic is both contradiction analysis and the grasping of the laws of the genesis of contradictions, and thus itself a method as well as a frame of reference.

Dialectic implies non-linear contextualization and iterative influence on the conditions of one's own course of development.

This developmental movement, which is more than an argumentative sequence of steps, deals with the most general laws of movement and at the same time participates in them by taking the internal contradictions seriously. [2].

Dialectic is a controversial topic in the social sciences and humanities because, on the one hand, it is limited to an understanding of method as the linear negativity of thesis and, on the other hand, it is supposed to be a political point of view. The humanities may have lost access to this methodological possibility, but experiences can be gained from areas beyond academic discourse.

From the very beginning, TRIZ moves beyond formal-logical conceptualizations and linear-argumentative descriptions. The agent is part of the contextual contradictions and their historical formation.

4 Dialectic in Research and Teaching: The Experience of the Theoretical Foundation of TRIZ

Bringing back the source of TRIZ; namely its dialectical foundation leads back to the historical genesis of this undertaking due to the contextual intertwining in the theoretical, but also institutional sense. Dialectic itself was and is a term that, because of its historical use, provokes categories that complicate its scientific use. One may say without hesitation that the term itself mutated into a means of struggle as well as an arena of confrontation and thus always accompanied the historical genesis of TRIZ.

Dialectic thus has a contradictory history and development itself. In Plato it was still a form of dialogical argument, [3] it shifts to the syllogistic trope utilization in the Middle Ages [4] and culminates at the beginning of modern times to the interplay of invention and judgment. [5] In all this time, dialectic as a method is context independent. The context is integrated at the latest by Hegel, in whom dialectic appears as a method and consideration of the movement of the concept itself. [6].

The situation changes again in the 19th century and dialectic is transfigured on the one hand to the linear sequence of thesis-antithesis and synthesis [7] and on the other hand declared to be the expression of the most general laws of motion of nature. [8].

The connection of method and context makes this enterprise increasingly a political undertaking and culminates at the latest with Stalin's work in a naturalized conception of a general conception of laws of motion. This should purely naturally, without any historical prescription, linearly open the view to the future. [9] Just this deterministic narrowness of a possible connection of method and context became after the Stalinist times a methodological and theoretical problem for the scientists of the Eastern Bloc and the basis for the development of TRIZ. Agents reminded themselves of the sociological source of their own doing.

- a. Already in the discussions of the Moscow Methodological Circle in the 1950s, the narrowness of formal logic and its linear argumentation become the basis of the argument. [10] It is recognized that dialectic must integrate the context and at the same time act on it, to have a dialectic that is not subject to the Stalinist traps. Dialectic is liberated from deterministic limitations as a method and contextualization of opposites,

of negations, and of the transformation of quantity into quality. It is understood that innovation and systemic consideration of contexts interact dialectically and escape any linearity.

- b. Altshuller will dock here and develop TRIZ as a dialectical work and methodological program. His insights follow the discussions in Moscow. One of the practical influences of these philosophical concepts was the declaration that invention itself can be an exact science that can meet the methodological requirements of natural science. In a dialectical and thus systematic way, methodology and the frame of reference are linked and contradictions themselves become the decisive factor. These appear as objects, target object and motor for the process. [11] Through contextualization by comprehensive patent evaluation, innovative research is, as it were, placed on the real ground of development and drawn into a systematic as well as dialectical connection of consideration and participation. [ibid. p. 30–35] The minimal machine is a tool, a target and an engine. The social scientist as inventor is both methodological worker and contextualized innovator.
- c. This approach received a completely new dimension through its institutional version in the GDR and the attempt to create inventor schools which combine construction and TRIZ directly. Altshuller's approach of a systematic-dialectical linking of method and context by emphasizing the role of contradictions found here a further theoretical development as well as a practical application to innovation processes. On the one hand, one tried to understand the fundamental problems of dialectic better and more comprehensively; contradictions themselves become the expression and the realization of the most general laws of the movement in an understandable as well as provable context. [13] On the other hand, one makes these scientific considerations immediately applicable to practice, thus changing the theoretical content at the same time. Innovations of the contradiction methodology are directly linked to real problems by institutionalization in inventor schools and thus transformed. [14] One recognizes that the social scientist is both an inventor in methodological, academic terms but also an innovator in practical terms through the comprehensive connection to the socio-technological environment. Innovation for science and for society go hand in hand here through the systematic use of contradictions as laws, trends and strategies.

Thus, for all three directions of TRIZ development, firstly, the emphasis on dialectic as source beyond argumentative linear constraints is crucial. Method and context as the ingredients of a comprehensive analysis of contradictions form the methodological core for the social scientist. And secondly, the social scientist as inventor of sustainable strategies in practice himself becomes the object of study of this systematic form of innovation. She herself becomes a developer as part of an interdisciplinary team. Accordingly, here she is always moving beyond a strict separation of natural sciences and social sciences, of theory and practice, of hard facts and soft presentation of analysis.[12].

TRIZ has always cultivated this heritage and produced applications and adaptations of the concerns in decades of experience for many fields.[13] Nevertheless, the emphasis on application and the concentration on the practical work of developers, engineers and programmers led to a forgetting of the actual sources, so to speak.

TRIZ has neglected the moment of further development of its own dialectical source in the social sciences and thus of the development of the social scientist as developer. Bringing back this source does not only mean to become clear about the role of dialectic in the historical genesis or to rethink the methodological basis, but to make TRIZ fruitful again for the social sciences in this complex sense.

5 Teaching, Research and Self-awareness

The identification and implementation of laws, trends and strategies are a contextual as well as contradictory matter, which poses new challenges to the social scientist both within academia and in the market economy. The experience of TRIZ thus leads to two different fields and, accordingly, to two different tasks. TRIZ in the social sciences means, on the one hand, the transformation of teaching and research in social sciences. On the other hand, it means to understand the self-perception as well as the activity of the social scientist differently.

In teaching and research these two fields are crucial, where dialectical methodology as well as contextualized analysis are intertwined. The social scientist must deal with requirements of the method as well as its fields of application.

In teaching social sciences, therefore, four possibilities arise for implementing the experience of TRIZ:

- a. Simple rational argumentation is a limitation, which can be improved by reference to contextual entanglements. Besides philosophy of science and logic, an awareness of the genesis of dialectic and its methodological content can broaden the perspective. It requires us to return to this scientific source beyond ideological overload.
- b. Systems theories and systemic contextualization are now part of the curriculum in the social sciences. However, the same linearity errors as in the step sequences of argumentation are repeated too often. Here, the genesis of systems theory and its contradictory content links can produce another view. TRIZ as experience and toolbox opens the view on applications as a regulator for theory building.
- c. Interdisciplinarity is indispensable for both the foundations of social science teaching, science-theoretical training, and application-oriented model building. Nevertheless, here it does not simply mean the union of different disciplines, but the common conceptual work on the subject matter. Infradisciplinarity is a skill that brings together different disciplinary perspectives through the cooperative work of the concept on the problem. Methods, contexts and contradictions become the new cornerstone of social science education through cooperative interaction.
- d. Modeling and simulation are both tools and research subjects for all three fields of science education. The future of social science will have to include more and more the possibilities of visualization, narration as well as the projection of strategies in education. Here, TRIZ is a model and a resource for experience.

Overall, teaching in the social sciences needs a stronger focus on the connection between method and context, which could be accomplished through the problem of contradiction and its attempts at commissioning through TRIZ. For research, on the other hand, two new possibilities arise, namely in the design of the research itself and

in the popularization of this enterprise. Research can be focused on two areas and so taking the new requirements seriously:

- a. Connecting innovations and strategies requires more spaces in which the individual disciplines can exchange ideas with each other. To achieve this, it is not enough to redesign teaching; institutional integration into the disciplines is needed.
- b. Accordingly, research collaborations are the next logical step and the future field of scientific cooperation. But here, simple interdisciplinarity is not very conducive, because the same problems of conceptual work of teaching take effect here, too. What is needed is living infradisciplinarity, i.e., joint work on the objects and the concepts used, even across disciplinary boundaries; application-specific conceptual work becomes a factor for the future of science.

However, these new opportunities for research are only one part of the shaping of this activity. At the same time, popularization is increasingly taking place, also in two areas:

- a. With the changes in teaching and research also the presentation of the results becomes crucial. This is by no means limited to a target group, but we must also consider these recipients as the social context. Against the background of today's inconsistencies in the socio-technological framework, it becomes even more important when presenting facts and results to put them into a critical appraisal at the same time.

The identification of laws, trends and strategies and their implementation in practical application must consider the contradictions of science itself as well as the objections against it.

- b. Policy advice and policy processing thus become a mutual requirement that the scientist must consider in teaching and research. Neither a simple projection of possible development stages nor a simple simulation of possible trends can suffice. Contradictions accordingly become the political concern of one's own scientific strategy.

All in all, against this background, research and teaching must be understood as an iterative coordination process of social reality and must have a lasting effect on the self-image of science. TRIZ in the social sciences becomes an activation of potential in civil society.

In addition, the role of the social scientist itself is tangentially affected and changed. The application of innovative methodologies in social sciences is not simply the change of teaching and research, but the opening of the role of the social scientist to be understood in a new way also outside of science.

The real work of projective as well as digital development in the socio-technological framework already clearly indicates this new connection. Every innovative application in the market economy today already needs the involvement of the user as well as the extraction of her needs in the creation of the architecture as well as the design. Increasingly, methods are being used that come from the social sciences.

The application of TRIZ experience in the social sciences improves teaching, research and the popularization of the social scientist, while developing a new profession for the market economy.

The social scientist can work in the development triangle of project work by firstly understanding and coordinating the cooperation of development team and end-user. Secondly, by methodically mediating between end-users and hardware as well as software development by identifying their conflicting requirements. And third, by bringing the development team and the product together in an enlightening way in design as well as in sales.

TRIZ thus becomes a guide for model building but also a model for the sustainable development of innovative approaches. The dialectical contradiction method becomes the subject, methodology and guidance of the social scientist as a skilled worker.

6 Projects and Projections

To study systematic innovation and to use these studies are thus of great interest for science, for the scientist but also for the market economy in a complex world as outlined in Sect. 2 and 3. The search for a source, such as dialectics in TRIZ, as we demonstrated in Sect. 4, is at the same time a search for design possibilities in academia, the changing economy and an increasingly demanding society. Projections of science and projects of business are not of a contradictory nature, rather they share the same contradictory intertwining of real processes, as we showed in Sect. 5.

Dialectic as a contradiction methodology and analysis is accordingly for teaching and research a possibility of sustainable participation as well as for the market economy to establish a new training strand. Systematic innovation today needs the ethicist and social scientist not only for the development of new smart products, but also for the scientific organization as well as for professional and content-related training. Beyond classical moral requirements, the scientist will be able to refer to the analysis and exploitation of contradictions for the challenges of the changes in the socio-technological framework and especially for the socially formative development of artificial intelligence.

Dialectical analysis is not the argumentative recommendation of step-like moral taxonomies, but the identification and possible pointing out of solutions that have long existed in real practice. Bringing back this dialectical source is thus recalling the linkages that accompany our social life and enable the design of new forms of coexistence. Innovation through artificial intelligence can be elevated to a new sustainable and responsible level through innovation in the social sciences and the humanities.

Bringing back the source of TRIZ is bringing back the social complexity for science and development.

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WTSP Report (6) Catalogs of TRIZ and Around-TRIZ Sites in the World (Preparing for Gamma Edition)

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Abstract. This is the sixth annual report of WTSP (World TRIZ-related Sites Project). We have already built the World Catalogs of Around-TRIZ (i.e., Creative Problem-Solving Methods in general around TRIZ) Websites (with 419 sites) by September 2022. But the World Catalogs of TRIZ Websites was made with only 62 Websites at that time, due to the lack of voluntary cooperation in many countries. Our difficulty is: “Many TRIZ colleagues support the WTSP Project, but very few of them actually work to build the World WTSP Catalogs”. The obvious reason is: “The talented people in TRIZ are always too busy in their business to do extra voluntary work”. In order to overcome the difficulties, we have made many different efforts to clarify our visions, build framework structures, show examples, send letters, publish results, etc. for 5 years and this year 2023. We now understand that the core of the hidden reasons is: “People do not yet recognize the (possible) Values (“Useful and Attractive”) of the World WTSP Catalogs because they have not yet really seen the Catalogs”. Therefore the present paper is dedicated to “explain the possible Values by showing the structures and examples and to convince people that we, the TRIZ experts in different countries, should create the Values and that such a Value creation is achievable with the procedure already demonstrated”. The paper summarizes the actual/targeted situations in 58 countries around the world for the preparation of the Gamma Edition of the World WTSP Catalogs.

Keywords: WTSP Project · World Catalogs of TRIZ Sites · World Catalogs of Around-TRIZ Sites · International Cooperation · Possible Values of WTSP Catalogs

1 Introduction

This is the Sixth Annual Report of **WTSP (World TRIZ-related Sites Project)**, which aims to build a system of Catalogs of Websites in TRIZ and related methodologies worldwide [1]. The Project is established and operated on a volunteer basis with the support of the global TRIZ community, and under the “TRIZ Home Page in Japan” Website [2] the WTSP website [3] is operated by Toru Nakagawa (the WTSP Project Leader).

In this Introduction section, we describe our Vision/Aims and Goals/Requirements and then clarify expected Values and how to create them. Understanding the Values of World WTSP Catalogs is the key to overcoming the difficulties of our project, as written in the Abstract.

1.1 Vision of the WTSP Project [1, 4]

In today’s world of highly advanced technologies and complex social systems, we humans and society are faced with numerous difficult problems, and we are struggling to solve them with some philosophy, strategies, methods, information, social/physical resources, and so on.

Here we focus on **Creative Problem-Solving Methods in general**. We particularly deal with the methods of **TRIZ (Theory of Inventive Problem Solving)** because of its deep concepts of systems, contradiction solving, practices of information handling, broad application results, etc.

In order to understand and apply such methods, we would like to have some reliable and systematized information resources. With any keyword, we can easily have a flood of information from fragments of webpages. Unfortunately, however, such information is messy and noisy, a mixture of good and poor, and unreliable.

Our Vision of WTSP is: “To build a system of reliable information resources on a global scale in the field of TRIZ and creative problem-solving methods in general. It should be open to the public, easy to understand, covering various aspects, scalable for expansion, and kept up to date.” [1].

To achieve this vision, we have made several basic decisions:

Websites as the unit of the information resource: Ordinary units can be papers, articles, webpages, patents, etc.; they are a record at one time (usually not updated), relatively small, and published in different places (need grouping later to fully understand). Books are good units of information, but readers have to buy them separately. Journals, conference proceedings, institutional/national repositories, etc. are much larger and often reliable, but they list many smaller documents without enough categorization. Websites often represent the thoughts and activities of a group of people, made available to the public in an easily understandable and systematized way, kept up to date over several years/decades, in their own quality.

Catalogs of Websites: Catalogs are not simple lists, but selected good items (i.e., Websites) are shown with brief/detailed explanations and categorization. This means we make special efforts to make the content reliable and useful.

Two pillars of Catalogs: Catalogs of TRIZ websites and Around-TRIZ Websites (covering Creative Problem-Solving Methods in general). We believe that TRIZ is one

of the most important methodologies for creative problem solving and that TRIZ people should learn other methodologies and people of other methodologies should learn TRIZ as well.

World Catalogs and Country Catalogs: Our basic strategy is to make Country Catalogs in each country and to integrate their world-worthy Websites into the World Catalogs; in fact, only a few countries have made their Country Catalogs and we have made the World Catalogs rather directly.

WTSP Website as a system to show: The system of the Catalogs is published on the WTSP Website, free of charge. The Catalogs can be used interactively on the WTSP Website [3], and can also be downloaded and used/printed on users' PCs.

1.2 Goals and Requirements of the World WTSP Catalogs [4]

Our **Goals** for the WTSP Catalogs are set in accordance with the Vision:

“To create Catalogs of selected Websites in the World in the field of TRIZ and related Creative Problem-Solving Methods. It should be published in the form of a Website, open to the public, free of charge, easy to understand, covering various aspects, scalable for building, and kept up to date”.

Three Basic Requirements for (Any) Catalog (from the user's point of view) are as follows, as we have found in this project:

- Req. 1: Collect good items (i.e. Websites) broadly, select them with evaluation, and show them in categories.
- Req. 2: Individual items should be introduced in a proper/fair manner, briefly or closely, and guide the readers/users to good items.
- Req. 3: It should be easy for users to find one or more items within the Catalog that meet their current interests/needs.

Our WTSP Project has been working to meet these basic requirements, as shown in Sects. 2 and 3.

1.3 Expected Values of the WTSP Catalogs [4, 5]

We now clarify the expected values of the WTSP Catalogs (especially of TRIZ Websites) from the point of view of different stakeholders:

For Site Owners: Individual website owners are given the opportunity to introduce their websites concisely, in a standard format, and also fully in a free format. They are encouraged to write a full introduction of their Website in free format, using illustrations/tables/etc. on 2 to 20+ A4 pages. The introductions should be highly valued by other TRIZ experts and Attractive to many TRIZ people.

For TRIZ leaders/experts/practitioners: The Catalogs provide an overview of the entire range of TRIZ-related Websites in the world. These people can quickly look for good and new websites, understand the development/progress of TRIZ and Around-TRIZ, and study new approaches and methods through the websites and their references.

For TRIZ practitioners/users/learners: The Catalogs are a useful source of information about good websites and their contents for learning/studying TRIZ and Around-TRIZ. We notice that these people are initially interested in websites that are easy to learn and apply TRIZ methods, that are written in their own language, and that are active in their own country. Later, some advanced practitioners/users go on to read/use simple but excellent websites in the World WTSP Catalogs.

1.4 Who and How to Create the Values of the Catalogs? [4, 5]

Who? – The answer is clear: Individual Website Owners, and collectively TRIZ leaders/experts/practitioners (including most Website Owners). Individual Website Owners contribute to the Value of the Catalogs by presenting their websites which attract many readers/users/professionals. Groups of TRIZ leaders/experts/practitioners contribute to the values of the WTSP Catalogs by collecting website introductions from site owners and editing manuscripts of (country) parts of World Catalogs that contain selected websites in a categorized manner. The usefulness of World Catalogs comes from the coverage, selection, and arrangement of presentations of good websites. A fair and unbiased selection of websites is the most important Value of the World Catalogs to be developed by the global TRIZ community.

How? – Ideally, by global cooperation of (almost) all the TRIZ leaders/experts/practitioners including the site owners. In practice, cooperation of such people in each of different countries may be a good basis.

If we notice the initial behavior of TRIZ practitioners/users/learners, we should prepare Country Catalogs of TRIZ Websites, where TRIZ is introduced from beginner to expert level in their own language, including translations from excellent global documents. We should also prepare the World WTSP Catalogs to include at least one Website from each country to reflect the approach/spread of TRIZ in that country.

1.5 Brief History of the Creation of the World WTSP Catalogs

- (Dec. 2017–2018) Nakagawa **proposed** WTSP as a volunteer-based international project, and 5 TRIZ leaders were invited as Global Co-editors. WTSP Catalogs in Japan were established as a pilot model. 80 members from 30 countries joined (or signed up to join) WTSP at TFC2018. [1]
- (2019) **Preliminary Edition** of World WTSP Catalogs was quickly built. TRIZ sites were cataloged with contributions from 4 countries and 2 internet surveys, while Around-TRIZ sites with the results of 5 cases of internet surveys. The difficulty of forming voluntary WTSP Teams in many countries became clear. [6]
- (2020) **Beta Edition** was published [4]: WTSP was presented online at 4 International Conferences (MATRIZ, ETRIA, AI, and ICSI) and a Japan conference.
- (2021) Nakagawa conducted Internet surveys of TRIZ-related sites in 52 countries individually [7, 8].
- (2022) Catalogs of Around-TRIZ sites were enhanced by refining the Internet survey results [9]. Catalogs of TRIZ Sites were made for UK and Germany by Nakagawa. [10, 11]

- (2023) Contributions to World TRIZ Sites Catalogs are intensively requested to the TRIZ community for the preparation of the Gamma Edition by Sept. 2023 [12], but the responses are currently slow.

2 Framework of the World WTSP Catalogs [4]

When we built the Beta Edition in October 2020 [4], the framework of the World WTSP Catalogs was essentially established, as shown in this Section.

2.1 Introduction and Evaluation of Individual Websites [13]

The basic items of our WTSP Catalogs are chosen to be Websites, as discussed in Sect. 1.1. Here we discuss how to collect, evaluate, present, and introduce them.

Scope: The term “**TRIZ**” is widely used throughout the world without much ambiguity; nevertheless, we should include keywords such as ТРИЗ, TIPS, Systematic Innovation, I-TRIZ, xTRIZ, MTRIZ, SIT (ASIT, USIT), Bio-TRIZ, etc. to cover many variations.

On the other hand, the broader fields of **Creative Problem-Solving Methods in general** include a large variety of methods developed by different groups of people in history and do not have proper/widely-used terms to cover the fields. Thus to search for Websites in the fields, we used several sets of internet surveys with keywords of general terms; such as Creative Thinking Method; Problem-Solving; Innovation; Quality/Value/Cost/Productivity Management; and Patent/IP. We use the term “**Around-TRIZ**” as the short form of “Creative Problem-Solving Methods in general”.

Domain: Websites of our interest usually have a single domain of URL with a large number of subfolders (subdomains) and Webpages. In other cases, they may be specific sub-sites of larger Websites of some institutions, or they may form a system of multiple domains with different roles (such as languages and territories).

Types/Roles: Corresponding to different activities related to TRIZ, we want to collect different types of TRIZ-related Websites; and we have found that the **Roles of Websites** (i.e., close to Roles of Website Owners) are important to categorize various Websites [13]. The Roles of sites are classified as (a) Information sending sites, (b) Promoter organizations, (c) Public organizations, (d) Academic organizations, (e) Developer organizations, (g) Information sharing, (h) User organizations, and (i) Personal. And they are further categorized on an ad hoc basis. Roles of a website are specified by a list of several subcategories of Roles (i.e., Main Role, and subsidiary Roles).

Evaluation Criteria: To include in the Catalogs, evaluation and selection of Websites are necessary. We set our multiple criteria for Website evaluation as follows:

- Quality (reliable, correct, novel, original, comprehensible, up-to-date,...)
- Usefulness (resourceful, reference, handy, practical, effective,...)
- Attractiveness (interesting, easy to understand, illustrative,...)
- Accessibility (open access, free/low cost, widely used,...)
- Scope (scope of the topic/field, scope of activities, comprehensive,...)

All these criteria are qualitative. Websites have their own strengths and weaknesses; we want our Websites to be especially good in some of these aspects, and reasonably good in others. We evaluate different Websites mostly on their strong aspects.

Grading: We grade the Websites in 5 levels by using the symbol marks such as:

- ◎: Most important (about top 30) in the World WTSP Catalogs
- : Important (about the next 100) in the World WTSP Catalogs
- : Worthy in the World WTSP Catalogs
- △: Worthy in the Country WTSP Catalogs
- : Unworthy or Irrelevant in the WTSP Catalogs

The grading of Websites is done separately for the TRIZ Sites Catalogs and for the Around-TRIZ Sites Catalogs. The grading of Websites (especially those of other (competing) experts) is delicate but necessary for practical reasons (Basic Requirement 1). We may show our ambiguity by using double marks (e.g., ○□ means ○ or □). Grades at the ◎ and ○ levels are (roughly) limited in number, and may only become clear after accumulating examples and comparing them with one another (but still qualitatively).

[Note: Many site owners do not like their sites to be evaluated by others, especially competitors. Many TRIZ leaders/professionals/editors hesitate to evaluate others' websites, for afraid of personal/organizational conflicts. However, evaluation is absolutely necessary for any Catalog. Even simple lists of websites are made after (implicit) evaluation. We have to overcome this mental barrier with our professional truth and with understanding of the Values of Catalogs created with good evaluation. To our relief, we do not try ranking but grading into 5 levels with criteria of multiple aspects weighing their positive sides. Site owners may propose their own site grade, and the editors may sometimes adjust the grade in comparison with many others. The grading is shown publicly and may be revised later. If a site owner wants to claim a higher grade, it may be a good idea for him/her to submit a full introduction (c) of the site to the Project.]

Basic Information for the Index: The following information about each Website is used and shown in the Index table of the WTSP Catalogs:

Site Code: Country/Survey Code + numbering to identify a Website.

Site Name: Typically, "Acronym (Full name)" or "Organization: Website name".

Site Domain URL: Multiple URLs may be displayed if necessary.

Site Location: The country where the Website organization's headquarter is located.

Site Language: Language(s) describing the Website.

Roles of Site: Show a few Site Roles with subcategories in order of importance.

Evaluation: Show the level of grading with 5 icons: ◎○□△—.

Single-line description: Short introduction in a line. Better omitted than long.

Remarks: Especially on the filename of the Full description (c).

Descriptions of Websites in the following 3 levels:

- (a) **Brief description:** Free format, 3 to 15 + lines, usually written by a surveyor/recommender, using excerpts from top pages and "About Us" pages, etc.
- (b) **Standard Form description:** One page in A4 tabular format, mandatory to be completed by the Website Owner. In addition to the Basic Information, answers on

the Application phase, Application fields, and Methods by choosing from preset categories. Free format introduction of the Website in about 5 to 10 lines.

- (c) **Full description:** Free format, 2 to 20+ pages in A4 in a separate file, optionally written by the Website Owner, encouraged to describe attractively by using illustrations, photos, tables, etc.; choose some suitable style/structure for the Type of Website.

2.2 Selection and Arrangement of Websites in the World WTSP Catalogs [14]

We have collected several hundred Websites for World TRIZ Sites Catalogs and also for World Around-TRIZ Sites Catalogs. Therefore, we decided to create the following 3 levels of World WTSP Catalogs, for TRIZ Sites as well as for Around-TRIZ Sites:

Top Catalog: Only the Most important sites (⊙).

Basic Catalog: Most important sites (⊙) and Important sites (○) together.

Extended Catalog: Worthy of World Catalogs sites (□) only.

In each World Catalog, all Websites are arranged in the order of their Main Roles. Thus the Websites are effectively classified by their Types and grades in each World Catalog, in order to make the Catalogs convenient for users and scalable for Catalog builders.

2.3 Structure of World WTSP Catalogs [4, 14]

The **source data** of a group of Websites is contributed to the World WTSP Catalog system by a Country team or a surveyor. Such a record consists of a pair of Index file and Site description file. Websites are arranged and specified in the Index file and have hyperlinks to access the corresponding site descriptions in the Site description file. The flexibility of the hyperlinks allows free rearrangement (and duplication) of the Websites in the Index file, without rearranging the Site descriptions.

The overall structure of the World WTSP Catalog system is shown in Fig. 1 from the user's point of view. On the top page of the World WTSP Catalog system, users see various indexes of Catalogs, such as source data Catalogs (of countries and surveys) and various forms of World WTSP Catalogs.

Each World WTSP Catalog has an Index file, which lists many Websites in a rearranged order and the hyperlink of each Website gives access to the corresponding site description stored in the source-data Site description file. The hyperlinks allow flexible rearrangement of Websites in different Indexes. This form of World Catalog can be used only interactively to browse the Website descriptions.

For the purpose of easy reading of the Websites in the World WTSP Catalogs, we have also prepared "**World WTSP Catalogs for Print**". Individual Site descriptions are copied from the source-data Site description files into the Site description part within "World WTSP Catalogs for Print" (in the rearranged order). Thus, "Print Type" World Catalogs can be printed easily in readable form and can be downloaded and used on users' PCs because the hyperlinks access the site descriptions stored in the same file.

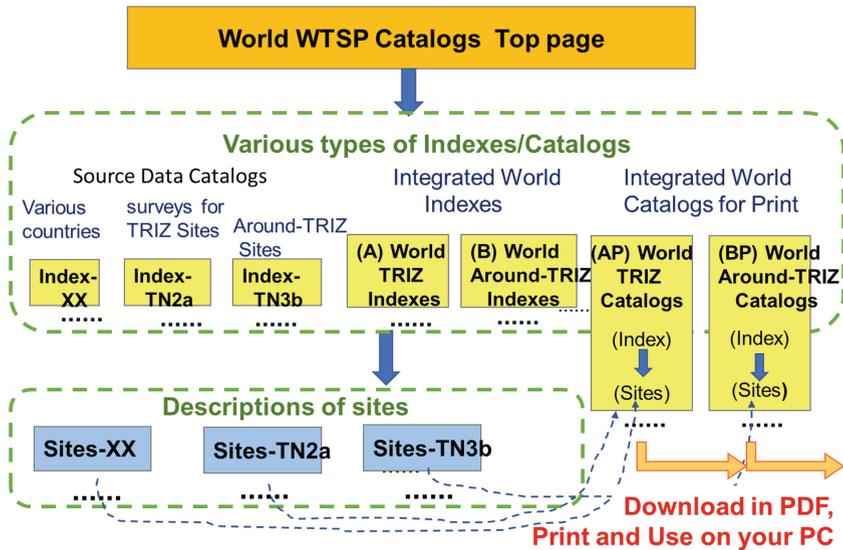


Fig. 1. Structure of the World WTSP Catalogs at the Top Page.

2.4 Building, Updating, and Using the World WTSP Catalogs [13]

The process of building the World WTSP Catalogs is also already established. Its outline is:

- In each country, list candidate Websites through recommendations and Internet surveys.
- Visit the Websites one by one to understand, briefly introduce, and even tentatively evaluate them.
- Ask the Website owners to present their own Website by filling out the WTSP Standard Website Description Form. And encourage them to take an optional advantage of attracting users and experts by writing full introductions to their Websites in free format in a separate file.
- Make a manuscript of your Country Part of the World WTSP Catalogs as a pair of Index file and Site Descriptions file. The manuscript is now submitted to the Project Leader.
- All the contributed data of Websites will be integrated into World WTSP Catalogs by rearranging the Websites according to their grading and categorization.

The first four steps can be cooperatively done by the voluntary WTSP Team and Website owners in each country, while the last step has to be done at WTSP Center (or Project Leader).

Various manuscripts at the intermediate stages shown above are stored separately on the back end of the system for further preparation. Updating the World WTSP Catalogs should be done incrementally or as an edition every 2 years, for example.

All World WTSP Catalogs are published on the WTSP Website (under the copyright of the WTSP Project), and can be used by anyone free of charge [3]. This is of significant value to many people, as discussed in Sect. 1.3.

3 The Current State (Beta Edition) of the World WTSP Catalogs [4, 9]

The Beta Edition of the World WTSP Catalogs was published in October 2020 [4] and fulfills the framework and structure described so far. Table 1 shows the number of Websites recorded in the World WTSP Catalogs as of Jul. 2022 [9].

Table 1. Number of Websites in the World WTSP Catalogs (Sept. 2022) [9].

(Main) Role of site	WTSP World Catalogs					
	(A) TRIZ Sites (2020)			(C) Around-TRIZ Sites (2022)		
	⊙ Most Important	○ Important	□ World Worthy	⊙ Most Important	○ Important	□ World Worthy
(a) Information sending sites	9	4		10	20	12
(b) Promotor organizations	5	4		3	8	6
(c) Public organizations	1	1		3	10	24
(d) Academia	0	0		2	17	33
(e) Developer organizations	5	8		5	37	84
-- (e5) Training organizations	2	7		0	9	19
(f) Publisshing organizations	0	6		5	17	13
(g) Information sharing	1	7		5	12	21
(h) User organizations	0	2		0	12	27
(i) Personal	0	0		0	0	5
(Total number of sites)	23	39		33	142	244

The Table shows the number of Websites for TRIZ (in the left columns) and for Around-TRIZ (in the right columns), classified into the grades (⊙, ○, □), and further classified into rows according to the Main Role of the Website.

3.1 TRIZ Websites in the World WTSP Catalogs

The data shown here for the TRIZ Websites are the same as in the Beta Edition (Nov. 2020) [4]. Four countries contributed their manuscripts of Country Catalogs: they are Japan (Toru Nakagawa), Malaysia (Eng Hoo Tan), China (Rung Hua Tan), and the Russian-Language region (Michael Orloff). Two cases of Internet surveys for TRIZ Websites written in English in the world and in the USA were contributed by Toru Nakagawa. Because of these limited source data, the World WTSP Catalogs of TRIZ Sites have only 23 ⊙ sites and 39 ○ sites. [15].

In spite of our appeals, voluntary WTSP activities have been inactive in many countries for these two years, resulting in too minor revisions in the World WTSP Catalogs to appear in Fig. 2.

3.2 Around-TRIZ Websites in the World WTSP Catalogs

In 2019, Toru Nakagawa conducted intensive Internet surveys for Around-TRIZ Websites. He detected about 1,000 websites and visited them one by one to build the second pillar (Around-TRIZ) of the World WTSP Catalogs at the © and ○ levels in Oct. 2020 [4, 16]. During Mar. - Jun. 2022, he visited all the Websites again, to revise the (Brief) introductions and evaluations of individual sites and to enhance the World WTSP Catalogs on the □ level [9]. Figure 2 shows the 30 © Websites in our Around-TRIZ World Catalog (including 10 © TRIZ Websites). [16].

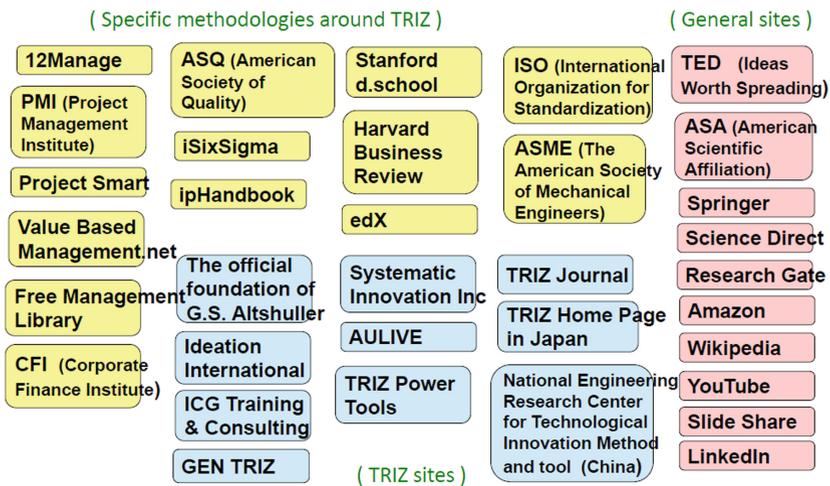


Fig. 2. Around-TRIZ Websites (©) in the World (Sept. 2022) [9].

As a result, the World WTSP Catalogs of Around-TRIZ Websites are quite well built, covering consistently (though limited in the English-language Websites) and having Brief introductions for all Websites (mostly written using excerpts from the target Websites). This strategy of building World WTSP Catalogs for Around-TRIZ Websites was chosen because we did not have strong partners in such broad and diversified fields of Creative Problem-Solving methods to ask for effective cooperation.

4 Recent WTSP Activities for Building the Gamma Edition of the World WTSP Catalogs

After having built the Around-TRIZ Websites Catalog (Sect. 3.2), we have decided to concentrate our efforts on enhancing the TRIZ Websites Catalogs (Sect. 3.1) to make their Gamma Edition by the time of ETRIA TFC2023.

4.1 Promotion of WTSP to Overcome the Inactive Cooperation

In order to overcome the difficulty in obtaining voluntary cooperation in the TRIZ community, we have made various promotion activities, besides the actual development of the Catalogs: [3].

- “Mission and Philosophy of the WTSP Project” was published(Aug. 2021);
- “Introduction to World WTSP Catalogs of TRIZ Sites and Around-TRIZ Sites” was published for the users (instead of the developers) (Jan. 2022) [17];
- Messages and reports of the WTSP were posted on LinkedIn more or less regularly every two weeks (Jan. 2022 – present).
- Papers and slides presented at ETRIA TFC2022 [9] and some other conferences were posted on the “TRIZ Home Page in Japan” (Oct. 2022).
- WTSP Communication Forum pages [18] were opened (Dec. 2022- present).
- [WTSP] Letters were sent to TRIZ leaders in Italy, France, Korea, Taiwan, etc. to help them coordinate WTSP Teams in such countries active in TRIZ (Dec. 2022).
- “Call for Contributions to the WTSP Catalogs of TRIZ Sites in the World (for Gamma Edition)” was published (Jan. 2023), and was sent individually to TRIZ colleagues in 30 countries asking for their cooperation (Feb.–Mar. 2023).[12]
- “Values of WTSP Catalogs for different TRIZ people: – And Who creates them” was published (Apr. 2023). [5]

4.2 Recent Activities to Enhance the World WTSP Catalogs of TRIZ Websites

As briefly reported at the TFC2022 [9], Nakagawa conducted **Internet surveys of TRIZ websites in 52 individual countries** (excluding the 6 countries already participating in the Beta Edition) (May-Nov. 2021) and detected 1200+ Websites in total. Figure 3 summarizes the current state of survey analysis of TRIZ Websites for all the 58 countries in the world.

Re	Country	Det.	☺	☹	☐	☐	☐	☐
A-Europe								
	Austria	26		4				
	Czech Repub	24		4	1			
	Denmark	14						
	Finland	21		4	1			
	Greece	8		1	1			
	Hungary	13			2			
	Iceland	11		1				
	Netherlands	33		2	3			
	Norway	4		1	1			
	Portugal	15	1	3				
	Romania	9		2	1			
	Spain	27		1	2	4		
	Switzerland	21		6				
C-MidEast								
	Iran	64		1	5			
	Israel	24		4				
	Turkey	27		4	5			
D-Asia								
	Bangladest	3						
	Hong Kong	16		1	4			
	India	45		3	2			
	Indonesia	37		3	5			
	Pakistan	11		1	1			
	Philippines	11						
	Singapore	15		1	2	2		
	Vietnam	24		1	6	3		
E-Oceania								
	New Zealar	7		2	1			
F - N America								
	Canada	30		1				
G- CS America								
	Argentina	10		1				
	Bolivia	6						
	Brazil	41		1	6	1		
	Chile	12		1				
	Colombia	19		1	1			
	Costa Rica	12		3				
	Mexico	23		4				
	Nicaragua	6						
	Peru	13		1	1			
	Uruguay	7		1				
H- Africa								
	Egypt	8		2				
	Kenya	6		2				
	Morocco	13		4	3			
	South Africa	9		3	3			
Country		Det.						
Belgium	22	Not yet						
France	55	Not yet						
Germany	68	See Table 3						
Italy	50	Not yet						
Poland	50	Not yet						
Sweden	19	Not yet						
UK	39	See Table 2						
Korea	72	Not yet						
Sri Lanka	6	Not yet						
Taiwan	45	Not yet						
Thailand	31	Not yet						
Australia	23	Not yet						
Russia	Already							
China	Already							
Japan	Already							
Malaysia	Already							
USA	Already							

Fig. 3. Current State of Survey for TRIZ Websites in the 58 Countries in the World.

Among them, **40 countries** (in the first 3 boxes in Fig. 3) were studied first. By visiting about 700+ websites one by one, he wrote Brief introductions (a) and evaluated

them provisionally. The numbers of Websites detected, and graded as \odot , \circ , \square , and \triangle (as TRIZ Websites) are listed in the table for each country (Nov. 2021). The analysis work met difficulties in many countries because of language barriers, even with the help of automatic translation by Google Translator or later by DeepL. These Websites, however, have not yet been integrated into the World TRIZ Sites Catalogs because their Roles have not yet been identified.

Analyses of the survey results for the 12 countries in the top right box in Fig. 3 were left undone for the time being. They include the countries active in TRIZ, such as UK, France, Italy, Germany, Taiwan, Korea, etc., where we can expect many good Websites in TRIZ. The survey analysis for such a country is obviously very difficult for any foreign surveyor, especially because many (more than half) of the Websites are written in their own non-English languages (except for UK). So we asked TRIZ leaders/colleagues in these countries for their proactive cooperation.

Lately, to demonstrate how to build the Country Part for such a country, Nakagawa worked to analyze the survey data of **UK** (Feb. 2022). The work was fruitful to find 5 \odot , 1 \circ , 8 \square , and 1 \triangle Websites for TRIZ, and 2 \odot , 3 \circ , 6 \square , and 3 \triangle Websites for Around-TRIZ. Then the results were combined with the data of Websites in UK already recorded in the Beta Edition of World WTSP Catalogs. Figure 4 lists the \odot and \circ Websites thus obtained in UK for TRIZ and Around-TRIZ. We are asking TRIZ leaders and experts in UK to review and revise the present manuscript.

TRIZ Sites

- \odot TJ (The TRIZ Journal)
- \odot Systematic Innovation Inc.
- \odot Oxford Creativity
- \odot CORE
- \circ IET (The Institution of Engineering and Technology)
- \circ Design Society
- \circ Southbeach Modeller
- \circ Science Direct
- \circ APM (Association for Project Management)

Around-TRIZ Sites

- \odot Project Smart
- \odot Managing Innovation (John Bessant)
- \odot My Mooc
- \odot Science Direct
- \circ Clarivate Analytics
- \circ Innovation Portal
- \circ Idea to Value (Edited by Nick Skillicorn)
- \circ IET (The Institution of Engineering & Technology)
- \circ MindTools
- \circ Southbeach Modeller
- \circ Solid Solutions
- \circ PatSnap
- \circ Minesoft
- \circ Emerald Publishing
- \circ IAM Media
- \circ Skills You Need
- \circ The University of Nottingham

Fig. 4. TRIZ and Around-TRIZ Websites in UK at the \odot and \circ levels.

Nakagawa next worked to analyze the survey data of **Germany**, struggling over a month with the help of DeepL. After checking with the data of Germany Websites recorded in the Beta Edition, we obtained the Germany Part of World WTSP Catalogs in Dec. 2022. It now contains 3 \odot , 6 \circ , 7 \square , and 3 \triangle TRIZ Sites and 2 \odot , 7 \circ , 18 \square , and 6 \triangle Around-TRIZ Sites. The \odot and \circ TRIZ sites are shown in Fig. 5.

In this survey work, he newly realized the real importance of Michael Orloff's Website and invited him to write a full introduction. The introduction of "DE-03 \odot Modern TRIZ Academy Website (Michael Orloff)" was published on the WTSP Website (Dec. 2022) [3] as an excellent example of a Website introduction.

- © **Modern TRIZ Academy (Michael Orloff)** (a1) Dedicated for information sending
- © **ETRIA (European TRIZ Association)** (b1) Dedicated association
- © **TriS Europe (Pavel Livotov)** (e1) Method developers
- **TRIZ.it! (Pavel Livotov)** (a1) Dedicated for information sending,
- **Springer** (f2) Publishers
- **Research Gate** (f3) Repository
- **Amazon.de** (f4) Book sellers, ==> Global (USA)
- **TriSolver (Pavel Livotov)** (e1) Method developers
- **Bionic Inspiration.org (Michael Sattler)** (i4) Personal Blog sites

Fig. 5. The © and ○ TRIZ Websites in Germany.

Then he started to work for Taiwan but had to stop in the middle realizing the heavy work due to the language barriers. We decided to rely on the voluntary cooperation of the TRIZ community in many countries around the world.

Thus, we issued a “**Call for Contributions** to the WTSP Catalogs of TRIZ Sites in the World” (Jan. 2023). The points are: To form a WTSP volunteer Team in each country, to contribute a manuscript of the Country Part of World WTSP Catalogs, and to submit site introductions written by the Site owners. We made a special promise that if Website owners write their site introductions both in the Standard Form (b) and a full introduction in free format (c), the introductions will be published additionally as independent pages on the WTSP Website. The Call for Contributions was sent to TRIZ leaders/colleagues in more than 30 countries individually and to some Website owners.

The current states of WTSP activities in important countries are summarized here:

South Korea: Min-Gyu Lee is working as the WTSP coordinator with the help of KTA (Korea TRIZ Association) and KOSCA, and has prepared the 0.7 Version of Korea Part of World WTSP Catalogs, which lists 27 Websites (©○□). He says that the Owners of these sites would not like to write their site introductions. He also found that there are only a few TRIZ Websites that show their TRIZ activities/methods/real applications, even though Korea is the world’s leading country in promoting/training/applying TRIZ in industry and academia. He notices that several big companies in Korea have achieved global success by introducing/promoting/training/applying TRIZ and they show their methods/applications/activities/etc. fully on their Intranet Websites, while not disclosing them to the public. Many consultants and academic experts support and cooperate with such companies, but are regulated in showing their TRIZ experiences openly.

Taiwan: Ming-Hung Sung (Feng Chia University) serves as the Country Editor, with the support of Daniel Sheu. When Sung visited the websites that were detected in Nakagawa’s survey, he found 9 of them are worthy in the World Catalogs. He wrote the introductions of the 9 sites in the Standard Form (b) for himself. We ask him to get feedback/revisions from the site owners. The manuscript of the Taiwan Part will be published in the near future, after combining Nakagawa’s notes.

France: Pascal Sire and Roland De Guio are joint Country Editors.

Italy: Matteo Spreafico is the Country Editor, with the help of Davide Russo.

Although we have not heard from these two countries recently, we assume that some preparation work is going on there.

Besides these countries, we have had some preparatory communications from Portugal, Spain, Belgium, Austria, Poland, Sweden, Israel, Thailand, Australia, Mexico, etc.

It is noteworthy that we have recently received **two Regional Editors**: Khaled Shoaib (Egypt) as Regional Editor for Middle East/North Africa (especially in the Arabic language) and Adehi Guehika (now in Canada) as Regional Editor for Africa (especially in English/French). We will be able to get new information about TRIZ in these regions.

We should mention here the 5 countries (shown in the right bottom box in Fig. 3) that have already made significant contributions to the Beta Edition [14].

Japan: As an early pilot project, Japan WTSP Catalogs were created (Mar. 2018) with 92 Websites. We have asked 30 + TRIZ colleagues (mostly organized in Japan TRIZ Society) to update and revise them, but so far no WTSP activities, to our pity.

Malaysia: Eng Hoo Tan sent us an update with 10 Websites.

China: We are asking Run Hua Tan, the Country Editor, to update the data completely to reflect the rapid development of their technologies and TRIZ, but have not yet received an answer.

Russian Language region (especially **Russia and Belarus**): In addition to the 37 Websites (Jul. 2019) included in the Beta Edition, Michael Orloff expanded the list (Aug. 2020) into 55 Websites (©○□), and Nikolay Shpakovsky added 8 more Websites (Aug. 2020); unfortunately these additional Websites are not yet integrated into the World WTSP Catalogs due to the lack of information about the Main Role of sites.

USA: The Beta Edition uses the results of the Internet survey (Jul. 2019). We are asking many TRIZ leaders/colleagues to form the WTSP Team of USA and update the data: but no positive reactions have been heard yet.

4.3 Tentative Status of the World WTSP Catalogs of TRIZ Websites

As written above, the World WTSP Catalogs of TRIZ Websites are in a tentative state waiting for manuscripts from many countries. The **TRIZ Websites at the © level** are tentatively shown in Fig. 6. Six websites marked with the star are newly included, but several more © websites are still missing, we suppose.

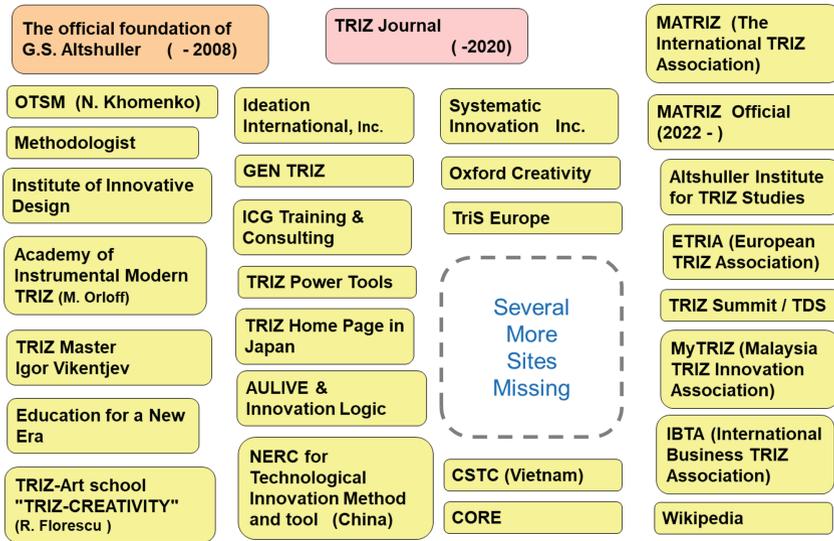


Fig. 6. TRIZ Websites (©) in the World WTSP Catalogs (tentative, Apr. 2023).

5 Concluding Remarks

5.1 Overcoming the Difficulties of Inactive Attitudes in the TRIZ Community

As written in the Abstract, our project encounters the difficulty that “Many TRIZ colleagues support the WTSP Project, but very few of them actually work for building the World WTSP Catalogs”. The obvious reason is that “the talented people in TRIZ are always too busy in their business to do extra voluntary work”. While struggling to solve the difficulty for about 5 years (Sects. 4.1–4.2), we now understand that the hidden core of the difficulty is: **“People do not yet recognize the (possible) Values (“Useful and Attractive”) of the World WTSP Catalogs, because they have not yet really seen the Catalogs”**. Therefore, the main purpose of the present paper is “to explain the possible Values (Sect. 1.3) by showing the structures and examples (Sect. 2–3)” and also “to convince people that we, TRIZ experts in various countries, should create the Values (Sect. 1.4) and that we can achieve the Value creation by following the procedure already demonstrated (Sects. 2.4, 3)”. See Note in Sect. 2.1.

5.2 Proposal of "Systematic Innovation Review" Website to Represent TRIZ

A simple but significant finding obtained through this project may be seen in Fig. 4. That is “Although we have many (hundreds of) good Websites in TRIZ, there is **no Website that can represent the whole field of TRIZ**”. This becomes clear when we see that “The Official Altshuller Foundation” Website has not been updated since 2008 and “The TRIZ Journal” has not been updated since 2020. Many Websites are run independently/competitively with different methods and approaches in TRIZ. The situation

is even more diversified/confusing in the broader field of Creative Problem-Solving Methods in general.

In Sept. 2022 we, the Global Co-editors of the WTSP Project, started to propose to “**Establish a New Website Representative in TRIZ**” [19]. We tentatively named it “Systematic Innovation Review” (or “SI-Review” in short) Website, with the intention to cover the broader fields of Creative Problem-Solving Methods in general in the future.

In order to be “Representative”, SI-Review will not try to compete with many other good websites/journals in publishing new original works, but rather to be compatible and yet outstanding with them by publishing new (or already established) overview/review works. It will accept different works of different methods/approaches in TRIZ in the broader sense (and Around-TRIZ). It should be run by an editorial board of 5 or more international and interdisciplinary editors. The SI-Review will publish several types/aspects of work, such as (overview) papers on methods, applications, promotional activities, standard texts, introductions, texts for children, etc. It should have a pool of candidate topics/documents recommended by many editorial advisors. It will regularly publish several papers every month, and keep them as an archive in a well-categorized and easily accessible way.

In a sense, SI-Review is similar to the World WTSP Catalogs, whose excellent websites are presented by turn in several lecture series; because the accumulated articles on a Website often resemble an overview of original papers focused on a topic. The (possible) Values of the SI-Review Website are almost the same as those of the World WTSP Catalogs (Sect. 1.3). How to get Editorial Board members, how to run the Website effectively, how to run it financially, etc. need to be solved in practice.

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TRIZ and Chaos: First Principles for Emergency First Responders

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Abstract. ‘Someone somewhere already solved your problem’ is a commonly used TRIZ heuristic. It is often complemented with a recognition that the ‘someone’ will be the person or industry that has had a more extreme version of your problem. Thus, when it comes to dealing with chaotic situations, it is to people that are forced to deal with chaos as an everyday part of their work that we might best turn to in order to establish what works and what doesn’t. This search is particularly problematic in that, during a chaotic event, oftentimes there is little or no connection between causes and effects and hence traditional situation awareness tools and strategies – like root-cause analysis – are potentially counter-productive. Successful chaos-incorporating occupations include emergency first responders, fighter pilots and, in a whole different dimension of danger, stock traders. Most visible of these, at least in terms of published success strategies is the OODA-loop work of USAF fighter pilot, John Boyd. Using the Observe-Orient-Decide-Act cycle as a start-point, the paper examines some of the benefits of incorporating TRIZ thinking into the cycle.

Keywords: Complexity · OODA · Asymmetric Threats · Law of Unintended Consequences · Dissonance · Contradiction · Situational Awareness

1 Six Stories

1.1 Three Kinds of People

Out in the long tail periphery of human knowledge, the amount of available data on which to build theories is fundamentally limited. Few if any researchers get to do experiments in which hundreds of humans are put into genuinely life-threatening situations, and so we are forced to consider anecdotal evidence. One such instance involves a person who happened to be scientifically trained, finding himself on board a sinking ferry, in a public area with a large number of other people, all gradually becoming aware, as the situation unfolded, that it was increasingly unlikely they would survive. Around a third of the people in that area, the scientist observed, quickly concluded that their lives were over. They sat calmly and accepted their fate. Another third of the people had the opposite reaction. Their ‘fight or flight’ instincts told them ‘flight’ was the best strategy, they looked at the available exits, ran towards them and, when they saw others had made

similar decisions, quickly found themselves in a logjam. Then panic set in. The scientist was one of the final third of people in that public area. When he found himself amongst the small number of survivors, he said there was almost no-one from the panicking second group. The survivors were the people from his final third. People that were able to take a beat, pausing long enough to get past the ‘fight or flight’ reaction and allow their conscious ‘slow’ brain to start doing it’s what it has evolved to do [1]. Which is to observe what’s happening around them, think about options, evaluate those options and then decide what to do next. Including, when the range of currently available options seems unsatisfactory, getting creative in order to create more. This is the sort of person that, we might usefully hypothesise, is either already a first responder, or has at least some of the potential to become one.

1.2 The Sinking of the Titanic

One of the most enduring segments in our TRIZ/SI workshops is the Ellen Domb originated, Titanic Exercise. The general idea of which is to allow participants to demonstrate that within a short amount of time (typically 5–10 min) it is possible to generate a suite of solutions that had the potential to save most or all the 1500 souls that lost their lives on the night of the sinking. In fact, in well over a thousand outings for the exercise, on only two occasions has a group failed to solve the problem.

The primary reason for the high success rate can be found in the two-minute framing of the exercise. First come the numbers: 2224 (officially) people on board the ship, 1178 lifeboat seats, 2 h until the ship sinks (known on the night, thanks to the ship’s architect), 4 h until rescue arrives.

The key to getting teams working on the right problem starts with framing the problem in a more effective manner. ‘What is the ideal result?’ ‘What would the perfect outcome be?’ Ideal and perfect are both words that force people out of the default trade-off way of looking at the world. Some undoubtedly struggle with this kind of thinking. They will respond (when provoked... and the fact that they do need to be provoked is perhaps already an indication that their deeper instincts are telling them they’ve got something wrong) with phrases like, ‘save more people’ or ‘fill the lifeboats’. No. Perfect means *everyone* needs to be saved. Perfect means preventing the ship from sinking. Perfect, if we really push the thinking, means delivering what the passengers were promised: arriving in New York on time on April 17.

Setting big goals like any of these three immediately forces people out of their comfort zones and into a more productive ‘breakthrough’ mode of thinking.

This is better, but still, typically, not quite good enough. More likely in fact to send people into paralysis than any kind of productive thinking. To achieve the latter requires a next level of thinking. One that allows them to see that, in the case of the Titanic, the primary thing that will prevent us from saving everyone is that the water is cold. Four minutes in the waters of the North Atlantic (clue: iceberg) will be fatal; in less than one minute, most will already be rendered unconscious and the next three minutes before actual death arrives are kind of irrelevant. What the exercise participants now have is, firstly, their stretch goal, and, secondly, the main reason (contradiction) they won’t be able to achieve it with the current thinking. Having delivered this insight, the new – much

more productive – problem has become one of working out how to keep the 2224 people out of the ocean...

1.3 Titanic Redux

...for most exercise participants, this new information gives them enough to do a reasonable job of finding solutions that will result in keeping the people alive. During the exercise, we're typically sitting in a pleasant, air-conditioned meeting room, rather than awaiting their fate on a ship they've begun to realise is sinking. Some will declare this difference is the main reason why 1500 people died: when we find ourselves in difficult situations – like the Sect. 1.1 ferry disaster – most people aren't able to do the sense-pause-respond thing. It is easy to have some sympathy with this view. Once people have bypassed their 'pause' capability and are relying on their 'instincts', when it comes to chaotic, asymmetric threat situations like the sinking of the Titanic, those instincts almost invariably turn out to be wrong. Often fatally so.

Wherever possible, first responders need to avoid allowing this state to arrive. The best way to do it is to anticipate what's coming – that's what 'pause' is all about. The second-best way is to disassemble the problem into one that prevents the onset of the paralysis or panic arising when the fight/flight part of our brain has taken over. The way to do that is to think about resources. And, specifically in the case of the Titanic Exercise, resources that will keep people out of the water: go find things that will float. An instruction that could have usefully been given to all 2224 people on board the ship that night. Better still, confer with the crew and then tell them to distribute themselves among the passengers and get them working in teams.

Again, easier to say what sitting in a comfortable room rather than a cold night in the middle of the North Atlantic, but that's why, in situations where fight/flight thinking is close to hand, instructions need to be kept simple. Simple and yet commensurate with the realities of the situation. Which as illustrated in the Complexity Landscape Model [2, 3] of the various stages of the Titanic sinking shown in Fig. 1, means 'simple' in a manner that follows the first principles of the system and its surroundings [4]. For the Titanic that would have meant things like: 'throw things overboard' (if they sink they've made the ship (slightly!) more buoyant; if they float they're a resource), 'collect all the life vests' (to stop people putting one on and then jumping in the water thinking it would save them), 'find sheets, blankets, tarpaulin and throw them overboard above the holes in the side of the ship' (the idea being that flexible things will tend to be drawn into the holes by the surrounding flow of water, and have a fair chance of blocking the holes).

For every complex (or chaotic) problem there are thousands of 'simple' wrong answers, but, if we understand the problem at a first-principle level, there is also the possibility of simple useful ones too. 'First Class passengers first' was a simple instruction given to the crew on the Titanic, but it was not consistent with first principles and probably helped ensure the death of many third-class passengers, whereas, 'find floating things' was, and any activity in this direction could only help... at least for a period of time. A period that the Fig. 1 image would tell us was appropriate, and then no longer so.

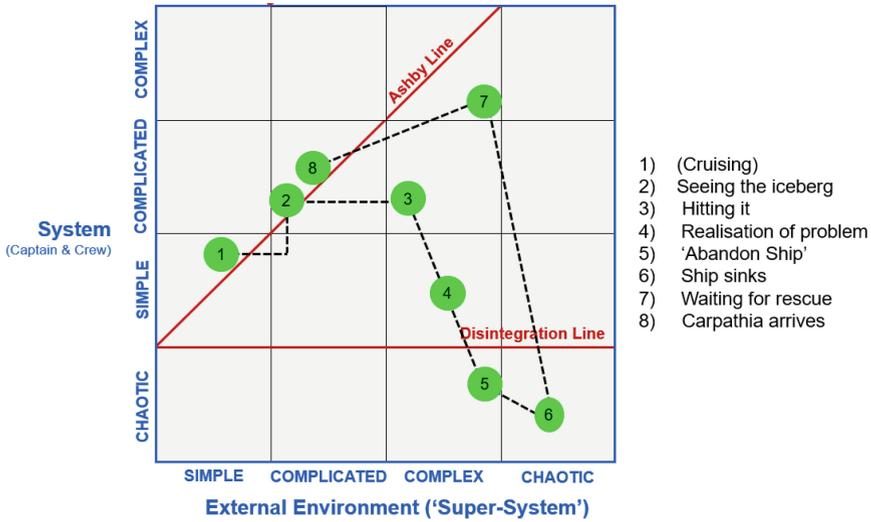


Fig. 1. Titanic Sinking Mapped onto The Complexity Landscape Framework.

1.4 Hillsborough

An FA Cup semi-final in 1989 rapidly descended from celebration to catastrophe. The 1989 Hillsborough Tragedy, and the ninety-six lost souls were all supporters of Liverpool Football Club. Now, over thirty years after the event, the subject is still raw for many people. The first coroner’s inquest, completed in 1991, ruled that the deaths were accidental. Families rejected the findings and fought to have the case re-opened. In 1997, Lord Justice Stuart-Smith concluded that there was no justification for a new inquiry. Private prosecutions brought by the Hillsborough Families Support Group against the police officer in charge of the crowd control operation, David Duckenfield and his deputy Bernard Murray failed in 2000. Then, in 2009, a Hillsborough Independent Panel was formed to review the evidence. Reporting in 2012, it confirmed 1990 criticisms and revealed details about the extent of police efforts to shift blame onto fans, the role of other emergency services, and the error of the first coroner’s inquests. The panel’s report resulted in the previous findings of accidental death being quashed, and the creation of new coroner’s inquests. It also produced two criminal investigations led by police in 2012: Operation Resolve to look into the causes of the disaster, and by the Independent Police Complaints Commission (IPCC) to examine actions by police in the aftermath. The second coroner’s inquests were held from 1 April 2014 to 26 April 2016. They ruled that the supporters were unlawfully killed due to grossly negligent failures by police and ambulance services to fulfil their duty of care (See Fig. 2).

Whenever it becomes necessary to look back on a tragedy to establish what happened in order to ensure it won’t happen again, one of the biggest challenges is recognising that there is no such thing as a ‘root cause’ in complex or chaotic situations. The second, often bigger, challenge for investigators is being able to filter out the information known after the event that couldn’t have been known by those responsible for dealing with

the event as it is unfolding. Hindsight, as the saying tells us, is twenty-twenty. In the moment, we can only work with what we're able to see right now. Taking that perspective, the Police responsible for the safety of people at Hillsborough, argued throughout the investigation(s) that the event was an unpredictable 'black swan'. Fortunately for the families of the victims, we now know this was not the case, and that a far better question to be asking was the point at which what should have very definitely been anticipated turned from being predictable to unpredictable. That's still not an easy question to answer, but mainly because the Police in this case, but first responders in general don't possess the Complexity Landscape framework:

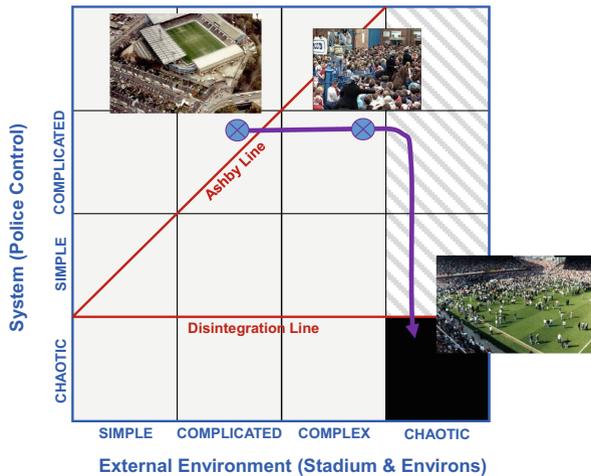


Fig. 2. Complexity Landscape Model for the Hillsborough Tragedy.

Nor do they understand systems [5]. Either the TRIZ originated idea of the S-Field as a minimum system of 'two substances and a field', or the Law of System Completeness and the need to comply with it if we are to be able to control the outcomes delivered by the system.

Because neither were known by the Police in the Hillsborough Control Room on 15 April 1989, they didn't realise the delays on the motorway between Liverpool and Sheffield, or the requests from the constables in the crowd to delay the start of the game, were signs that they were missing one system and massively overloading another.

1.5 Critical Mass at the Critical Point

Much as it might be difficult for a British person to admit, by most accounts, Napoleon was a very effective military general [6]. Or at least he was during the earlier parts of his career, before the almost inevitable hubris of success took over and he decided to march the French Army to Moscow in 1812. As subsequently discovered by Prussian General and military theorist, Carl von Clausewitz, prior to the disastrous invasion of Russia, what made Napoleon successful was his (probably innate) understanding of applying a

critical mass of resources at the critical point [7]. In practical terms, Napoleon would march his soldiers on a random walk around Europe, sending scouts over the next hill to see what was on the other side. If the scouts returned with a message that there were large numbers of enemy combatants, Napoleon would then march his men in the opposite direction. If the scouts said that the enemy over the hill was small in number, then Napoleon would march his troops over the hill and fight them. If you're going to pick a fight, in other words, pick one you know you're going to win. An excellent way to achieve the all-important 'sense of progress' [8] for the troops you're about to send into battle – morale is everything – and, perhaps even more important, helping to build their trust in his leadership. Early Napoleon was one of life's multipliers [9]: someone capable of getting those under his leadership to do double what an average leader would.

1.6 Trolley Problem Redux

If the ferry disaster described in the Sect. 1.1 story apparently offers the prospect that a third of the population at large has what it takes to be a good first responder, the Trolley Problem [10] not only stops that thought in its (excuse the pun) tracks, but goes further in suggesting that very few individuals indeed have what it takes. The popular trolley problem and related thought experiments was originally designed to highlight the differences between deontological (rule-based) and consequentialist (outcome-focused) systems of morality. In case you don't know it, it goes something like this:

Imagine that you see five children playing on a railway line. Suddenly you see an out-of-control trolley zooming down the line towards the kids. On a bridge over the railway, you see a very fat man. It suddenly occurs to you that if you push the fat man off the bridge his sheer size and bulk will stop the trolley and the children will be safe. However, the fat man will almost certainly die. The ethical question facing you is, "would you push the fat man off the bridge?"

Since this difficult moral dilemma problem went viral, and produced literally thousands of responses, it is very clear that none of the respondees possesses the traits that we would like a first responder to have. Or, if they did, their thoughts weren't given a public airing. All the published responses fall into the Zero-Sum Bias trap, assuming that the only options were the two given ones: are you going to do nothing and watch five people die, or do something and kill one? A genuine first responder, I like to think, would refuse to accept the question as an either/or. A genuine first responder would be tapping into their innate contradiction-solving skills to find, reflecting back on Sect. 1.2, a more ideal outcome in which neither the five children nor the very fat man have to lose their lives. This is not to say that first responders don't find themselves in overwhelmingly asymmetric situations where they are surrounded by unprecedented death and destruction and have myriad seemingly impossible choices to make. Sometimes history look back on such situations and declares the first responders did a good job. In others – the recent 'withdrawal' from Afghanistan, Haiti, the even more recent earthquake disaster in Syria – the After-Action Review reveals a host of lessons to be learned. First responders understand what it feels like to constantly be between rocks and hard places. They are taught how to deal with the traumas of emerging from their either/or decisions. For the most part, they are not taught how to see past both the rock and the hard place. The key word being 'and'.

2 One System

Like many other areas of life right now, the first responder ‘industry’ has a leadership problem. Or a risk one. Or a bravery one. Or maybe too much emphasis on creating a culture of asking for permission and not enough on seeking forgiveness. The hierarchical permission-granting management systems we build might be useful in Simple, stable times, but when Chaos arrives, they are deadly. Hierarchies mean the person at the top decides, which in turn means that every layer in the hierarchy slows the dissemination of instructions downwards, and the flow of on-the-ground feedback from travelling upwards. Yes, chaos, needs someone accountable for setting the direction, but it also, in the presence of asymmetric threats, needs as many people engaging their brains. Most modern military institutions, thanks in no small part to the changing threat landscape (large enemy armies to largely autonomous but strongly networked terrorist cells), have learned the power of Commander’s Intent: the person in charge defines the desired outcomes and then empowers on- the-ground ‘teams of teams’ [10] to work out how best to achieve them. For the most part this way of working has not yet been translated into the world of the first responder, where Plausible Deniability seems to be a big part of leadership ethos. To some extent this is understandable: if the leader of an NGO sends people into an emergency and they die, that is not going to be seen as a good thing. Nor an acceptable one.

So, what happens? Leaders seek to train their responders to deal with different situations, to teach them the ‘right’ thing to do [11–14], forgetting that Chaotic situations preclude even the possibility that there is any sort of ‘right’ (what might be ‘right’ at this moment, could devolve into catastrophe in the next few seconds). Not to mention that every Chaotic situation is unique and that there can never be enough ‘training scenarios’ that could conceivably cover even a fraction of the variety of possible threat situations. Consequently, what ends up happening is that new first responders get ‘trained’ by watching what more ‘experienced’ first responders do. This is certainly a strategy. Just probably not a very sustainable or effective one. Or one that can be defended by procedure-bound managers. To get them on board, demands that, first of all, they can be shown that there are repeatable, teachable ways of thinking that will enable the first responders under their authority to act more effectively to the benefit of all [15].

Enter, John Reed [15], “*When you first start to study a field, it seems like you have to memorise a zillion things. You don’t. What you need is to identify the core principles – generally three to twelve of them – that govern the field. The million things you thought you had to memorise are simply various combinations of the core principles.*”

According to Reed’s thinking, what’s currently missing from the First Responder’s Instruction Book is credible knowledge of systems and principles.

There are undoubtedly small numbers of highly effective first responders out there in the world. They might not be able to elicit the systems and principles they have instinctively developed over the course of their experiences, they just ‘know’ what they’re going to do in any given situation. The problem with these traits from a leadership perspective is they are not only unteachable, but they are also quite threatening to the perceived need for plausible deniability. This in turn means the effective first responders don’t respect the leaders, and, worse, avoid becoming leaders themselves – far better to be saving lives than filling forms. The net result is a world of box-ticking first responder

managers caught in a vicious cycle: they don't trust the most effective responders because they can't describe their 'formula', or, worse, tell the managers there 'is no formula', and in turn the effective first responders don't trust the managers whose instructions they're supposed to follow.

Here, perhaps is where all the TRIZ research to reduce the whole world down to first principles has a role to play. 'Someone somewhere already solved your problem' is a key TRIZ-based aphorism. As is the recognition that the 'someone' is likely, 'someone with a more extreme version of your problem'. First responders in asymmetric threat situations are by definition people experiencing some of the most extreme versions of different problems, but – fortunately – by no means the only ones.

So, what are the 'three to twelve' first principles that might enable first responders to deal with a zillion different threat situations? Well, six might be a good place to start. Given that effective first responding, as with all outcome-delivering activities, demands the existence of a system, and a system demands the presence of six essential elements. More specifically, the six elements illustrated in Fig. 3.

The next six sections examine each of the elements in turn, relating them back to the six stories from Sect. 1.

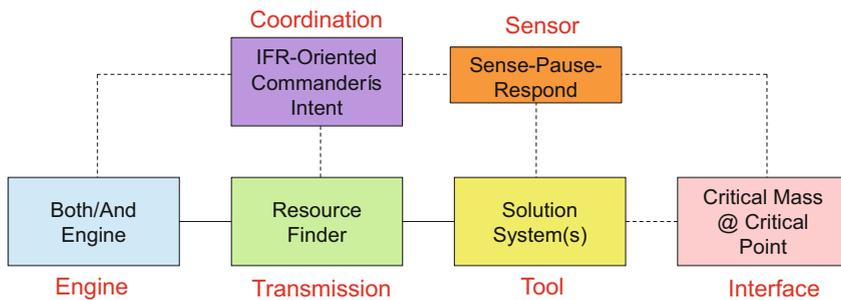


Fig. 3. The Six Essential Elements of a System for First Responders.

2.1 Coordination

Successful completion of the 'Save the Titanic' Exercise begins with defining better questions for people to think about. The military gets it right as far as 'Commander's Intent' is concerned, but often doesn't get it right in terms of working out how far to push the intent part of the equation. What TRIZ tells us is that the best way to frame intent, is to start with the ideal. The practicalities of a real-world threat situation might well force first responders to back away from the 'perfect' outcomes they can conceive, but that shouldn't stop us from formulating what the ideals are. Ensuring all survivors 'stay alive' is a pretty good start point. Establishing all the reasons we won't be able to achieve the ideal is a good second point...

2.2 Engine

...here is perhaps where we see TRIZ's biggest contribution to the first responder story. Starting with the 11 million plus contradiction-solving case studies already baked into the Contradiction Matrix tools, there is already a solid foundation of 'someone, somewhere already solved your (first responder) problem' knowledge database upon which to build. Before that, the need is to get the both/and mentality already present in the most effective first-responder 'instincts' into those of all the others. And especially the managers.

This is not to suggest that first responders are going to be opening up Contradiction Matrix sheets in the middle of an emergency situation. The 'pause' in Sense-Pause-Respond exists to encourage stronger thinking, but it still needs to be fast enough to be able to serve the urgency of a rapidly unfolding situation. Are we going to teach first responders the 40 Inventive Principles then, as an easier first step? Or maybe, it is possible to make an even easier first step? A step based on a continuation of Law of System Completeness thinking, that says, if there are six essential parts to a solution, and we can consider changing any of the six, what are the most effective ways to change each of the six? Fig. 4 tries to stick a stake in this ground. In effect it says, if we were going to teach first responders six of the forty principles, which six should we choose and why?

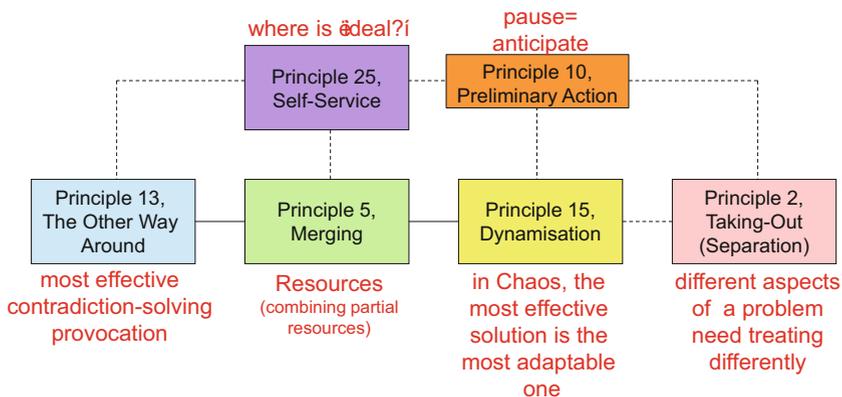


Fig. 4. Top Six Inventive Principles for First Responders.

2.3 Tool

The Tool part of a system is the part that is going to deliver the intended useful function ('save lives', etc.). All we need to think about here is the fact that if first responders are going to be able to control the achievement of those useful functions, they need to observe the Law of System Completeness. If they aren't yet at the 'control' stage and are merely looking to open the possibility of achieving a useful outcome, the two-substances-plus-field rule defining what a minimum system must contain is the next best thing. Which, given that 'substance' is often deemed to be too abstract, often distills

down to finding ‘fields’, i.e. sources of energy. Energy, whether it comes in the form of human labour, backhoes for clearing debris, mobile phone signals, or thermal imaging cameras for detecting human life, is the beginning of every system.

2.4 Transmission

The second critical aspect enabling a successful outcome of the Titanic Exercise is to get people thinking about resources. Resources, connecting to the previous, Tool, part of the system, could simply mean ‘substances’ and ‘fields’, but more pragmatically means ‘stuff that can help us do ‘x’” (where ‘x’ is a useful function like, ‘keep people dry’). We’ve never actually pulled out a 9-Windows template when working with first responders on a problem, but when we’ve become stuck at the end of an apparently fruitless search for resources, we’ve used it (or an abbreviated version thereof) to help responders reframe their thinking. Similarly, we’ve used Inventive Principle 5, Merging, to remind people that very often something only becomes a useful problem-solving resource when we combine it with another something. Partial resources are still resources. Ditto things that aren’t resources by themselves but might well contain resources within them. The very fat man is more than a 200 kg mass. Or, to shift to a more realistic scenario, when faced with a victim in the throes of bleeding out, one of the most effective ways to stem the flow of blood is to tear up clothing to make a tourniquet. The second-best way, the way to stem the problem at source, is to mix some of your blood with some of the victims. There’s a fair chance that your blood type won’t match theirs and mixing two different blood types is an excellent way to produce clotting.

2.5 Interface

Napoleon is our best ‘interface’ person – faced with myriad possible things that a first responder needs to address when arriving at an emergency, the only sensible way to start deciding which can be addressed and in which order, is to apply the ‘critical mass at the critical point’ heuristic. In the first instance, the limitation will be the critical mass part of the equation – if we don’t have any resources, we don’t have any system. When we acquire some resources, what do they allow us to do? Creativity, of course – our Engine – needs to kick in at this point: how can we utilise what we have to save the five children and the very fat man..., but if the answer is ‘we can’t’ then we need to apply the ‘critical point’ test in order to make sure we don’t end up killing everyone by spreading what we do have too thinly. This is a tough one. One that emphasises the need for the best Engine we can muster.

2.6 Sensor

Last but certainly not least is the part of the system necessary to ensure each of the other five parts are coordinated with one another. Here’s the part of the system that we get to take advantage of the work of a ‘someone with a more extreme version of your problem’ first responder, the Top Gun fighter pilot, Colonel John Boyd [17]. Boyd’s most lasting contribution to the art of surviving in extremely fast-moving chaotic situations is the

OODA Loop – Observe, Orient, Decide, Act. In effect, the middle pairing of Orient and Decide is the ‘Pause’ part of Sense-Pause-respond. To survive as a fighter pilot in a dogfight against enemy fighter pilots is to, first of all have a shorter OODA Loop cycle time than they have, and secondly, to do a better job of Orienting and Deciding. Translated into the world of the asymmetric threat first responder, this pairing means understanding the ‘pulse rate’ of the chaos – how quickly are things changing? – and, following the needs of the other elements of the Law of System Completeness, being able to orient thinking around ideal outcomes, available resources and contradictions to be solved.

3 A Zillion Emergencies

The chaos created when asymmetric threats turn into overwhelmingly asymmetric outcomes is typically dealt with utilising the ‘best efforts’ thinking of first responders. Those ‘best efforts’ are predominantly transferred from the experienced responder to the novice during live situations. On the one hand it might be said that this is the only kind of learning that works. On the other, The Basic Laws of Human Stupidity [18] should tell us that the good intentions of first responder leaders, if they are not well informed, can all too easily conspire to deliver the worst of outcomes. Good intentions are not enough. Neither, however, are attempts to train other responders through the extremely rare realities of emergency situations that, almost by definition, are rare events. The contradiction that needs to be solved here is the one between theory and practice. Napoleon, probably unwittingly hit upon a practice that worked, but it wasn’t until von Clausewitz was able to step back and see the bigger picture, that the ‘critical mass at the critical point’ heuristic was able to become visible to all.

This paper is a long way away from being authoritative, but it is hopefully a step in the right direction. It is a piece of work that, like von Clausewitz is borne of asking first responders lots and lots of no doubt annoying questions in order to try and understand them better than they understand themselves. And, of course, adding a new Engine into the mix. An engine that allows first responders to bring to tap into the evidence base unwittingly created through the 11 million best contradiction-solving inventors and problem solvers of the world. And not only that, to create a universal taxonomy into which the After-Action Review of all future crisis situations can be appropriately placed. Which, in theory, helps managers tackle the plausible deniability problem.

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Assessing Business Excellence Approaches from the Perspective of Directors: Exploring the Role of TRIZ

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Abstract. In today's volatile, uncertain, complex, and ambiguous (VUCA) business environment, organizations relentlessly pursue excellence as their ultimate objective. Extensive research is dedicated to identifying the most suitable approaches that ensure organizational sustainability and optimize financial performance. This study delves into various schools of excellence, including Total Quality Management (TQM), Lean Management (LM), Lean Six Sigma (LSS), and the Theory of Inventive Problem Solving (TRIZ). The primary focus is to ascertain the most effective business excellence approaches that drive performance improvement. Additionally, the study explores the correlation between mastering excellence approaches and companies' overall performance.

Given the paramount importance of this issue for organizational directors, this article presents a comprehensive survey aiming to unravel the ideal approach in the relentless pursuit of excellence. Notably, a key finding derived from this study underscores the significance of the philosophy of relative systematization, emphasizing the critical need for adaptability to specific organizational contexts. TRIZ, with its abstract approach, emerges as a highly suitable framework to address this philosophy. To achieve better outcomes within the organizational context, future excellence approaches should integrate this philosophy and emphasize adaptability. Furthermore, effective communication efforts by the TRIZ research community are of utmost importance in fostering the widespread adoption and utilization of TRIZ.

Keywords: TRIZ · Business Excellence · TQM · LM · LSS · Relative Systematization · Directors

1 Introduction

Organizations actively pursue superior financial results and a stronger market position, driving managers and scientists to develop strategies and approaches in their relentless pursuit of excellence. In contemporary times, excellence is increasingly associated with structured frameworks and programs such as EFQM, Malcolm Baldrige, and Deming

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models (Carvalho et al., 2021). Some authors characterize excellence as a transformative journey that requires organizations to adapt and integrate various quality, continuous improvement, and optimization tools into their reality and available resources (Carvalho et al., 2021). EFQM (2020) defines excellence as the ability to propel an organization forward and enhance its performance. Saleh and Watson (2017) describe excellence as an ongoing process that relies on internal standards, processes, and actively engages stakeholders to meet their expectations. According to Elyoussoufi et al. (2023), excellence is defined as continual growth and progress towards ideal and sustainable achievements.

Numerous studies establish a strong link between excellence and Total Quality Management (TQM), emphasizing its vital role in the development of business excellence and its integration with other fields (Ghafoor et al., 2020; Carvalho et al., 2021; Gupta and Vrat, 2019; Tajammal et al., 2018). On the other hand, Lean Management (LM), as defined by Porter (1991), is considered the primary strategy for achieving business excellence, demonstrated by its effectiveness in optimizing costs, improving quality, and reducing lead times, with the integration of Six Sigma (SS) being crucial for complementary benefits (Antony et al., 2017). Furthermore, TRIZ, a systematic innovation approach, has gained significant usage in the management field since the 1990s, offering structured problem-solving tools for non-technical problems (Zlotin et al., 2001).

The research community is actively striving to enhance and demonstrate the effectiveness of schools of excellence. Understanding how organizational directors perceive these schools, identifying impactful practices on organizational performance, and assessing the influence of mastering these approaches are crucial.

To address these objectives, a survey involving 28 companies from diverse industries and countries was conducted. It quantitatively examined the excellence approaches of high-performance companies compared to low-performance companies, focusing on challenges and the influence of mastering excellence schools. The concept of relative systematization emerged as a novel idea applicable to future excellence models, utilizing the systematic innovation methodology of TRIZ.

The background encompasses TQM, LM, LSS, and TRIZ as business excellence approaches. The methodology section provides details and participant information. The results section presents findings, and the paper concludes by discussing the role of TRIZ in responding to the findings and proposing future research opportunities.

2 Background

Achieving business excellence is a pivotal objective for organizations striving to thrive in today's fiercely competitive environment. Several approaches, including Total Quality Management (TQM), Lean Management (LM), Lean Six Sigma (LSS), and the Theory of Inventive Problem Solving (TRIZ), have emerged as means to attain excellence.

Numerous researchers have examined the correlation between business excellence and TQM. Ghafoor et al. (2020) and Tickle et al. (2016) delve into the evolution of business excellence, highlighting the replacement of older TQM models with newer ones. While the older TQM models suffered from ambiguity, the modern models, such as the Malcolm Baldrige model and the EFQM, offer structured guidance for TQM implementation. These models build upon the fundamental principles of TQM and provide

a comprehensive approach to achieving excellence (Ghafoor et al., 2020; Tickle et al., 2016).

Based on the Toyota Production System (TPS), Lean management focuses on the elimination of waste and continuous improvement, resulting in notable enhancements in quality, reduced delivery times, and heightened customer satisfaction (Garcia-Buendia et al., 2022). However, Lean management primarily addresses operational issues and may not fully consider strategic aspects, agility, and creativity (Antony et al., 2017).

The integration of Lean management and Six Sigma methodologies gave rise to Lean Six Sigma (LSS), widely employed for process improvement. LSS aims to enhance process performance, customer satisfaction, and financial outcomes (Laureani & Antony, 2019). Nevertheless, LSS has faced criticism for its limited focus on internal performance and inadequate attention to strategic elements, leadership, culture, and external factors (Antony et al., 2017).

Research on TRIZ began in 1946 when engineer Genrich Altshuller embarked on a study of patents (Elyoussoufi et al., 2022). Today, TRIZ and its systematic innovation updates embody the culmination of over 2000 person-years of research, encompassing not only patents but also successful problem-solving across various domains of human activity (Mann, 2021). TRIZ's creative power empowers business models to uncover innovative solutions for constraints and problems, enabling companies to create "blue ocean" markets (Elyoussoufi et al., 2023).

While these models and practices offer benefits such as improved productivity, enhanced quality, and customer focus, they also exhibit weaknesses. They can present barriers, as observed in the case of TQM's initial ambiguity (Tickle et al., 2016). Lean management may lack strategic considerations and creativity, and LSS primarily emphasizes operational performance while necessitating additional agility to detect problems (Antony et al., 2017). Furthermore, the mastery of TRIZ demands a significant investment of time, leading to a decline in its recent usage (Sojka & Lepšík, 2020).

This research aims to compare different schools of excellence by evaluating the performance of companies across diverse sectors and countries. The study seeks to identify the most appropriate practices for achieving business excellence while taking into account the strengths and weaknesses associated with each model.

3 The Methodology

The research methodology employed for this study encompassed both quantitative and qualitative approaches. A comprehensive survey was conducted among 28 company directors, presented in table, to identify the key success factors and practices enabling sustainable organizational development.

The survey is divided into three parts. The first part includes general information about the participants, such as gender, country, company size, and company performance. The second part consists of a questionnaire addressing the various problems companies encounter in their daily work, the approaches they employ to overcome these problems and ensure sustainable development, their success factors, and their level of proficiency with different tools of excellence. The third part consists of an open-ended question that allows directors to share their own experiences in the pursuit of excellence.

Table 1. General information about the survey participants.

N°	Age	Country	Post	Company's field of activity	Years of experience
1	37	Morocco	Director	Service	<5years
2	58	Morocco	Director	Service	>10years
3	36	Morocco	Director	Industry	>5years & <10years
4	49	Morocco	Director	Service	>5years & <10years
5	51	Morocco	Director	Training	>10years
6	43	France	CEO	Aeronautics	>10years
7	36	Morocco	operation manager	Industry	>5years
8	31	France	Director	Service	<5years
9	38	Mauritania	CEO	Service	>10years
10	42	Morocco	operation manager	Industry	>10years
11	37	Tunisia	operation manager	Aeronautics	>5years & <10years
12	60	Morocco	Director	Finance	10years
13	48	Republic of Congo	CEO	Service	>10years
14	51	France	operation manager	Industry	>10years
15	39	Morocco	Director	Construction	<5years
16	40	Morocco	Director	Construction	>10years
17	58	France	Director	Service	<5years
18	45	Morocco	operation manager	Automotive	>10years
19	38	Morocco	operation manager	Automotive	<5years
20	38	Morocco	Director	Service	>5years & <10years
21	48	Morocco	Director	Training	>10years
22	32	Morocco	Director	Service	>5years & <10years
23	50	Morocco	Director	IT	>10years
24	46	Morocco	operation manager	Industry	>10years
25	38	Morocco	Director	Construction	<5years
26	40	Morocco	operation manager	Automotive	>5years & <10years
27	49	Morocco	operation manager	Industry	>10years
28	65	Morocco	Director	Automotive	>10years

The survey has identified, as shown in Table 1, the participation of 21.4% of international directors from France, Mauritania, Tunisia, and Congo, in addition to Moroccan participants. The survey specifically targeted the top management of companies. Among the participants, 64% hold positions as directors or CEOs (Chief Executive Officers), while 25% are Operations Managers or Plant Managers. Furthermore, 53% of them have over 10 years of experience as top managers. The companies surveyed represent diverse business activities and sizes, with 25% being multinational corporations, 32% SMEs (Small and Medium-sized Enterprises), and 28% VSEs (Very Small Enterprises).

Table 2 shows that the performance of the companies varies across a range of financial performance scales, ranging from 3 (poor) to 9 (very good). We observe that 75% of the companies have good performance, while only 25% consider their financial performance unsatisfactory. Additionally, participants evaluated their teams' motivation and

Table 2. Companies' performance according to participants.

N°	Financial performance maturity	People commitment maturity	Problem solving maturity	Innovation Maturity
1	3	3	2	3
2	7	6	8	7
3	8	7	8	8
4	5	4	7	5
5	9	9	9	9
6	3	7	7	6
7	9	9	10	9
8	8	8	5	5
9	5	8	7	8
10	8	8	7	7
11	8	7	7	7
12	8	8	10	9
13	8	7	7	8
14	6	8	5	5
15	7	6	8	8
16	5	3	4	3
17	8	10	9	8
18	8	7	7	8
19	8	8	9	7
20	7	6	6	6
21	8	10	9	8
22	8	7	7	6
23	6	5	6	8
24	4	4	3	2
25	6	5	6	3
26	9	9	8	8
27	5	9	6	7
28	6	5	6	6

autonomy, innovation ability, and problem-solving capacity. Table 3 reveals a correlation between financial performance and the maturity of other skills. Subsequently, the investigation will explore the correlation between financial performance and the excellence approaches adopted by the entrepreneurs.

Table 3. Correlation between companies' performance

Pearson Correlation	Financial Performance	Integration maturity	Problem solving maturity	Innovation maturity
Financial performance	1	0,638**	0,705**	0,670**
Integration maturity	0,638**	1	0,698**	0,713**
Problem solving maturity	0,705**	0,698**	1	0,844**
Innovation maturity	0,670**	0,713**	0,844**	1

** The correlation is significant at 0.01 (bilateral)

To analyze the information, we have chosen to present the data based on the performance of the companies, categorizing them into high performance and low performance. The objective of this comparison is to identify the practices adopted by companies based on their performance. We will provide definitions of excellence and practices as provided by the managers. Finally, through a correlation study, we aim to answer the following questions: Is there a relationship between companies' performance and the implementation of any excellence schools? Does mastering excellence tools contribute to promoting business excellence?

4 Results

4.1 High vs. Low-Performance Company Practices to Achieve Excellence.

Figure 1 illustrates that 48% of the problems faced by entrepreneurs are categorized as simple. These problems can typically be resolved through the application of their intellectual capacities and experiences. Additionally, 21% of entrepreneurs believe that the issues they encounter are complicated, requiring a systematic search for root causes to be resolved. Meanwhile, 21% of entrepreneurs face a combination of simple, complicated, and complex problems simultaneously. It is worth noting that only 7% of companies report dealing with complex problems.

According to Fig. 2, the most significant problems encountered by entrepreneurs are primarily related to human complexity and team management. The third most important problem is customer payment delays. This problem is not specific to any particular country but mainly affects SMEs and VSEs in the service and construction sectors. On the other hand, industries such as industrial, aeronautical, and automotive sectors are facing intense competition problems. As shown in the graph, the most efficient companies recognize the need to stabilize their processes through standardization. Additionally, it is worth noting that only a few companies are affected by legislation and the quality of suppliers.

The comparison between high-performance and low-performance companies reveals that most low-performing companies need to focus their energy on leadership and team commitment, while high-performing companies also recognize the need to stabilize processes and manage cash flow.

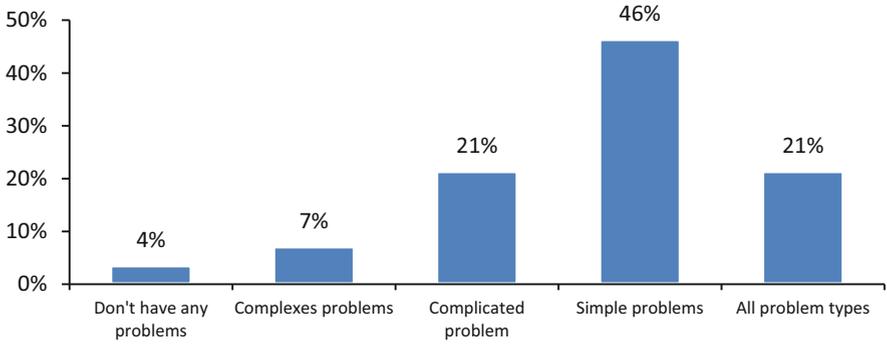


Fig. 1. Problems categories encountered by participant organizations.

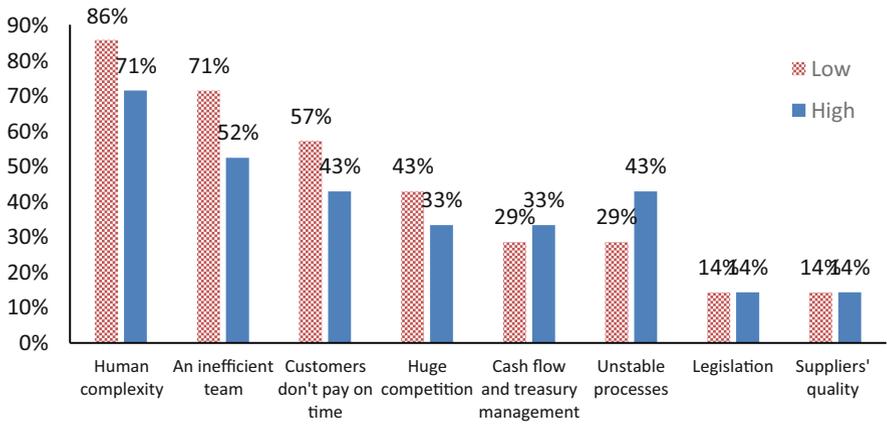


Fig. 2. The most important problems encountered by companies.

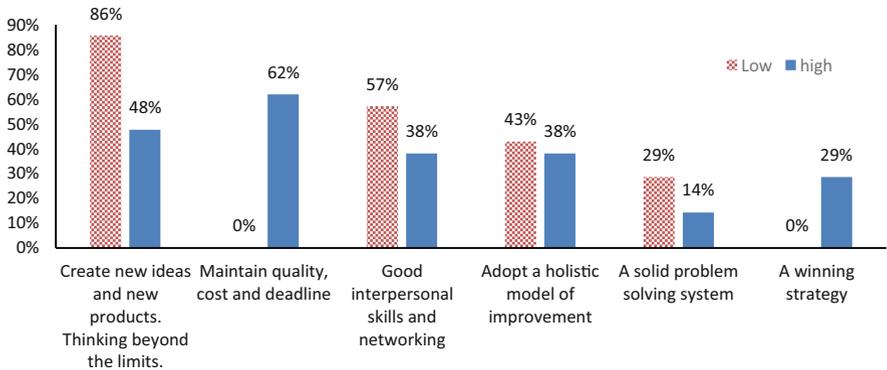


Fig. 3. Business Excellence success practices.

Comparing the practices of companies to achieve excellence in Fig. 3, we notice that low-performing companies challenge themselves to find innovative solutions, with a ratio of 86%, to overcome their problems. Moreover, 57% of these companies are committed to developing managerial and interpersonal skills, while more than 40% are dedicated to a problem-solving and continuous improvement approach.

On the other hand, high-performance companies are adopting practices to enhance their performance in terms of quality, cost, and time. These companies recognize the value of a winning strategy and adopt a balanced approach that encompasses holistic continuous improvement, innovation, and creative thinking for differentiation, as well as effective leadership to foster strong internal and external connections.

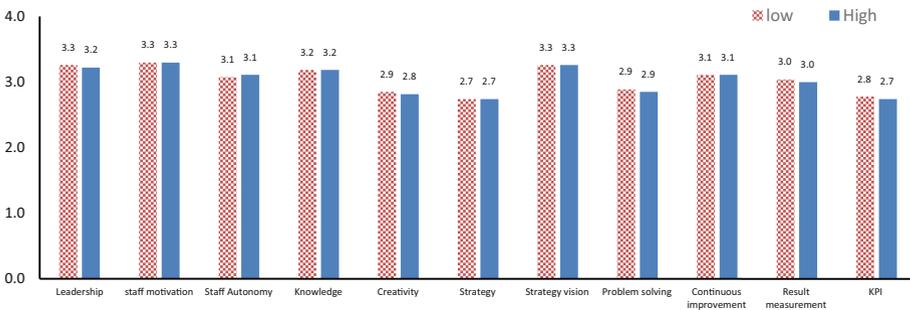


Fig. 4. Success factors' importance assessment (4: very important, 1: not important).

In accordance with the graph illustrating excellence practices, the importance of success factors (Fig. 4) indicates that entrepreneurs from both high and low-performance companies view these factors with equal significance. They recognize leadership, team motivation, knowledge capitalization, strategic vision, and continuous improvement as the top factors contributing to success. However, it is important to note that the actual practices implemented by different business leaders may vary based on the specific challenges they face and the unique context of their respective companies.

Overall, the findings highlight the complexity of challenges faced by entrepreneurs and the importance of adopting flexible practices to overcome them. It underscores the significance of effective leadership, continuous improvement, and adaptability in driving business excellence. Moreover, the data does highlight the importance of innovation for differentiation and overcoming low performance. It indicates that low-performing companies place a strong emphasis on innovation as a means to find innovative solutions and improve their performance. We conclude that the ideal excellence model should be flexible and adaptable, taking into account the relative preferences and needs of the entrepreneurs and their organizations according to their context and considering system evolutions. We refer to this approach as 'relative systematization'.

4.2 The Relationship Between Mastering Excellence Models and Achieving Excellence

The selection of success factors prompts us to inquire about the school of excellence followed by these entrepreneurs in their pursuit of desired performance. This inquiry seeks to uncover the level of mastery attained in these schools and its consequential impact on companies' performance.

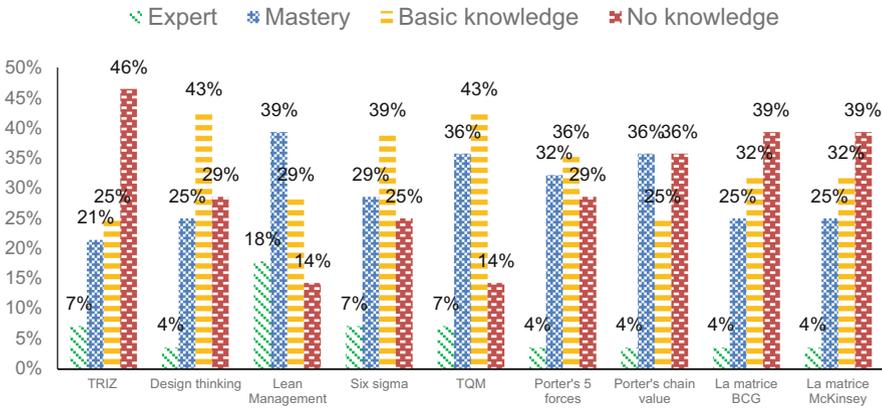


Fig. 5. Mastering level of some business excellence tools.

Figure 5 reveals that Lean management stands out as the sole school exceeding a mastery rate of 50%, with 39% of participants demonstrating proficiency in its tools and 18% considered experts in its approach. Additionally, the data indicates that over 30% of participants possess familiarity with Total Quality Management (TQM) and strategic tools such as Porter's Five Forces and Porter's Value Chain. Notably, several directors exhibit a foundational understanding of design thinking, Six Sigma, TQM, the BCG matrix, and the McKinsey matrix. This demonstrates their cognizance of the significance attributed to various excellence schools encompassing innovation, Lean Six Sigma (LSS), TQM, and strategic thinking.

Further observations from Fig. 5 disclose a notable level of non-familiarity with TRIZ, reaching 46%. Complementing this information, a survey conducted within a LinkedIn population yielded a comparable unfamiliarity percentage (as depicted in Fig. 6). Moreover, among those familiar with TRIZ, 37% employ it for technical problem-solving purposes, while a mere 15% utilize it to address strategic and managerial challenges.

To enhance our analysis, we endeavored to establish the degree of correlation between the performance of companies and the level of mastering excellence approaches and tools, as outlined in Table 4.

Based on the findings presented in Table 4, which highlights the bilateral correlations between companies' performance and their mastery of excellence approaches, it is evident that there exists a weak correlation between tool mastery and companies' performance. However, noteworthy correlations at a significance level of 0.05 emerge

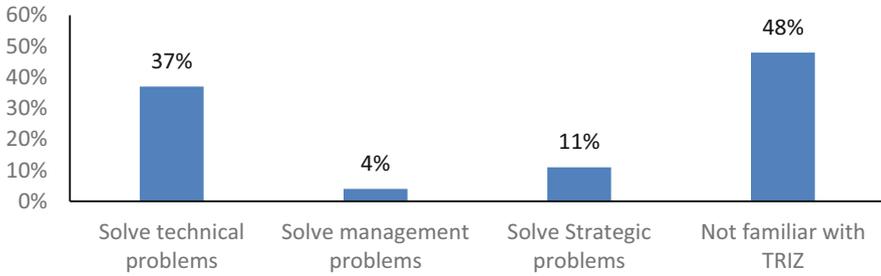


Fig. 6. Application areas where TRIZ is utilized for problem-solving.

between the mastery of design thinking and companies’ performance, as well as between the mastery of Porter’s Five Forces and performance.

Table 4. Correlation between mastering excellence approaches and companies’ performance.

	Performance	TRIZ	Design thinking	LM	SS	TQM	Five_force	porter_CV	BCG_matrix	Mckinsey matrix
Performance	1	0,240	0,409*	0,125	0,029	0,002	0,427*	0,325	0,155	0,319
TRIZ	0,240	1	0,738**	0,550**	0,528**	0,400*	0,519**	,513**	0,143	0,103
Design_thinking	0,409*	0,738**	1	0,712**	0,623**	0,480**	0,651**	0,608**	0,298	0,446*
LM	0,125	0,550**	0,712**	1	0,888**	0,726**	0,672**	0,651**	0,354	0,354
SS	0,029	0,528**	0,623**	0,888**	1	0,902**	0,714**	0,681**	0,434*	0,384*
TQM	0,002	0,400*	0,480**	0,726**	0,902**	1	0,677**	0,681**	0,471*	0,335
Five_force	0,427*	0,519**	0,651**	0,672**	0,714**	0,677**	1	0,846**	0,622**	0,480**
porter_CV	0,325	0,513**	0,608**	0,651**	0,681**	0,681**	0,846**	1	0,663**	0,576**
BCG_matrix	0,155	0,143	0,298	0,354	0,434*	0,471*	0,622**	0,663**	1	0,771**
Mckinsey_matrix	0,319	0,103	0,446*	0,354	0,384*	0,335	0,480**	0,576**	0,771**	1

* The correlation is significant at 0.05 (bilateral)

** The correlation is significant at 0.01 (bilateral)

Examination of the correlation table reveals significant associations between the mastery of design thinking and other approaches such as LM (Lean Management), LSS (Lean Six Sigma), Porter’s Five Forces, and Porter’s Value Chain. Additionally, a strong correlation is observed between LM, LSS, and TQM approaches, given their complementary nature and shared operational philosophy and tools. Similarly, a significant correlation is found between the diagnostic and strategy development tools employed by companies.

In summary, the analysis concludes that participants exhibit varying levels of mastery in different excellence models and practices. Lean management stands out as the most widely mastered school, indicating its popularity and effectiveness. However, there is a notable lack of familiarity with TRIZ, suggesting a potential area for improvement. The correlation between tool mastery and company performance is generally weak, implying that mastery alone does not guarantee excellence.

5 The Relevance of TRIZ in Response to Questionnaire Findings

The findings of this study highlight the complexity of challenges faced by entrepreneurs and emphasize the importance of adopting flexible practices to overcome them. The data underscores the importance of innovation in differentiating and improving performance, particularly for low-performing companies. These findings suggest that a flexible and adaptable approach, considering the relative preferences and needs of entrepreneurs and their organizations, is crucial for achieving excellence in varying contexts and among system evolutions. We term this approach “relative systematization.”

In light of these findings, it is worth discussing the potential contribution of TRIZ to addressing the challenges identified. TRIZ offers an abstract and structured methodology for problem-solving and innovation, making it a valuable tool for entrepreneurs and organizations. By incorporating TRIZ principles, entrepreneurs can enhance their problem-solving capabilities and generate inventive solutions to complex challenges. TRIZ provides a broader perspective beyond traditional excellence models, complementing existing mastery in other approaches such as Lean management (Elyoussoufi et al., 2022) or in strategic thinking (Elyoussoufi et al., 2023).

Furthermore, the analysis reveals a weak correlation between tool mastery and company performance suggests that mastery alone does not guarantee excellence. This further supports the need for a comprehensive and adaptable approach, which TRIZ can facilitate (Mann, 2019). By embracing the concept of “relative systematization,” entrepreneurs can tailor their approach to excellence based on their specific circumstances, taking into account the dynamic nature of their business environment.

In conclusion, TRIZ can contribute significantly to addressing the challenges highlighted in this study. Its systematic and structured approach to problem-solving, innovative thinking, and adaptability aligns well with the requirements of achieving business excellence. By incorporating TRIZ principles, entrepreneurs can enhance their problem-solving capabilities, foster innovation, and adapt their practices to achieve sustained excellence in a rapidly changing business environment.

6 Conclusion

In conclusion, the study underscores the complexity of challenges faced by entrepreneurs and emphasizes the significance of adopting flexible practices to overcome them. Effective leadership, strategic vision, and continuous improvement emerge as success factors in driving business excellence. Furthermore, the data highlights the importance of innovation for differentiation and overcoming low performance.

To achieve business excellence, organizations need to embrace a flexible and adaptable approach that considers the relative performance and needs of entrepreneurs and their organizations within their specific contexts and evolving systems. This approach, referred to as “relative systematization” enable companies to adopt the convenient approach for them context. TRIZ can respond to relative systematization trough it abstract approach.

Importantly, it should be noted that mastery alone does not guarantee excellence, as the correlation between tool mastery and company performance is generally weak.

This highlights the need to adopt TRIZ as a tool that guides entrepreneurs in finding the appropriate approach and ideal solutions.

In light of these findings, future research should focus on addressing the gaps in familiarity with TRIZ and exploring strategies to innovate an ideal framework for business excellence including relative systematization and TRIZ. By bridging these gaps, organizations can further strengthen their pursuit of business excellence.

This study acknowledges several limitations. Specifically, the survey was restricted to a sample size of 28 candidates from diverse French-speaking countries. To attain more robust and conclusive findings, future research should involve a larger and more diverse participant, encompassing multiple countries and various sectors.

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TRIZ-Based Model of the Social System

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Abstract. The creation of a social system model is highly required nowadays to see and predict social systems through contradictions identification and resolution. Design/methodology/approach. An analysis of existing (historical) approaches to social systems modeling - an analysis of the negotiation model set as a basement for this research.

Findings / Results. We propose a novel model for social systems. This model explains how and where system contradictions arise and proposes ways to eliminate them.

Research limitations/implications. Our research covers only the communications between agents in the social system. It has not yet been validated via actual case studies; however, it is planned as the next step. Practical implications. Detection and elimination of contradictions in social systems during communication between agents. Social implications. Prediction of social system development is a critical factor in sustainable social development.

Originality/value/conclusions. The proposed model makes it possible to apply the TRIZ approach to improving social systems.

Keywords: Social system · Communications · Negotiations · Contradiction

1 Introduction

Building a model is essential to research because it allows researchers to simplify complex phenomena and understand their underlying mechanisms. A model represents a system or process, helping to explain how it works, predict its behavior, and make decisions based on it.

Building a model involves making assumptions about the system or process being studied, simplifying it, and representing it in a simplified form. It allows hypotheses to be tested, predictions to be made, and insights to be gained that would be difficult or impossible to obtain through observation or experimentation alone. It is essential for the social system as an example of a system where experiments are difficult to replicate and, in some cases, may be unethical or otherwise impossible.

A social system model represents the different components of a social system and their interrelationships. Social systems are complex, dynamic, and evolving, and a social systems model helps us to understand and analyze them better. Here are some reasons why a social systems model is needed:

1. To identify and analyze social problems and, as a next step, to find controls and ways to solve them. This part is a fundamental approach for any system under TRIZ analysis.
2. Predicting the next evolutionary steps based on general and specific evolutionary laws and regularities and predicting the effects of changes.
3. To improve social systems: A social system model can be used to identify areas where the social system is not working effectively and to develop strategies for improvement.

Various models for social systems have been proposed in the literature, including Tektology by Bogdanov, the Theory of Action by Talcott Parson, and the Social System Theory by Niklas Luhmann. However, while instrumental, these models present limitations and gaps that can hinder their practical application in specific scenarios. Notably, they often fail to address explicitly the inherent contradictions within social systems and how these can be resolved. Additionally, the models' differing focus, whether on social action, information, or communication, may not entirely reflect the multifaceted nature of social systems.

Our specific objectives:

- To examine existing models of social systems, assess their elements, hierarchy, and interactions, and highlight the current gaps and limitations.
- To propose a new model for social systems based on the TRIZ concepts, providing a system view based on the evolutionary and problem-solving approach.
- To demonstrate the application of this model in a real-world context, focusing on its ability to identify and resolve contradictions within the social system.

2 Existing Models and their Comparison and Models

In most scientific and engineering disciplines, their own system models are used to represent the object of study. These models serve as a standard for analyzing the object and solving traditional tasks within the framework of a particular discipline. This section presents specific models of social systems that are applied in disciplines related to the organization and functioning of human communities.

2.1 Tektology (Bogdanov)

Tektology is a theoretical framework Alexander Bogdanov developed to create a universal science of organization and management [3]. At the core of Tektology is the "social system," a collection of interacting components that work together to achieve a common goal. Bogdanov argued that social systems could be analyzed using a range of disciplines, including biology, psychology, and physics. He believed that understanding the principles of organization and management in these different fields would make it possible to develop a comprehensive science of organization and management.

2.2 Theory of Action (Talcott Parson)

Parsons and Shils (2001) [11] proposed the Theory of Action (TOA) as a conceptual framework for analyzing objects within an environment. TOA focuses attention on the action as an organizing principle for understanding the behavior of a living organism. TOA assumes that (a) behavior is oriented toward goals or achievements, (b) action takes place in situations, (c) action is normatively regulated, and (d) action involves effort and energy, that is, it is motivated. In TOA, objects can be classified as physical, social, non-social, or cultural.

TOA concerns three systems. A social system involves the interaction of two or more actors, where one is the object of the other, and the other is considered the alter. A personality system involves the interactions of a single actor, where the actor’s action is organized for needs fulfillment. A cultural system does not involve the action of a single actor but rather is organized by values, symbols, and norms that guide the actor’s interaction.

Parsons also believed that social systems are characterized by a high degree of complexity and interdependence. He argued that social systems must maintain a delicate balance between the needs of the individual and the needs of the group in order to function effectively. The authors are offering a model of agents in the social system, which can represent his theory (see Fig. 1).

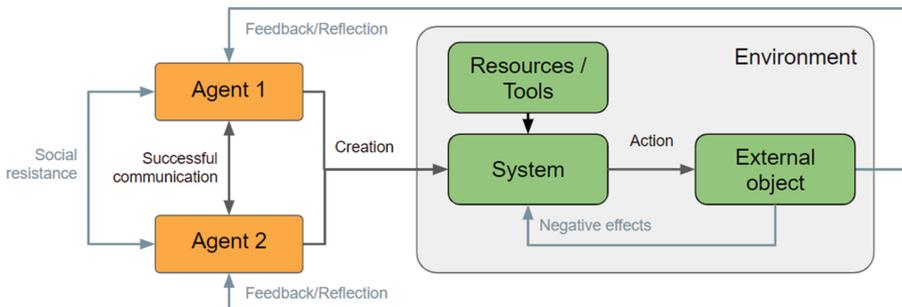


Fig. 1 Model of Agent in the social system

The following table demonstrates the matching of Talcott Parson’s theory of action principles to the model of agent in the social system (Table 1).

From the other side, the model represents in more detail how the agent performs the action. To perform the action, the actor must create the system. He can use his own efforts and energy and can use available resources and tools for that. In case when an actor’s own efforts and energy, as well as additional resources and tools, are not enough to perform the action, he is faced with the necessity to organize (by Bogdanov) the social system by attracting the other agent(s).

As the Summary of the Theory of Action:

The social system involves the interaction of at least two agents. We will present the model of the social system for two and more agents below. The personal system involves a single agent but includes feedback from the environment to the agent.

Table 1 Mapping of Theory of Actions principles to the model of the agent in the social system

Principle of TOA by Talcott Parsons	Object in the Agent model
(a) behavior is oriented toward goals or achievements	Mental model, Goal, Action, Feedback
(b) action takes place in situations	Environment, External object, Action
(c) action is normatively regulated	Mental model, Decision, Action
(d) action involves effort and energy, that is, it is motivated	Body (effort & energy), Resources and tools, System, Action

2.3 Social System Theory (Niklas Luhmann)

Niklas Luhmann offered a view of systems thinking that differed from Talcott Parsons' TOA. Whereas TOA sees action as the fundamental element of systems, Luhmann sees information as the vital element. Luhmann's theory improves on Parsons's idea by removing some of the objections to object boundaries created by anthropomorphic actors and changes. It adds a unique view that systems evolve in relation to themselves and not merely in response to environmental factors.

Niklas Luhmann theorized that system differentiation occurs only through self-reference, i. e. the system refers to itself in order to bring about a separation from its environment. This is possible because the system itself creates its own description as different from its environment. Therefore, the system is created by self-organization of these differences, a process called autopoiesis. This process takes place in a temporal environment. Self-referenced differences are created only momentarily and require meaning to persist (Luhmann, 1984). Meaning depends on information and connectivity within the system, but complete point-to-point connectivity between all elements in an autopoietic system is not possible. Complexity is the threshold at which point-to-point connectivity of system elements is no longer possible. Complexity is therefore a measure of indeterminacy or lack of information with the consequence of apparent instability. The result is an interdependence of elements to counteract the constant disintegration of the system due to complexity. Time itself generates this internal interdependence, making the system more and more dependent on information from the environment (Luhmann, 1984).

Communication is the primary mechanism through which social systems operate, and Luhmann saw it as a self-referential system. In other words, communication refers only to other communication, not external reality. This allows for the creation of a self-organizing system that can maintain its own stability and adapt to changing environments.

The social system a mass network of communication between people, can be in the form of:

- A social system proper, is a closed network of people, such as religion, law, art, education, science.
- organizations, which are networks of self-reproducing solutions.
- systems of interactions that reproduce themselves on the basis of presence rather than decision-making.

Luhmann also argued that social systems are characterized by a high degree of differentiation, meaning that each subsystem has its own specific function and operates according to its own logic. This differentiation allows for greater complexity and adaptability within the social system.

The authors are offering a social system model, which can represent his theory (Fig. 2).

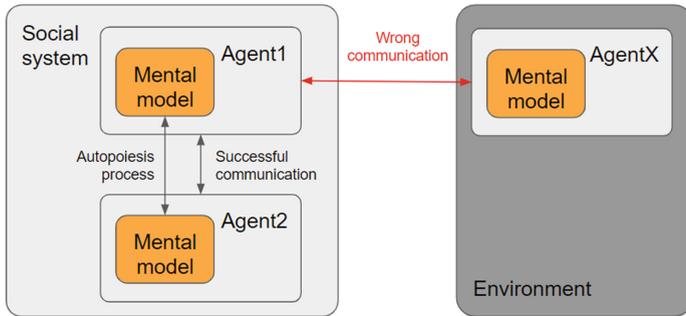


Fig. 2 The model of the social system by Niklas Luhmann

The key difference between Parson's theory of action and Lohmann's social system theory is their focus. Action theory is primarily concerned with the study of social action and the balance between the needs of the individual and the needs of the group. In contrast, social systems theory is concerned with understanding social systems as complex, self-organizing systems that function through communication and differentiation.

Another difference is the approach to social action. Action theory emphasizes the role of values, norms, and expectations in guiding individual behavior and social action. In contrast, social systems theory sees social action as a product of communication within social systems.

3 New Model Development

3.1 Social System Model Compatible with TRIZ

The model of a system in TRIZ is designed to identify contradictions within the system and synthesize a solution that eliminates this contradiction. The type of system in the TRIZ system model can vary (Kuryan and co-authors, 2021) [7], such as a technical system, process, flow, information system, or business system. The TRIZ framework declares a fundamental requirement on the system model: the ability to describe the contradiction within the system.

Based on the requirement for detecting contradictions within a social system, the authors proposed a social system model that combines the aforementioned specific models of social systems and, at the same time, allows for the detection of contradictions within the social system as follows Fig. 3.

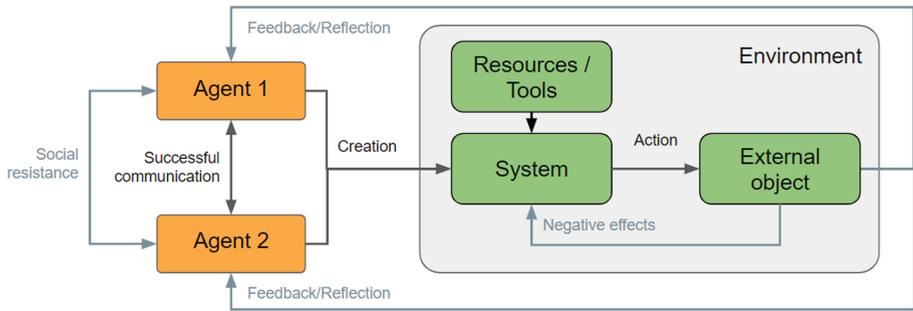


Fig. 3 Minimal social system model

A minimal social system is at least two agents that are communicating and self-reflecting (by Luhman) [8] and collaborating to perform the action (by Parson and Bogdanov). The motivation to collaborate is addressed to the possibility of joining efforts, energy, and resources to create a system that performs a more effective action. On the other side, communication in the social system is a source of social resistance and negative effects. Of course, there are more models of social systems, but the authors have taken the ancestor models from which these studies are based.

3.2 Approach to the Creation of the TRIZ-based Social System Model

Genrich Altshuller (1984) [2] analyzed tens of thousands of patents and formulated the basic TRIZ postulates:

1. Technology develops naturally. The laws of technical system evolution are used in solving problems and developing systems
2. The type of problem can classify any inventive problem along with the selection of a type of solution
3. In order to solve complex, inventive problems, it is necessary to identify and resolve the contradiction that is embedded in the problem.

The power of the TRIZ approach is an effective combination of system thinking and problem-solving methodologies. Based on this, we can analyze and develop systems focusing on the problems that are appearing and solving in the systems.

We applied this approach to clarify the social system model presented on Fig. 3.

The research goal is as follows: what kind of problems appear in social systems and how these problems can be solved by existing methods or by TRIZ methods.

For our research of social systems in the first stage, we used the models of negotiations [1]. Negotiation is a widespread way for social agents to interact.

Definition: Negotiation is the process of reaching a reasonable agreement that best serves the legitimate interests of each party, fairly regulates competing interests, is sustainable and considers the public interest. [R. Fisher, W. Ury, 5].

Schematically our approach is presented in the following figure (Fig. 4).

The approach is based on the TRIZ-based problem-solving process defined by Vladimir Petrov (2020) [12]:

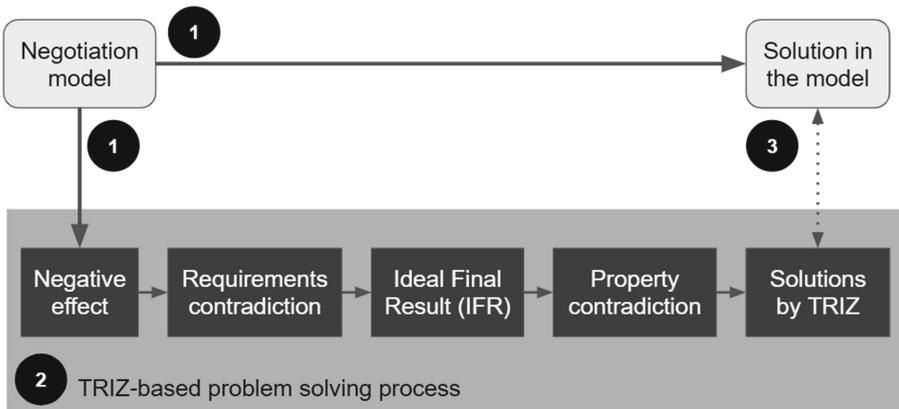


Fig. 4 The TRIZ-based approach to researching the negotiation models

1. Based on the description of the negotiation model, we identify the initial problem that can appear during communication (negotiation) between agents and the proposed solution. Initial problem we define in the format of a negative effect (a kind of surface contradiction in TRIZ).
2. Then we solve the initial problem according to the TRIZ-based problem-solving process and define the basic TRIZ concepts: requirements contradiction, ideal final result (IFR), and property contradiction. For defined property contradiction, we generate the solutions using TRIZ tools.
3. In this step, we can compare the solution proposed in the negotiation model (step 1) and solutions generated by TRIZ (step 3).

3.3 Negotiation Model “Emotions: Empathy” Example

According to Paul MacLean’s theory of the “triune brain” (Paul D. MacLean. Triune Brain. 1988) [9] emotions originate in the brain’s limbic system, which is radically faster than the neocortex responsible for critical thinking. Daniel Kahneman (2013) [6] also demonstrates the existence of two separate systems of thinking: an emotional and intuitive process that happens first followed by the slower and more effortful process of rational logic.

According to the theory, if an agent in negotiations loses control over emotions, they can prevent him from thinking rationally and achieving his negotiation goals. The practice of negotiations confirms that the manifestation of uncontrolled emotions should be considered as an undesirable effect in negotiations.

The negotiation model “Emotions: Empathy” is oriented for the situations when the opponent (one of the agents) in negotiations tries to activate the other agent’s emotions. This negotiation model is defined by (Marshall B. Rosenberg 2015) [10] as follows: “If someone says that they are feeling ugly, don’t tell them they are beautiful, this only reassures them, they are probably looking for empathy. Instead, say: “Are you feeling unhappy with your appearance today?””.

The results of TRIZ-based problem-solving process for the initial problem identified in the negotiation model “Emotions: Empathy” are as follows:

- **Undesirable effect:** The opponent is trying to evoke empathy for himself, which may prevent the agent from negotiating (emotions will interfere with rational decision-making). For example, the opponent says he feels ugly. (This may evoke empathy, pity, or guilt, which will promote a decision in favor of the opposing party not based on logic or rational judgment.)
- **Requirements contradiction:** If the agent does not show empathy towards the opponent, it does not lead to the activation of emotions (emotional decision-making), but does not increase (or even decrease) the trust of the opponent in the agent.
- **Ideal Final Result:** The agent's behavior itself will increase the opponent's confidence in the agent, while the agent will not have to make an emotional decision.
- **Property contradiction:** The agent must show empathy for the opponent to increase the opponent's trust in the agent, and the agent must not show empathy to avoid activating his or her own emotions, which could prompt an emotional decision
- **The solution in the model:** the negotiation model recommends: use the question to express empathy. For example, "Are you unhappy with your appearance today?"
- **Solutions by TRIZ:**

Structural:

- a. involving an assistant on the agent's side of the negotiation, who demonstrates a high level of empathy toward the opponent, and the agent maintains control over his or her emotions during the negotiation.
- b. the agent outwardly shows emotions but does not feel them internally and remains rational in decision making

In-Time:

- a. for a certain period, give vent to emotions and show empathy to the opponent during this period not discuss negotiation issues, but then take control of emotions and proceed to discuss negotiation issues. This solution presupposes a certain level of training for the agent in negotiating.
- b. Show empathy in advance without linking it to the negotiation. Phrase you look wonderful today before the discussion even begins.

3.4 Negotiation Model "Cooperation" Example

This section examines the application of the negotiation model of Cooperation (Douglas Stone, and others.) [13] in a situation where a negotiator is engaged in a dialogue with a terrorist who has taken hostages and is demanding a ransom to safely escape from the scene of the crime.

According to Guy Olivier Faure and I. William Zartman. (2010) [4], the goals of negotiating with terrorists are: 1) protecting the lives of the hostages; 2) apprehending the captors; and 3) recovering or protecting property. An important aspect of such negotiations is that the negotiator is interested in reducing the risks to the lives and health

of the hostages for as long as the hostages are under the terrorist's control. The terrorist is interested in maximizing the risks to the hostages because that is how he is going to get the required ransom and safe exit. Thus, there is a conflict of interest between the negotiator and the terrorist.

The negotiation model [5] "Cooperation" is defined as follows: *"Lecturing doesn't work as it makes people become defensive. Instead, try and work on a joint activity to lower their guard and get them to open up. This is what hostage negotiators do, they work with kidnapers on the task of getting food or medical supplies."*

People often think that if we accept another person's story then we must reject our own. Don't think of it as a binary choice, embrace both. Extend an invitation by using phrases such as:

- Can you help me understand?.
- Let's work on how we might?.
- I wonder whether it is possible to..."

The results of the TRIZ-based problem-solving process for the initial problem identified in the negotiation model "Cooperation" are as follows:

- **Negative effect:** Terrorist refuses to guarantee the preservation of lives and the release of hostages without a ransom
- **Requirements contradiction:** The negotiator offers terms that will minimize the risks to the hostages during the time until their release, then he reduces the risks to the lives of the hostages while they are held by the terrorist, but the terrorist refuses to discuss such terms until the ransom is paid and they leave safely
- **Ideal Final Result (IFR):** The terrorist himself must wish to remove the risks to the hostages before and during their release
- **Property contradiction:** The risks to the lives of the hostages while in possession of the terrorist, including the moment of their release, must be minimal for their safety, and the risks must be high during this period of time for the terrorist to accept such conditions (ransom payment and their safety)
- **TRIZ-based solution:**
 - Involving the terrorist in the development of a joint solution so that he himself suggested a way to reduce the risk to the lives of the hostages and meet his demands
 - Sharing opposing properties in the structure: the negotiator offers to exchange some of the hostages for part of the amount requested by the terrorist or for handing over water and food to the terrorist (the total risks to all hostages are reduced since some of the hostages are released)

3.5 Hostage Release Example (on the Higher Level)

The hostage problem on a micro-level is a negotiation problem, but on a macro-level is a problem to make free people with avoiding losses.

A terrorist has taken hostages for profit. When negotiating with him, it turned out that he demanded \$1 million and a helicopter for the release of the hostages.

Surface Contradiction: Terrorist wants \$1 million and a helicopter to free hostages.

Requirement Contradiction: The terrorist demands \$1 mil and a helicopter, then he will release the hostages, but in doing so, we will facilitate the terrorist's criminal activity.

Ideal Final Result (IFR): The terrorist frees the hostages, but we do not contribute to the terrorist's criminal activity.

Property contradiction: You need to give the terrorist \$1 mil and a helicopter to let the terrorist release the hostages, and you don't need to give him \$1 mil and a helicopter not to encourage criminal activity.

TRIZ-Based Solutions:

1. **in space.** To give the terrorist what he demands at the scene of his crime and to deprive him of it elsewhere.
2. **in time.** For the duration of negotiations and until the terrorist has released all the hostages, provide the terrorist with what he demands, deprive him of it, and arrest him.
3. **In structure.** At some point, such as in a helicopter, everything is prepared to catch the terrorist and arrest him.
4. **by condition.** Until the hostages are released, give the terrorist what he demands. Once the hostages are released, the terrorist is arrested (create all the conditions so that he can be easily and, without unforeseen incidents, arrested the terrorist).

3.6 Clarified Agent's Mental Model as a Part of the Social System Model

Based on the contradictions defined by analysis of the negotiation models, we detected key objects associated with these contradictions. The set of these objects allows us to build the clarified mental model of the actor in the social system presented on Fig. 1 (Fig. 5).

4 Results

During the analysis of the negotiation model set, initial negotiation problems were detected. We applied the TRIZ-based problem-solving process to these problems. As a result, we defined contradictions in negotiations and generated TRIZ-based solutions for them. In some cases, the solutions generated by the TRIZ approach are more efficient than the solutions proposed by the initial negotiation model.

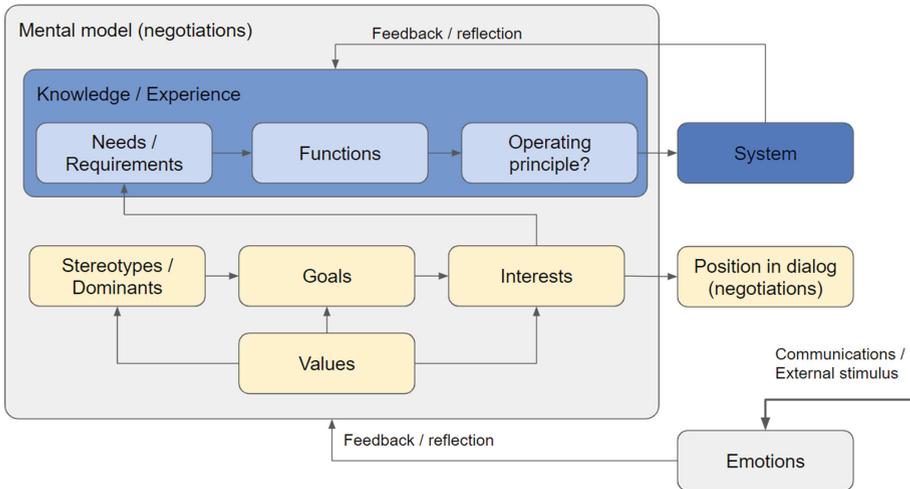


Fig. 5 Clarified mental model as a part of social system model

5 Discussion

The article shows one example of the application of one of the laws of systems development in the form of hybridization. In the future, we will show the possibility of using other regularities of systems development in social systems, and we will try to identify new regularities of social systems development.

The collection of negotiation models includes about 100 different models. We will analyze them using a reverse-engineering algorithm. Based on the results of the analysis, we will refine the social system model in terms of communication between actors.

Today's advancement in artificial intelligence, in large language models exposed through ChatGPT and other generative AI applications, overcame human performance in many areas and successfully passed the Turing test. Such an ability to mimic humans raises existential questions to society, which finds its reflection in the recent open letter "Pause Giant AI Experiments: An Open Letter". The first question raised there is very related to the social model proposed "Contemporary AI systems are now becoming human-competitive at general tasks, and we must ask ourselves: Should we let machines flood our information channels with propaganda and untruth?" "As we have shown in the model people's goals and consequently behavior depends on the feedback and alignment received from outside: from in-person negotiation, from authentic or digital conversations, or one-way directed messages like advertisement coming various channels, including digital. Differentiating artificial messages generated by robots at scale from real humans becomes an existential question and not something from science fiction. It possesses the next-level questions on the societal level that deserves attention from the research community.

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TRIZ Case Studies



Reduction of Bubble-Induced Defect in Semiconductor Lithography Process

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Abstract. In this study, methods for suppressing the occurrence of air bubbles in the photoresist (PR) dispensing apparatus of photo lithography system in semiconductor manufacturing process were analyzed. The proposed ways are intended to reduce product defects by targeting the specific areas where air bubbles are generated in the manufacturing equipment. The semiconductor industry faces the major challenge of reducing product defects by suppressing nano-particle contamination and bubble generation in PR. The width of the circuit pattern has narrowed as exposure technology in scanner equipment has improved especially using extreme ultraviolet (EUV) light sources. As a result, managing the smaller size of particles and bubbles has become increasingly difficult. Currently, semiconductor manufacturing equipment can manage wet particles and bubbles as small as 19 nm, and the industry continues to push for even smaller sizes. This paper aims to analyze the root cause of bubble generation in the dispensing system that delivers PR from the bottle to the nozzle for coating the wafer. By employing TRIZ inventive principles, the analysis leads to a detailed and efficient improvement plan that can be applied to existing mass production facilities to achieve zero instances of air bubbles. Furthermore, the proposed device designed to eliminate the root cause of air bubbles is incorporated into the newly developed facility, effectively reducing air bubbles and particles and ensuring high cleanliness.

Keywords: TRIZ · Lithography · Photoresist · Bubble · Defect

1 Introduction

Recent semiconductor photo lithography processes have been able to drastically shorten the process sequence and produce more delicate patterns by applying extreme ultraviolet (EUV) exposure equipment. This has made it possible to produce products that can integrate more semiconductors per wafer. Therefore, nano-particle contamination remains one of the major challenges in the semiconductor industry [1]. The critical particle size that the semiconductor industry has managed so far is in the range of 26–32 nm. However, as the current EUV photo process gradually reduces the size of the structural pattern, the

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industry must be able to manage particles as small as 19 nm. Furthermore, this critical particle size is continuing to get smaller and smaller. This presents a technical limit that is difficult to achieve with existing commercial systems currently in use today.

The photoresist (PR) is a key chemical solution used in the process of drawing semiconductor circuits on semiconductor wafers through exposure. When PR is applied on a wafer and exposed to light engraved with a specific pattern, PR undergoes a chemical change, resulting in the formation of a circuit. Since particles placed on the pattern become product defect [2] sources, improving particle contamination in the manufacturing process is a main factor in improving process yield [3]. Previous studies have attempted to control the thickness of the layer by using a small amount of PR to reduce the amount of expensive PR used [4, 5].

In this study, we aim to improve the PR dispensing system to reduce product defects and improve productivity. Specifically, we analyze the root cause of air bubbles in fluids, which have long been a problem in the lithography process for manufacturing, and seek ways to improve the system to eliminate them. The study presents efficient improvement plans for existing mass production equipment and proposes new device for newly developed equipment to minimize the generation of bubbles.

2 Problem Analysis

The main focus of research and system design for particle reduction in the PR dispensing systems has been to improve PR stagnation. PR is composed of high molecular weight compounds in addition to solvents, and when the chemical solution is stagnant in the tube or parts, the high molecular weight compounds in PR combine with each other to form gel-like particles. Bubbles or particles can act as seeds for the formation of these polymer particles. When these particles are ejected onto the wafer, they can create defects in the product [6].

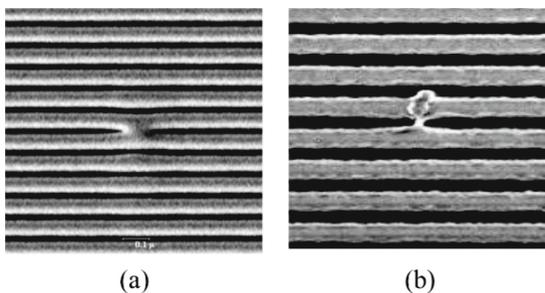


Fig. 1. (a) Line open defect due to a bubble and (b) a nano-bridge defect because of a particle associated bubble

In this section, we will employ TRIZ to comprehend the mechanism of air bubble formation during the movement of chemical solutions through facility tubing. Our goal is to analyze the root cause of bubble generation and devise a solution that can effectively

minimize the defects caused by bubbles as illustrated in Fig. 1(a) and the defects triggered by particles that adhere to the zeta potential of bubbles as shown in Fig. 1(b).

2.1 Root Cause Analysis

One of the recurring issues during PR transportation process is the formation of bubbles in the pump inlet region. These bubbles can flow into the pump, causing equipment stoppages and resulting in product defects when they are discharged onto the wafer. To understand the root cause of this problem, we conducted a Root Cause Analysis (RCA) starting from the observed bubbles and identified the causal relationship leading to the formation of nano bubbles, as illustrated in Fig. 2.

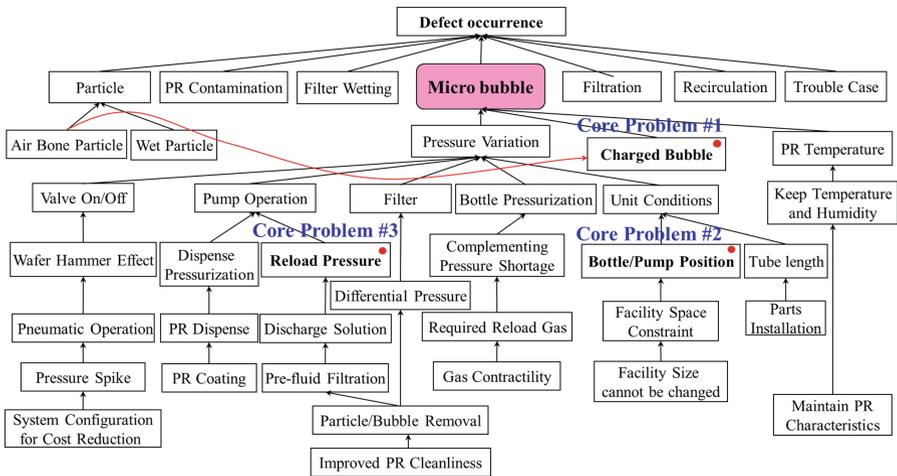


Fig. 2. The root cause analysis and three core problems for nano bubble generation.

Our analysis revealed three core problems associated with nano bubbles. The first one is the presence of charged bubbles. It was confirmed that negatively charged bubbles could cause particle defects by attracting positively charged particles. We decided that further understanding and analysis were needed for the second core problem, which is the correlation between the position of the bottle and the pump, as well as the third core problem, which is the differential pressure generated during PR reload operation of pump. We planned to verify these through experiments.

2.2 Experimental Verification

To further analyze core problem 2 and 3 and identify the causes of bubbles, we constructed a test device shown in Fig. 3. Through this, after reviewing the bubble generation-related factors by RCA, we intend to quantitatively review the location of the PR bottle and the pressure variation of the fluid, which are judged to be most relevant. To analyze

the correlation between the pump and the bottle as install location point of view, fluid discharge experiments were conducted under different height conditions.

As shown in Fig. 4, experiments confirmed that the average pressure of the chemical solution measured based on the pump inlet was directly proportional to the installation height of the bottle. The gauge pressures were measured at the pump inlet and recorded as + 4.8 kPa, -1.3 kPa, and -8.1 kPa for each bottle position (+0.5 m, -0.2 m, and -0.7 m height, respectively). By applying the simplified form of the Bernoulli equation, represented by Eq. (1) with P - pressure, ρ - density, g - gravity acceleration, v - velocity, the calculated results were found to be very close to the measured values, which were + 4.9 kPa, -1.9 kPa, and -6.9 kPa. Therefore, it can be concluded that the observed pressure difference is due to the gravitational potential energy.

$$P_1 + \frac{\rho v_1^2}{2} + \rho g z_1 = P_2 + \frac{\rho v_2^2}{2} + \rho g z_2 \tag{1}$$

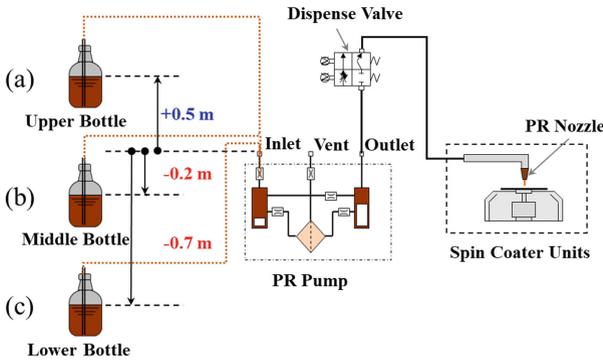


Fig. 3. Schematic of the PR dispensing system and an illustration of test conditions at different bottle positions (a), (b) and (c).

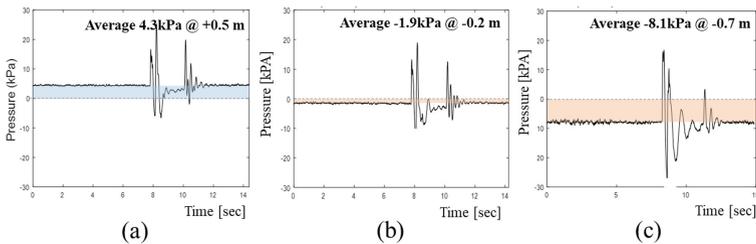


Fig. 4. Pressure variation during a dispensing cycle at the pump inlet for different bottle positions.

Furthermore, in order to investigate how the difference in physical pressure of the chemical solution, depending on the physical mounting position of the part, affects bubble generation, a test was conducted by dispensing the chemical solution 1000 times in each bottle position condition. Through this experiment, it was observed that when

the average pressure of the solution measured at the pump inlet was 4.8 kPa, -1.3 kPa, and -8.1 kPa, respectively, the amount of bubbles generated was 0.00 mL, 0.03 mL, and 0.07 mL, respectively. This bubble trend was found to be inversely proportional to the pressure as shown in Table 1. This confirms that the solubility of a gas in PR can be explained using Henry's law, which states that the solubility of a gas in a liquid is proportional to the partial pressure of the gas in equilibrium with the solvent.

Table 1. Comparison of test results regarding pump inlet pressure and generated bubble volume under different height conditions during a dispensing cycle.

Bottle Height (m)	Theoretical Pressure (kPa)	Average Pressure (kPa)	Minimum Pressure (kPa)	Bubble Volume (mL)
(a) Upper: +0.5	4.9	4.8	-8.4	0.00
(b) Middle: -0.2	-1.9	-1.3	-11.5	0.03
(c) Lower: -0.7	-6.9	-8.1	-18.0	0.07

Based on the experimental results, we can confirm that maintaining a positive pressure in the chemical solution inside the tube, including the pump, is the first key design parameter to effectively reduce bubble generation.

2.3 Improvement of Existing System

In this section, we will review the improvement plans for existing mass production facilities based on the experimental results from the previous section. Since there are limited elements that can be changed in existing facilities, we have identified modification items to suppress bubble generation while minimizing potential changes, using the inventive principles of TRIZ. The identified items are summarized in Table 2.

The first modification item is to change the position of PR bottles upward. Due to safety reasons, PR is supplied in one-gallon glass bottles, which are stored in a cabinet divided into upper and lower parts. There are a total of 16 bottles stored in the cabinet. To increase the pressure of the fluid by utilizing potential energy, all the PR bottles are placed on top of the cabinet.

Table 2. TRIZ invention principles and modifications to improve fluid pressure.

Principle No	Inventive Principle	Corrective Action
#12	Equipotentiality	Change bottle installation height upward
#5	Merging	Reduce bottle quantity (16 → 8ea)
#11	Prior Compensation	Increase buffer tank size
#34	Rejecting, Discarding	Eliminate unnecessary valves and unions

Second, due to space constraints at the top of the cabinet, the number of PR bottles is reduced by half from 16 to 8. In supplying one type of PR, the two-bottle system, in which two bottles are alternately used, was applied in the existing system as shown in Fig. 5 (a). The facility can continue the process of supplying PR by replacing the supply of PR with a second bottle when PR supply in the first bottle is exhausted. Besides of this, the facility secures time to replace the exhausted PR bottle. In spite of these essential functions, in order to overcome space limitations, the two-bottle system is changed to a one-bottle system as shown in Fig. 5(b).

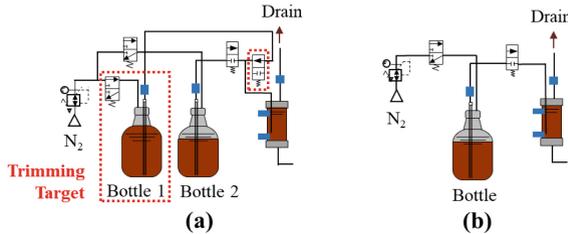


Fig. 5. Optimization of PR bottle system from (a) two-bottle system to (b) a one-bottle system.

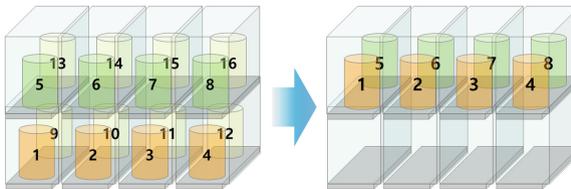


Fig. 6. Schematic illustration of PR bottles before (left) and after (right) optimization.

By combining the first and second changes mentioned above, we can modify the system design to overcome space constraints and retrofit the installation of PR suppliers on top of the cabinet to increase the potential energy of PR as shown in Fig. 6.

Third, the capacity of the reservoir tank for storing PR as a buffer is increased. Therefore, in order to secure adequate time for bottle replacement when PR is exhausted in one-bottle system, the capacity of the reservoir tank is greatly expanded from 50 mL to 200 mL as shown in Fig. 7.

In conclusion, the last modification to the existing system is to remove redundant parts such as valves, unions, and tubes that are no longer necessary due to the simplification of the system. These parts can cause additional pressure drop and particle generation, so their removal can improve the flow path. By implementing all four modifications, the fluid pressure can be increased by 8 kPa using physical potential energy, which is expected to reduce the occurrence of bubbles and improve the operation rate of the facility while minimizing defects caused by bubbles. The results of the facility improvements are presented in Chapter 3.



Fig. 7. The reservoir tank optimization of numbers and size before and after tanks' schematic illustration.

2.4 Modified Modeling of Smart Little People

One of the fundamental requirements in developing a new photo track facility is to install a considerable number of PR bottles in a confined space, without any limitations on the installation height, to provide various types of PR. To comprehend the pressure drop occurring in a 7–10 m long tube from the bottle to the pump, a small human model is utilized to analyze the system.

The modified version of the smart little people (SLP) model can provide a simplified and intuitive way to understand the pressure drop in the system as compare to classical SLP method [7]. By using a ringer as the reservoir tank, a medical tube as the long PR tube, and two syringes as the PR pump, it becomes easier to visualize the flow of PR and the pressure drop that occurs. Using the model of SLP as PR allows for a better understanding of how the fluid moves through the system and the effects of gravity on the pressure drop. This modified version can be a useful tool in the design and optimization of new photo track facilities.

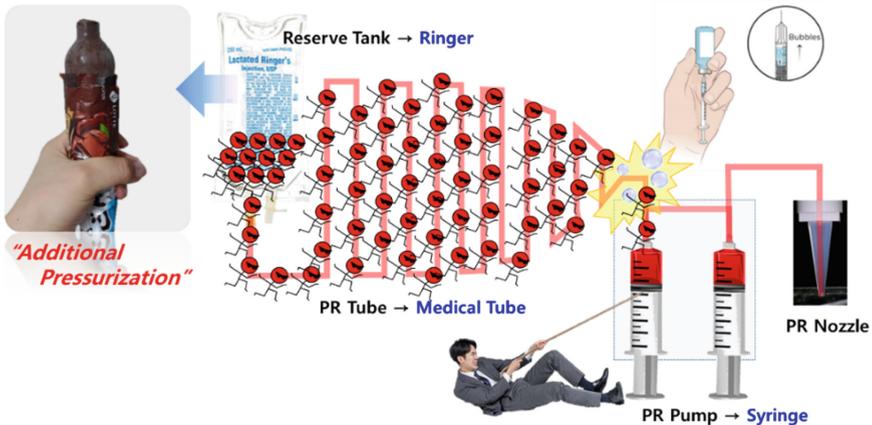


Fig. 8. The modeling of Smart Little People with alternative system for PR dispense units.

From this observation, it can be inferred that bubbles might occur at the syringe inlet, similar to the bubbles generated when filling a syringe with liquid from an ampoule, as shown in Fig. 8. To prevent the occurrence of such bubbles in the system, it is expected

that additional pressurization can be performed, as if the ring is squeezed by hand, like a pouch-type ice cream, to prevent pressure drop of the fluid.

This solution is expected to prevent the occurrence of bubbles in the system and improve the flow of fluid by compensating for pressure drops inside the tube. The system design of the auxiliary pressurization device is shown in Fig. 9 and it is focused on controlling the pressure inside the tube instead of the reservoir tank. The effectiveness of this solution will be evaluated further through experimental tests in the next chapter.

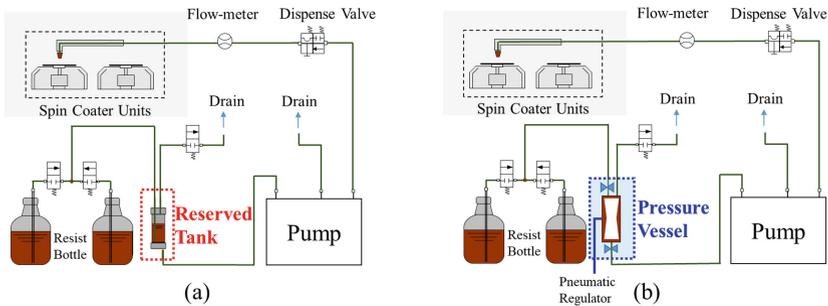


Fig. 9. (a) Conventional PR dispense system and (b) new system with the novel pressure vessel.

The introduced pressure vessel in this study consists of an inner tube with a four-leaf clover-shaped cross section and a circular outer tube for injecting air to control it in a dual structure coaxially. The inner tube is used for the flow and conveyance of PR while the outer wall of the outer tube has a tube through which gas can be inserted and discharged to supply and remove gas with a desired pressure profile. The gas is injected between the inner and outer tubes as shown in Fig. 10 which causes the inner tube to contract and expand, indirectly controlling the fluid pressure of PR in the inner tube.

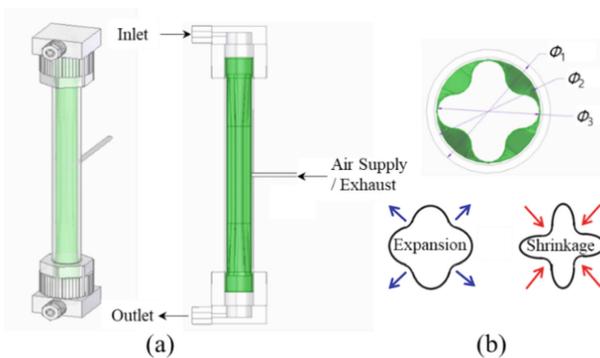


Fig. 10. (a) Pressure vessel configuration (b) Cross-section of pressure vessel as expansion and shrinkage operation.

In particular, the auxiliary pressurization device is designed to maintain positive pressure during PR reload operation, with effective control performance ensured by

feedback from the pressure sensor built into the pump. The contraction and expansion of the inner tube can be effectively controlled through feedback control of the pressure sensor and valve operation at the container inlet and outlet. The inner tube is optimized and designed for durability and control performance during operation.

3 Evaluation Results

This section presents the tools used to analyze the root cause of the bubble generation problem and the proposed solutions for improving air bubble problems in mass production lines. The experiments conducted were aimed at identifying the underlying factors contributing to the problem, and the results obtained provided a basis for designing effective solutions. The proposed solutions include remodeling of existing equipment and the application of newly designed parts to new facilities. The effectiveness of the proposed solutions was confirmed through experiments conducted in actual mass production lines. Overall, this section highlights the significance of a systematic approach to identifying and addressing problems in semiconductor manufacturing processes.

3.1 Results of Application

Air bubbles generated at the inlet of the PR pump are a major issue in the photolithography process for semiconductor manufacturing, as they frequently trigger equipment alarms and cause unexpected shutdowns. Chapter 2.2 of this study confirmed that these bubbles are produced when the pressure of the chemical solution drops to negative during the PR reload operation, which refills the stage inside the pump after PR dispensing operation.

In order to address this issue, the modification items proposed in Chapter 2.3 were implemented in two photolithography facilities, and the occurrences of bubble alarms were compared and reviewed for one month before and after the improvements. The results showed in Fig. 11 that the alarm trend was completely eliminated. Additionally, long-term monitoring of the same facilities for an additional six months confirmed that they continued to operate without any bubble alarms.

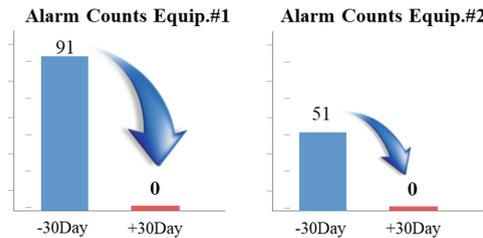


Fig. 11. Comparison of the number of bubble induced alarms for a month with 4 photo track equipment before and after improvement.

3.2 Results of Experimentation

Reducing the number of PR bottles in a facility and placing them all in an upward position in the latest photo lithography process, which requires a variety of semiconductor manufacturing, is realistically very difficult. Therefore, in Chapter 2.4, an auxiliary pressure vessel was proposed to suppress bubble generation by maintaining the pressure at the inlet of the PR pump without reducing the number of PR bottles or placing them upward. This was applied to a newly designed facility along with software featuring a dedicated control algorithm to establish a new PR dispensing system.

The auxiliary pressure vessel mentioned above can effectively reduce the pressure change of PR moving in the tube through the use of a control algorithm that pressurizes and decompresses the chemical solution through the contraction and expansion of the inner tube. This helps to effectively reduce the generation of bubbles. The results of the pressure profile check for the pump refill section after the chemical liquid discharge, without using the proposed auxiliary pressurization device in this study. The pressure at the pump inlet gradually decreases to approximately -5 kPa to transfer the chemical liquid from the PR bottle to the internal stage of the pump using differential pressure. This pressure change creates the worst conditions for bubble formation in the entire pump operation sequence.

On the other hand, the pressure profile obtained by applying the proposed auxiliary pressurization device with an effective algorithm to correct PR pressure during the reload operation of the pump. It can be observed that the PR reload operation is carried out while maintaining a stable pressure of about 15 kPa at the pump inlet with minimal pressure changes. This not only suppresses the generation of bubbles by preventing the negative pressure of PR and maintaining a positive pressure, but also prevents the generation of additional bubbles by suppressing effective pressure fluctuations in the overall operating cycle condition.

In conclusion, by analyzing the root causes and implementing effective improvements, restrictions on the installation location and quantity of the PR bottles can be removed, providing design flexibility to load a large amount of the PR bottles in various locations.

4 Conclusion

In the semiconductor lithography process, chips can be manufactured with a narrow line width as the technology of a scanner facility that performed exposure develops, and for this reason, management of nano particles is of utmost importance. This study was conducted to improve the management of smaller wet particles and air bubbles in the photo track facility with these process technology advances. The root cause of air bubbles, a chronic problem in the photo process, was found to be the lack of pressure management. The fluid pressure in the PR dispensing system had to be managed with a more positive pressure, and the pressure change had to be further reduced during the transportation of the chemical liquid.

Overall, based on these improved design methods, a method of improving existing equipment that utilizes the potential energy of the PR bottles was devised and implemented. Additionally, new parts were invented and proposed that can increase the pressure at weak points, along with control algorithms, and were applied to the new facility. Through these comprehensive activities, we have continuously improved product quality and productivity. We hope that the results of this study, which identified quantitative trends based on a physical understanding of the facility, will serve as a valuable reference for managing critical particles and bubbles at the 15–17 nm level in the future.

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Research on Production Innovation Problem Identification Process Based on FRT

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Abstract. The design and development of modern products is a process of ongoing improvement. At the same time, voice of customers (VOC) for products or services tends to be diversified. In order to avoid the problem that a single development form is difficult to grasp the current mainstream trend and meet the individual needs of customers, the study we report in this article addresses an innovative method combining user needs and current product research status. Through the study of Theory of Constraints (TOC) and innovative methods, the two classic tools of TOC, Current Reality Tree (CRT) and Future Reality Tree (FRT), are mainly used to establish the process of problem discovery and solution with LT dimensional representation. It mainly includes the establishment of CRT, the determination of “injection” according to product status and the transformation from CRT to FRT. The approach provides design ideas for developing and improving new products. The target product can meet the diversified needs of customers. According to VOC and product status, the approach combines the two basic tools of TOC, CRT and FRT, with technical problems as well as expands the application scope of TOC from management to engineering. What’s more, it puts forward a new systematic innovative idea. The program used in this article was partially corrected using ChatGPT3.

Keywords: CRT · FRT · LT table · Requirement Mining · TOC · Systematic Innovation

1 Introduction

The design and development of modern products is a process of continuous improvement. The ultimate purpose of product design improvement is to meet the needs of users, so the process of product design and improvement is carried out on the basis of user needs. Due to the uncertainty in the process of product innovation and the diversification and individuation of market demand, there are problems of high cost and low success rate in the development and improvement of products.

Theory of Constraints (TOC) was used to improve productivity in management, but in recent years, it has been applied to solve engineering problems. Scholars have integrated TOC with TRIZ to optimize innovation processes and used TOC to identify supply chain constraints [1]. However, TOC has been primarily used for enterprise management, and its potential in engineering has not been fully realized.

This article uses Current Reality Tree (CRT) and Future Reality Tree (FRT) in TOC thinking process to study product innovation problem identification. The process involves analyzing the current status of the product with CRT to find the root cause of each problem. Using the invention principle and LT dimension, X-resources are selected to generate innovative solutions. FRT is used to verify the logic of the new scheme, and the feasibility of the process was tested with the hot melt welder.

2 Thinking Process Tools of TOC

TOC began with the production scheduling algorithm in 1979, which achieved triple crop yields in a short period of time. The results were reported publicly at the APIC conference in 1980. Its development continues as an effective method for production applications. In the mid-1990s, companies of all sizes began to use this approach worldwide. Goldratt has developed a set of logic tools, collectively known as TOC Thinking Process logic tools (TP tools). TP tools mainly include CRT, FRT, Evaporating Cloud (EC) and other five tools (see Fig. 1) [2–6]. TP tools serve as a guided decision process to represent logic, to construct or characterize problems, and these tools can be used alone or in conjunction with other innovative methods.

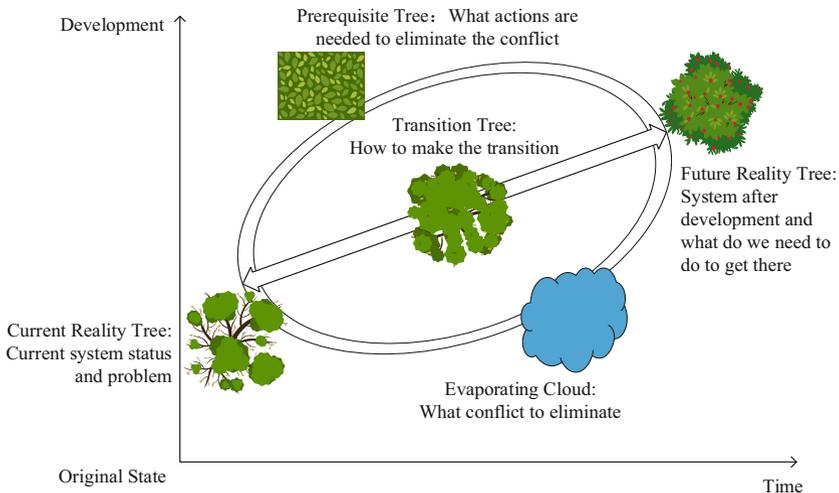


Fig. 1. Relationship between TP tools.

In recent years, many domestic and foreign scholars have actively explored new ways to use TP tools in collaboration with other innovative methods for new product development and product performance improvement, and have made preliminary achievements.

3 LT Dimensional Representation

A dimension is a property of a physical quantity that can be divided into fundamental quantities and derived quantities. All derived quantities can be derived by basic quantities, so as to establish the functional relationship between all physical quantities, which is called quantification. Different dimensional systems have been established in physics (e.g., Gaussian system, CGS system), but the commonly used system is the LMT dimension, with length, mass, and time as the basic quantities. Any other derived dimension can be expressed as

$$\dim A = L^\alpha M^\beta T^\gamma \quad (1)$$

α , β and γ represent the index of the corresponding dimension.

Using fewer quantities to represent the problem makes it easier. In 1873, Maxwell introduced the LT system, which measures in two dimensions (length and time). Batini analyzed fundamental physics quantities and proposed a kinematic system with two fundamental quantities (L and T). The dimension of a charge in an L-T moving system was first proposed. Using fewer quantities simplifies problem representation.

$$\dim m = \dim e = L^3 T^2 \quad (2)$$

The relation between physical constants is established by using LT dimension to represent charge. Length and time are used to represent other physical quantities. This physical quantity representation method is called LT dimensional representation method. The LT table can be obtained by combining the LT dimensions. The commonly used LT table is shown in Table 1 [7].

Table 1. LT table.

Time	L ⁻²	L ⁻¹	L ⁰	L ¹	Length	L ²	L ³	L ⁴	L ⁵
T ⁶					L ² T ⁻⁶	L ³ T ⁻⁶	L ⁴ T ⁻⁶	L ⁵ T ⁻⁶	
T ⁵					L ² T ⁻⁵				
T ⁴			L ⁰ T ⁻⁴	Specific gravity, pressure gradient	Intensity of pressure, tension, stress, elasticity modulus	Surface energy, Surface tension, inflexibility	Force, temperature gradient	Temperature, energy, moment of force	Power
T ³			L ⁰ T ⁻³	Electric current density	Electromagnetic field intensity, Ductility, Dynamic viscosity	Electricity current	Momentum, impulse	Angular momentum, angular impulse	
T ²		L ⁻¹ T ⁻²	Mass density, Angular acceleration	Acceleration, Magnetic resistance, Magnetic displacement	Voltage	Quality, electric quantity	Magnetic torque		
T ¹	L ⁻² T ⁻¹	Volume charge density	Frequency	Velocity	Area change percentage, Magnetic flux	Volume deficit		L ⁴ T ⁻¹	L ⁵ T ⁻¹
T ⁰	L ⁻² T ⁰	Curvature, Variation of conductivity, Resistance	Dimensionless constant	Length	Area	Volume	Moment of inertia		
T ¹	L ⁻² T ¹	Resistance	Period, persistent period	L ¹ T ⁻¹	L ² T ¹	L ³ T ¹			
T ²	Permeability	Permeance		L ¹ T ²	L ² T ²				
T ³	L ⁻² T ³	L ⁻¹ T ³	L ⁰ T ³	L ¹ T ³					

4 Proposed Method

4.1 User Requirement Mining and Relevant Patent Analysis

The survival of the product is based on the user. Through the acquisition of user requirements and the analysis of the current product related information, we can obtain the user’s demand for the current product and the technical status, which is very effective for the subsequent improvement of the product.

This paper adopts user requirements through data mining using K-means topic clustering. K-means algorithm randomly selects k seed points as original center points, calculates the Euclidean distance between each sample point and seed point, and assigns the point to the data set of the closest center point. The point then moves to the center of the data set, and the process repeats until the center point stabilizes. The Euclidean distance is calculated using a standard formula.

$$P = \sqrt{(x_2 - x_1)^2 + (y_1 + y_2)^2} \tag{3}$$

where P is the Euclidean distance between points (x_1, y_1) and (x_2, y_2) .

Given a set of observations (x_1, x_2, \dots, x_n) , where each observation is a d-dimensional true vector. The purpose of using K-means is to partition the n observations into k ($k < = n$) sets S (“S”_“1”, “S”_“2”, ..., “S”_“k”) such that the Within-cluster Sum of Squares is minimized. The quantity is calculated as follows:

$$arcmin \sum_{i=1}^k \sum_{x \in S_i} \|x - u_i\|^2 = arcmin \sum_{i=1}^k |S_i| Var(S_i) \tag{4}$$

where u_i is the average of the points in the set S_i . In the cluster calculation, u_i is used as the cluster center for distance calculation, and is gradually optimized with iteration. This is equivalent to minimizing the squared difference of S-pairs of points in the same cluster.

$$arcmin \sum_{i=1}^k \left(\frac{1}{2|S_i|} \right) \sum_{x,y \in S_i} \|x - y\|^2 \tag{5}$$

And it also follows that

$$\sum_{x,y \in S_i} \|x - y\|^2 = \sum_{x \neq y \in S_i} (x - u_i)^T (u_i - y) \tag{6}$$

Using K-means algorithm can intuitively reflect the information that the researcher wants [10]. The meaning of using K-means algorithm in this paper is to merge the information of the same meaning expressed by multiple users, so as to increase the efficiency of subsequent analysis to improve the product.

4.2 Contradiction Zone Determination Based on CRT

CRT is a fully-logic-based tool designed to identify and describe cause and effect relationships. This feature helps users uncover core issues that cause Undesirable Effects (UDEs) [2–6]. Text is the main source of CRT “data”, but some digitized data can also be used to prove certain points. Identifying contradiction zones is a prerequisite for subsequent use of tools to solve problems. The determination of the contradiction area defines the minimum area to solve the problem, which can ensure that the system has a small change in the process of solving [8, 9].

Establish CRT Based on User Requirements. To build a CRT based on a current product, the user must have a comprehensive understanding of its development. Understanding the cause-and-effect relationship in the current product is essential in the CRT model. The current bad state of the system, expressed as UDE, is a cornerstone in analyzing the current situation and identifying necessary conditions to achieve the system goal. In this article, we can use the UDE syntax rules to describe the original collection is not satisfied by prior art and define them as UDE.

UDE to the user generally means unnoticed needs and under-fulfilled needs, often with “negative” emotions. These feelings provide a direction for product developers to improve their products. UDE are connected cause-and-effect to form a network graph, which can be called CRT, and its basic structure is shown on the left in Fig. 2.

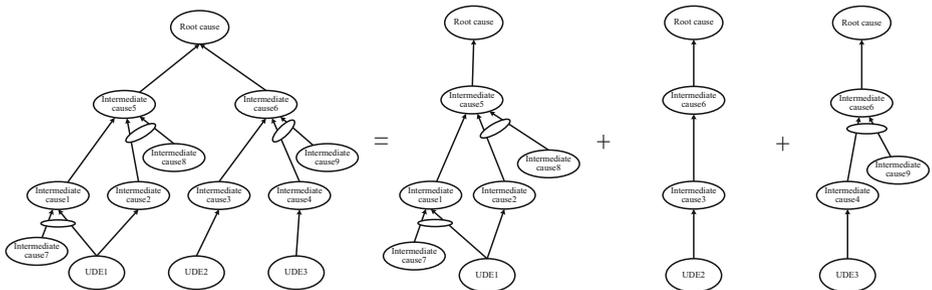


Fig. 2. The splitting process of CRT.

Identify Contradiction Zones Based on Branches of UDE. The CRT that has been established is split to obtain a single UDE branch about the target product. The main structure can be summarized as: UDE_x → (intermediate reason 1 and 2) or intermediate reason 3 → intermediate reason 4 → → Root cause.

Researchers identify contradiction areas by categorizing UDE branches and delimiting the scope for contradiction resolution. The process involves classifying CRT terminal UDE into technical and non-technical types, analyzing only technical UDE, and obtaining a complete logical relation chain.

4.3 Contradiction Resolution Algorithm Based on LT Table

Based on the kinematic system represented by two fundamental quantities L and T, Bartini proposed the LT table, as shown in Table 1. LT table expresses the law of conservation of physics to some extent and clarifies the relationship between physical constants. The horizontal row and vertical column of LT table represent the evolution trend of space resource and time resource respectively. The core idea of using LT tables to resolve technical contradictions is to find the ideal X-resource. According to Thom and Alexandr's research, the formula of cusp mutation based on contradiction and X-resources is

$$E(x) = 0.25x^4 + 0.5mx^2 - nx \quad (7)$$

In this formula, x represents the state coordinates of the action object, m represents the tool control parameter, and n represents the X-resource control parameter. The $E(x)$ value of the potential function represents the bad effect. From a mathematical point of view, the goal of the invention problem is to minimize the value of the potential function $E(x)$. Only by selecting two parameters m and n reasonably can the contradiction be controlled and resolved. From the formula analysis, the dimensions of these two parameters are x to the second power and x to the third power respectively. Therefore, the dimension of LT can be used to analyze the contradiction and find the X-resources needed to resolve the contradiction [7–9]. TRIZ divides contradiction into management contradiction, technical contradiction and physical contradiction. Management contradictions can be transformed into technical contradictions and physical contradictions after analysis [11], so we only discuss the solution of LT table for technical contradictions and physical contradictions.

LT Table Resolves Technical Contradictions. Technical contradiction occurs when a function produces both useful and harmful results or when introducing a useful function leads to the deterioration of one or more subsystems. It involves the interaction between active objects and tools, which can have both harmful and useful effects. The introduction of a tool control parameter m can exacerbate the technical contradiction, while the identification of an X-resource can resolve it. The evolution trend of material-field resources in three-dimensional space of LT table is represented by the diagonal line in the LT table [7–9].

Bartini used logical multiplication to find physical properties of X-resources that resolve contradictions. To do this, determine the two parameters leading to the contradiction and their LT dimensions. Multiply the dimensions of these parameters to obtain the dimension of a new parameter z , which forms a matter-field resource. Find the corresponding physical quantity in the LT table based on the calculated LT dimension of the X-resource. Adjust the positioning of parameters in the LT table dynamically to select the most appropriate physical quantity of X-resource according to the evolutionary law.

LT Table Resolves Physical Contradictions. Physical contradiction occurs when a subsystem or component is required to have a property to fulfill a function but has the opposite property at the same time. The solution to physical contradiction involves separating the two sides of the contradiction while unifying their opposites, and this is achieved through the separation principle. The transformation rules of the substance-field model in TRIZ follow the trend of “object of action - tool - X-resource”, and the

evolution trend of substance-field resources along the diagonal tends towards the velocity dimension $L/T = v$, which is consistent with the law in the LT table [7–9].

When the problem in the technical system is manifested as physical contradiction, the parameter that causes the physical contradiction should be determined first, and the specific position of the parameter in the LT table should be determined, and then the X-resource parameter that can maintain the useful effect and reduce the harmful effect should be selected based on the evolutionary trend in the LT table.

4.4 Evaluation Process of Innovative Solutions Based on FRT

FRT verifies the innovative scheme logically and begins with “injection” to verify existing causal links leading to the desired outcome [2–6]. It helps to anticipate and locate all potential UDE of proposed actions and prevent them before significant investment. FRT is useful for verifying action outcomes and avoiding UDE.

FRT evaluation process has three steps. First, establish the relationship between Desirable Effects (DE) and UDE. Second, transform the initial solution into “injection”. Finally, verify whether the solution satisfies the logical relationship between expected results. If the scheme solves the existing problems and generates no new sub-problems, it can proceed to the next step of evaluation. If the scheme cannot be implemented, it is abandoned. The whole analysis process is shown in Fig. 3.

5 Case Study

5.1 Application Background and Requirements Analysis

Hot melt welder is the core equipment of hot fusion welding technology, it uses the principle of hot fusion welding to heat the workpiece to the melting point, and through a certain force to connect the two workpieces together, can control through program, automatic operation and other ways, improve the consistency and reliability of welding, reduce the error of manual operation, improve production efficiency. The overall structure of the hot melt welder is shown in Fig. 4.

This paper collected comments on various hot welder models and brands from shopping platforms using a Python-based crawler, resulting in over 15,000 comments. Data preprocessing included removing common stop words and technical phrases, as well as marketing and logistics factors.

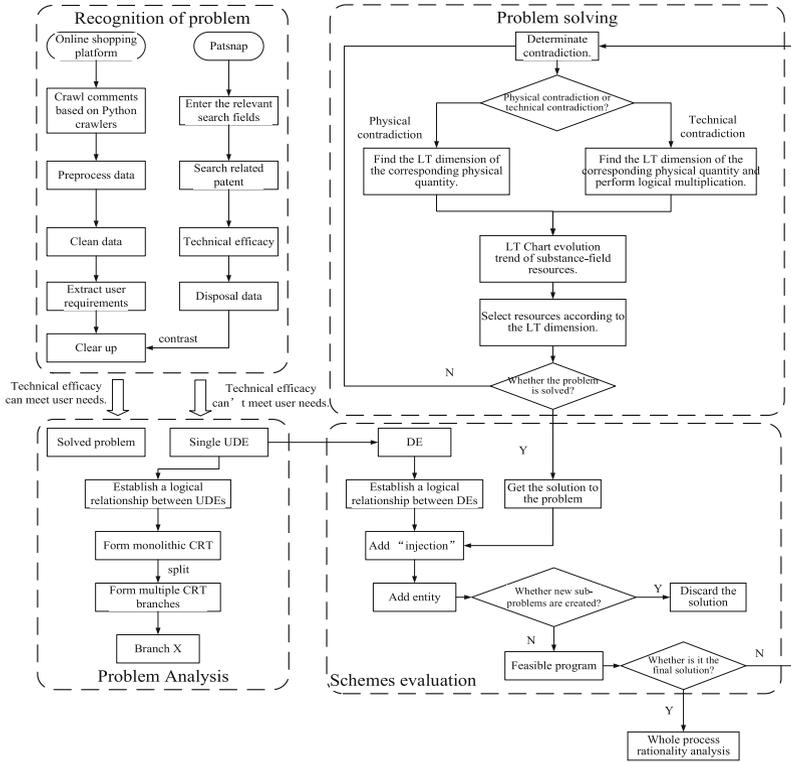


Fig. 3. Technical route.

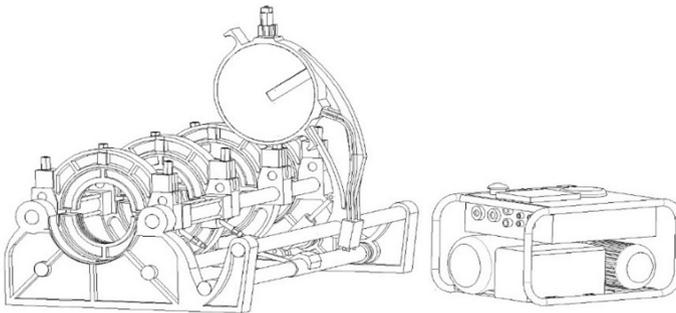


Fig. 4. Hot melt welder.

5.2 Problem Solving Process

Obtain Current Product UDEs by Comparing Customer Requests with Patents. By cleaning the comment content of Jingdong shopping platform users, the word frequency statistical list of comments on hot melt welder in the platform is obtained after statistics.

The article examines user comments and identifies “quality”, “materials”, and “workmanship” as frequently mentioned phrases, indicating that users prioritize overall performance and strength. “Speed”, “heating”, and “hot melting” are also emphasized, indicating that users value the thermal efficiency and effectiveness of the hot melt welder. Table 2 summarizes the findings regarding UDEs.

Set up CRT to Determine the Contradiction. The CRT consists of three layers: behavior, intermediate cause, and root cause. The behavior layer contains multiple user-defined UDEs, representing complaints and shortcomings of hot melt welders from user comments. The CRT is built based on logical relationships. According to Table 2, researcher could build CRT.

Table 2. Analysis of main causes of UDE.

UDE	Content	Main cause
UDE1	The hot melt welder is of poor quality	The unstable welding quality, bad heating effect, the high failure rate and poor safety
UDE2	Welding quality is not up to standard	Insufficient welding strength, welding crack, welding deformation and uneven welding quality
UDE3	The preheating time is too long	The welding material is too thick or the temperature requirement is higher. The working temperature of the hot melt welder can't meet the requirements of the material
UDE4	The heating effect is poor	The bad heating effect is usually related to the heater structure, heating time and other reasons
UDE5	Operating trouble	Trouble to adjust the temperature, long preheating, many operating steps and the operation is difficult
UDE6	Lack of milling function	There are safety risks and low manufacturing cost

Use LT Table to Resolve Contradictions. Through the establishment of CRT diagram in the previous section, we have a preliminary understanding of the current technical situation of the hot melt welder. The UDE derived from the comments can be analyzed to find the corresponding root cause. To some extent, the process from UDE to root cause can reflect the contradiction of problems. Since the analysis process of multiple contradictions is similar, the analysis process of contradiction 1 is taken as an example here, and the analysis process of other contradictions is not detailed (Table 3).

Contradictions are determined by CRT branches. Analysis of UDE2 and splitting of corresponding branch from CRT. To define the contradictions existing in the system, first of all, it is necessary to give a clear description of the problem, after which the contradictions of the system can be determined: 1. System name: hot melt welder; 2. System function: heat two sections of solid plastic pipe to molten state to complete welding; 3. System components: frame, console, heating plate and so on; 4. Core of contradiction: the object of action is polyethylene pipe and the tool is heating plate; 5. Contradiction description: improve the control accuracy of the hot melt welder, reduce the interface reaction force deviation, improve the welding quality of polyethylene pipe. But increasing the control precision will make the complexity of the system deteriorate and the cost increase. Define the problem as contradiction 1.

Determine the core physical quantity and the corresponding LT dimension (Table 4). The analysis identified improvement and deterioration parameters for each contradiction and determined invention principles based on the contradiction matrix. For contradiction 1, available principles were replication, separation, and vibration. The X-resource was identified as separating different functions in different materials, with a similarity structure used for other modules. The LT table was used to select dimensions for the technology contradiction, with pressure and surface energy as possible X-resource dimensions. The invention principle suggests a structure with functionally similar types, resulting in a scheme to adjust the control system of the hot melt welder to compensate for different net interface forces for different materials.

Table 3. Contradictions correspond to general engineering parameters and inventive principles.

Contradiction	Improvement parameter	Deterioration parameter	Principles of invention
1	No.29 Manufacturing precision	No.36 Device complexity	26,2,18
2	No.17 Temperature	No.36 Device complexity	2,17,16
3	No.6 Area of stationary object	No.11 Stress or pressure	10,15,36,37
4	No.26 Amount of substance	No.36 Device complexity	3,13,27,10
5	No.38 Extent of automation	No.36 Device complexity	15,24,10
6	No.29 Manufacturing precision	No.36 Device complexity	26,2,18
7	No.26 Amount of substance	No.31 Object generated harmful factors	3,35,40,39

Table 4. Evolution trend of X-resource.

Dimension	L^{-2}	L^{-1}	L^0	L^1	L^2	L^3
T^{-5}						Surface energy
T^{-4}					Pressure	
T^{-3}				Electric current density		
T^{-2}			Mass density			
T^{-1}		Volume charge density				
T^0	$L^{-2}T^0$					

Generate the solutions. Through the analysis of contradictions, we can determine the corresponding core physical quantity in each contradiction, and find the most suitable solution to the contradiction according to the LT dimension of the core physical quantity and the evolution trend of the substance-field resource of X-resource. The resulting solution is shown in the Table 5.

5.3 Program Evaluation Process

FRT was used for qualitative evaluation of the innovative scheme. Firstly, UDE at the bottom of CRT was reversed into DE, the intermediate reasons were adjusted appropriately, and the lines where logical questions appeared were marked. Secondly, the innovative scheme is taken as “injection”, and the specific position of “injection” is the line where the logical question appears in the FRT of the previous step. Finally, review the overall logical structure. The FRT is shown below (see Fig. 5).

Table 5. Summary of innovation schemes.

Number	Solution name	Specific efficacy
1	A control system for a hot melt welder facing different materials	Various materials have corresponding net interfacial forces and the control system can apply different net interfacial forces to materials
2	A circular heating plate resistance wire layout scheme	Multilayer wiring, staggered wiring and resistance wires with different resistance values are used to arrange the heating plate
3	Using liquid medium instead of metal resistance wire heating	The specific heat capacity of liquid is larger than that of most solids, so Liquid heating is used instead of resistance heating
4	The new material of “heat shrinkage and cold expansion” is used to replace the heavy pipe	The new material used in the pipeline maintains its mechanical properties while reducing processing difficulties by allowing thermal fusion welding to reduce shrinkage thickness as temperature rises
5	A heating plate temperature monitoring and control system	The temperature of multiple points of the heating plate is monitored, and the effect of temperature change is realized by adjusting the temperature of the resistance
6	A tool self-locking device	Infrared sensors are arranged around the hot melt welder. When objects are detected around the machine, the tool self-locks and stops running. When there is no object within 2m, the tool runs
7	An automatic hot melt welder	Liquid heating replaces resistance heating and integrates the functions of the milling cutter and heating plate, increasing welding process monitoring and reducing operating steps

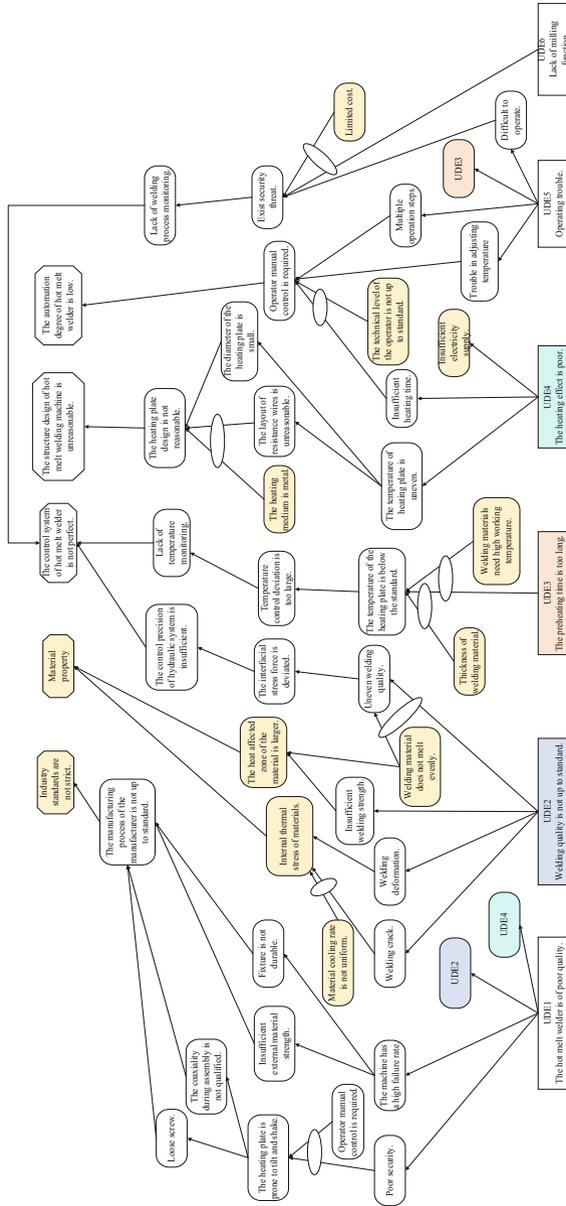


Fig. 5. FRT of hot melt welder.

6 Conclusions

Starting from user comments on shopping platforms, this paper uses CRT and FRT, two basic tools of TOC, to analyze and evaluate problems. In the face of the contradiction in the system, the invention principle and LT dimension are used to solve the problem

(see Fig. 3). Taking the hot melt welder as an example, the rationality of the method is verified.

User comments may not fully address technical issues, and the CRT construction process is subject to subjective influence. Researchers may have varying perspectives, and professional knowledge or practical experience is needed for innovative solutions. Non-technical factors can be addressed through management methods [12]. Future research will focus on improving the objectivity of the methodology.

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The Impact of Using Resources on Waiting Time in the Queuing Model with FlexSim

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Abstract. This paper is part of a sequence of articles by the author. The previous report identified the method and result of using a contradiction matrix and 40 inventive principles to trigger three consecutive resources and alleviate the waiting time measurement error in the general framework. A FlexSim program was executed and the results compared, to show the superiority of our approach in the form of given distributions in incoming customer events and processing times. However, no detailed contrast between the content vs. time plots were made. This paper gives a simple sequence of inter-arrival and process time and shows the intrinsic significance of the dynamic waiting time in five cases. The simulation is run for 25 s, to sketch the influence of the three consecutive resources. Finally, some insights are provided by comparing the waiting time for each customer in five cases.

Keywords: Content vs Time Plot · Dynamic Waiting Time · Resource

1 Introduction

1.1 A General Review

A resource is a means to accomplish a function. When the means proposed by a system cause a contradiction, it is because of the mismatch in attributes between the giver and the receiver of the function. If the attributes of the giver or receiver of the function can be adjusted, the contradiction problem can be resolved entirely [1]. The giver and receiver of this function can be regarded as a resource. However, through the transformation of resources, their attributes can be adjusted to an appropriate quality or quantity, as well as the appropriate time for resource use, and the appropriate location for their use, so that conflicts can be resolved and ideal solutions can be achieved.

When seeking resources, the most challenging task is to use the hidden resource. The so-called ‘hidden resource’ means that the resource already exists but needs to be transformed appropriately to meet the needs of the problem [2]. This study applies a hidden resource to the M/M/1 waiting time problem of the simulation software FlexSim, to solve the problem of inaccurate measurement of customer waiting time in a queue. This study is an extension of the discussion in the paper by Deng [3]. The original problem and tentative solution are presented as follow.

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A simple queuing model with two possible outcomes is presented: a happy customer and an unhappy customer due to waiting for more than 200 s. To simulate this problem in the original attempt, one uses incoming customers to the queue as a trigger to update the waiting time. This approach saves a timer to keep track of time for each customer in the queue, causing an inaccurate measurement of the waiting time in the queue. This phenomenon creates a technical contradiction: one wants to save a timer (parameter 26, the amount of substance) yet causes inaccurate measurement (parameter 28, accuracy of measurement). From the contradiction matrix [1], one can easily arrive at inventive principles (IP) 13, 2, and 28. One can use these IPs to trigger the following possible solutions.

1. Use outgoing customers from the waiting line to update the time (this should have been thought of in the tutorial.) It is from IP 13.
2. Use incoming customers to the service desk to update the time (this is thinking outside the box.) It is from IP 2.
3. Use outgoing customers from the service desk to update the time (this is thinking outside the box.) It is from IP 2.
4. Use a measurement error limit of 30 s for waiting time and update the waiting time automatically whenever there is no update for more than 30 s (this is thinking outside the box). It is from IP 28.

That paper [3] proposed a problem structure and a means of resolving contradictory problems. However, the dynamic effects produced by these means were not stated. This study quantifies the dynamic effects and explains why these effects occur.

1.2 Problem Description

The waiting line issues explored in this study are as follows. First, there is a waiting line to receive customers who enter the system. The customer has two options: 1) Receive service from the service desk or 2) When waiting time exceeds 200 s, leave the waiting system angrily. This research wants to understand the waiting time of customers in a waiting line, as a way to improve the service quality of this system.

There are two solutions to this problem in FlexSim: solve problems using the 3D Model (3D Model) or the process flow model (Process Flow Model). The 3D Model is an object-oriented problem-solving method. Each object represents a fixed resource (Fixed Resource) that performs a specific function, which can be a mechanism for generating customers, a waiting line, a service desk, or an exit (Sink). 3D Model is a visual and intuitive modeling method suitable for beginners. The process flow model is an activity-oriented problem-solving method. The two modeling methods are described below.

1.2.1 3D Model

The 3D model has the advantage of being easy to understand and learn. It regards each object as an entity in the real world. An object is either fixed, such as a machine or waiting line, or mobile, such as customers, operators, or vehicles. Each object is connected with the others by a connecting line, to show how the flowing object moves around the system. The customer has two options: 1) Receive service from the service desk, 2) When waiting

time exceeds 200 s, leave the waiting system angrily. Thus, there is no line between the waiting line with the server and the existing sink for unhappy customers, see Fig. 1.

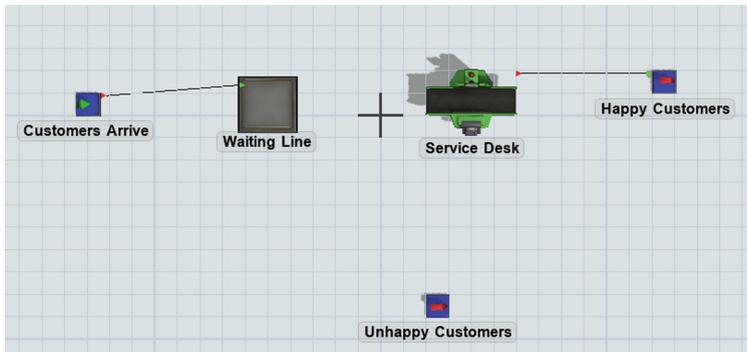


Fig. 1. A 3D model.

1.2.2 Process Flow

In the process flow, the activities are used to represent what is happening in the simulation. Unlike the 3D model, the object represents what the entity does. The activities are also connected by a line, to show how activities are linked. The process flow is like a program and not easy to visualize. However, because it is abstract it can represent more complex systems in a logical way, as shown in Fig. 2. Figure 2 shows that there are two lines from the activity *Acquire: Get Service*. Exit line 1 goes to the activity *Delay: Service Time*, while exit line 2 goes to *Sink: Unhappy Customers*. This resembles the two possible outcomes for customers in the waiting line. Furthermore, there is a blue line connecting *Resource: Service Desk*, which means that the customer must acquire a resource first, before it can proceed to the service.

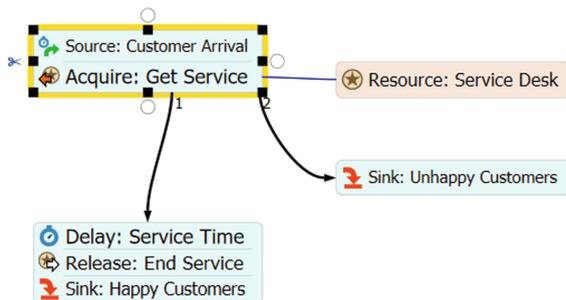


Fig. 2. Process flow.

1.3 Resource Management

Based on the contradiction matrix, one can derive three consecutive resources to mitigate the measurement error in waiting time. These resources are: 1) add one more event as the outgoing customer from the waiting line, to trigger the update of the waiting time of the customers in the waiting line (this is called 3D Model: Stage 1). 2) In addition to the outgoing customer from the waiting line, two more events are added: incoming customer to the service desk and outgoing customer from the service desk (this is called 3D Model: Stage 2). 3) Besides the events in the second stage, one more event is added, i.e., when the waiting time is not updated for more than 30 s, the system will update it automatically (this is called 3D Model: Stage 3) (Deng [3]).

The simulation result of 3D Model: Stage 3 were highlighted below. The average aggregate waiting time error is reduced from 22.13% to 2.37%. The error is reduced from 99.42% to 14.89% for the maximum waiting time. If considering different customers, one finds that the average waiting time error is reduced from 27.50% to 0% for a happy customer. The error is reduced from 77.43% to 0% for the maximum waiting time. As for the unhappy customer, the average waiting time error is reduced from 18.94% to 5.18% and the error is reduced from 99.42% to 13.89% for the maximum waiting time. Thus, new resources completely solve the measurement error of waiting time in the case of a happy customer. For an unhappy customer, the error is significantly reduced but not eliminated.

1.4 Probe Unknown Area

Even though the performance of resource management is good in 3D Model: Stage 3, the ways in which the content of the waiting line and server status evolve over time are still unknown. This paper bridges the gap by investigating content over time (in the waiting line as well as the system) and the status of the server over time, for given inter-arrival times and service times, similar to those in Beaverstock et al. [4]. The customer number is indicated in the three plots, to show where the customer is in the waiting line and who is being served by the server. The details are given below.

2 Literature Review

2.1 Queue Length Information

Time is precious. Whenever one visits a store to buy coffee or groceries, for example, people are time-sensitive and prefer to minimize their time spent at the store. There is another factor which influences customer decisions when visiting the store: the quality of the products (Ghosh et al. [5]). Taking coffee as an example, since the omnichannel service is available because of the rapid growth of the application (app), it is very convenient to order coffee via the app; however, will customers always buy coffee online? Not necessarily. Even though ordering coffee is time saving, the customer will still need to get it at the store, and they want to make sure that the coffee is not cold. The queueing information at the store could influence the customer so that they may buy it online or offline or, even, not buy it at all. This illustrates the fact that queueing information is crucial to the purchasing decisions of customers, as well as to the managers of the stores, for management purposes.

Queue-length information can influence the customer strategy as to whether to join the queue at the store. When customers can observe the service-queue length prior to travelling, via service providers or through Google search, the probability of their travelling monotonically decreases with observed queue-length (Hassin et al. [6]). Therefore, when system congestion is high, it is better for the service provider to increase throughput by disclosing the queue-length information, whereas at low congestion, the provider benefits from concealing the information.

The queue-length information not only influences the purchasing decision of customers joining the queue, it will also drive the renegeing behavior in the queue (Aksin et al. [7].) Askin et al. [7] showed that a patience-enhancing effect of a queueing experience starts when customers observe a fast-depleting queue. On the contrary, a customer could abandon a queue if they perceive that waiting is above a threshold. Of course, service time is also important for forming a renegeing strategy as they define 'short' and 'long' service times relative to expectations. When a customer observes relatively short service times early in the wait, an early relative progress effect increases patience for the entire wait.

2.2 Research Gap

When measuring the performance of a service system, most researchers only focus on a macroscopic perspective of average queue length, average waiting time and busy rate of a server. So far, there has been no microscopic perspective about how the customer leaves (reneges on) the queue. In particular, there has been no research on the actual waiting time of both happy and unhappy customers. This research follows on from the resource management issue, from a TRIZ perspective (Deng [3]), and investigates how different resource strategies can influence the microscopic behavior of the customer by using a hypothetical example, similar to Beaverstock et al. [4]. Three different time plots for queue length, customers in the system, and busy status of a server are generated in each resource scenario. Furthermore, each customer ID are presented in the three graphs, to show how customers move around as the time advances.

3 Experimental Setting and Results

Suppose that there is a simple queueing model with inter-arrival, arrival and service times, as shown in Table 1. Note that the first customer comes in at 0 s, i.e., when the system is available. Time is recorded in seconds and the customer will leave the queue if they have waited more than 3 s. The simulation time is run for 25 s and the simulation runs are analyzed in five cases, as shown below. For Case 5 in Model: Stage 3, the system will update the waiting time whenever no update occurs within 0.45 s. The update interval of 0.45 s is calculated from the ratio between waiting threshold and update interval between the previous case study and the current case study. It should be noted that, in the previous case study, the corresponding waiting threshold and update interval were 200 s and 30 s, respectively; whereas, in our case, the waiting threshold drops to 3 s, so it is easy to calculate the update interval to be 0.45 s.

Table 1. Event time.

	1	2	3	4	5	6	7	8	9	10
Inter-arrival time (s)	0	2	1	2	3	2	6	4	4	1.5
Arrival time (s)	0	2	3	5	8	10	16	20	24	25.5
Process time (s)	7	1	5	0.5	3.5	3	2	1.5	3	4

3.1 Case Studies

3.1.1 Case 1: Timer

If the timer is installed for each incoming customer, then the time plots for the queue length, customers in the system and server busy status are shown below (Fig. 3).

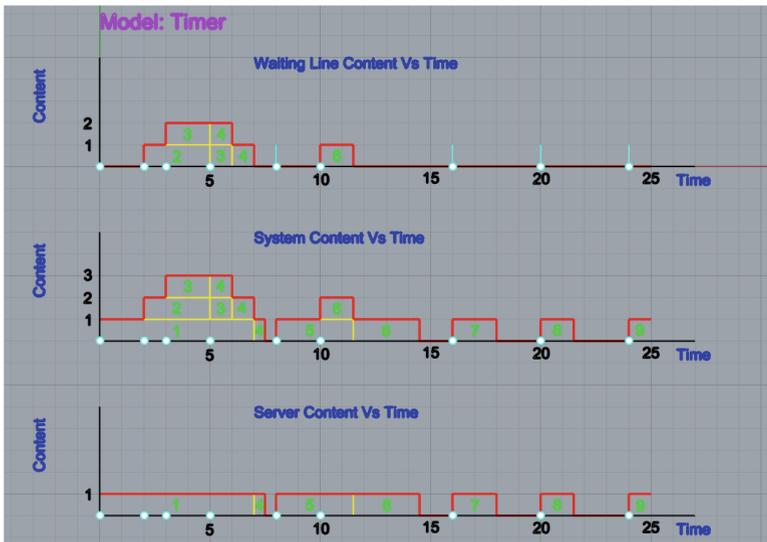


Fig. 3. Time plots for Case 1.

The time for an incoming customer to the system is represented as a round dot displayed on the axis of abscissas. Since the first customer comes in at time 0, there is a round dot at 0 on the axis of abscissas. Spikes are shown in the waiting line content vs time plot, indicating that, at that moment, a customer passed through the waiting line but did not stay.

The three time-plots provide a vivid status description of the discrete simulation. For example, during time 5–6 s, there are three customers in the system. Customer 1 is being served and customers 3 and 4 are waiting in line. From the server content vs time plot, it is clear that, during the 25 s simulation run, there are two unhappy customers (customers 2 and 3) leaving the system, and their waiting time is exactly 3 s. There are

six happy customers (customers 1, 4, 5, 6, 7, and 8) leaving the system. Their waiting times are 0, 2, 0, 1.5, 0, and 0 s, respectively. It is easy to read the waiting times from the system content vs time plot. For example, customer 1 is not shown in the second tier or above, so their waiting time is 0 s; whereas, customer 4 appears for 2 s in the second tier or above, so their waiting time is 2 s.

3.1.2 Case 2: Model-Default

In this case, the incoming event is used as a trigger to update the waiting time in the queue. Then, the time plots for the queue length, customers in the system and server busy status are shown below (Fig. 4).



Fig. 4. Time plots for Case 2.

From the server content vs time plot, it is clear that, during the 25 s simulation run, there is one unhappy customer (customer 3) leaving the system, and their waiting time is 5 s, which is above the threshold of 3 s. This is because the waiting time for customer 3 is only updated as an incoming customer to the queue. In this case it is at time 8 s. Also, customer 3 is ready to get service but is reneged to the unhappy sink. It shows that when pulling the customer from the queue, the priority of the unhappy sink is higher than that of the service desk. There are seven happy customers (customers 1, 2, 4, 5, 6, 7, and 8) leaving the system. Their waiting times are 0, 5, 3, 0.5, 2, 0, and 0 s, respectively. In summary, using the model-default case, it is possible for both the happy and unhappy customers to wait for more than the threshold of 3 s.

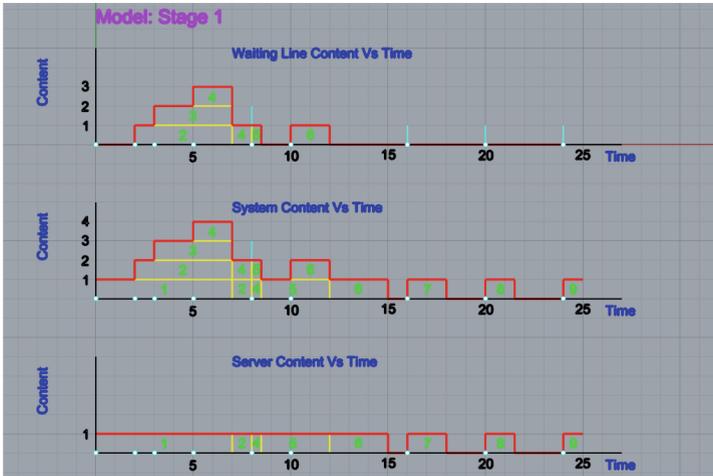


Fig. 5. Time plots for Case 3.

3.1.3 Case 3: Model-Stage 1

This is the case for adding one more event, as the outgoing customer from the waiting line triggers the update of the waiting time of the customers in the waiting line, in addition to the default model in Case 2. Then, the time plots for the queue length, customers in the system and server busy status are shown in Fig. 5.

There is one unhappy customer (customer 3) leaving the system and their waiting time is 4 s, which is above the threshold of 3 s. This is because the waiting time of customer 3 is updated when they enter and leave the queue. In this case, it is customer 1 leaving the server at a time of 7 s which causes customer 2 to leave the queue and enter the server. Note that, in Case 2, the unhappy customer (customer 3) waits for 5 s but the unhappy customer 3 waits for 4 s.

There are seven happy customers (customers 1, 2, 4, 5, 6, 7, and 8) leaving the system. Their waiting times are 0, 5, 3, 0.5, 2, 0, and 0 s, respectively. Thus, it is clear that additional resources in Case 3 do not improve the measurement of the waiting time for the happy customer; however, it does reduce the measurement of the waiting time for the unhappy customer.

3.1.4 Case 4: Model-Stage 2

This case is for adding two more events, as the incoming and outgoing customer from the server triggers the update of the waiting time of the customers in the waiting line, in addition to the default model in Case 3. The three corresponding time plots are shown below.

There are two unhappy customers (customers 2 and 3) leaving the system and their waiting times are 5 and 4 s, respectively, which are above the threshold of 3 s. This is because, at time 7 s, the waiting time of customers 2 and 3 are updated when customer 1 leaves the server. At this moment, the waiting time for customer 2 is 5 s, which is more

than 3 s, and so they leave the system and become an unhappy customer. Customer 3 has a similar experience. It should be noted that there is a difference for customer 2 (between Cases 3 and 4) although, in two cases, customer 2 is positioned first in the waiting line and ready to receive the server. We need to consider why customer 2 receives service in Case 3 and yet, in Case 4, customer 2 did not receive service? It is because in Case 3, there is no mechanism to update the waiting time of customer 2. So, customer 2 enters the server, triggering the update of the waiting time of customer 3. In Case 4, because customer 1 leaves the server, it triggers the update of waiting time of customers 2 and 3 immediately, issuing the leaving of the two customers unhappily (Fig. 6).



Fig. 6. Time plots for Case 4.

3.1.5 Case 5: Model-Stage 3

In Case 5, besides the events in the second stage, one more event is added, i.e., when the waiting time is not updated for more than 0.45 s, the system will update it automatically. The corresponding three time plots are shown below.

There are two unhappy customers (customers 2 and 3) leaving the system and their waiting times are 3.45 and 3.35 s, respectively, which are above the threshold of 3 s. This is due to the fact that the system updates the waiting time every 0.45 s if nothing happens during the time interval.

There are six happy customers (customers 1, 4, 5, 6, 7, and 8) leaving the system. Their waiting times are 0, 2, 0, 1.5, 0, and 0 s, respectively. It is clear that additional resources in Case 5 do improve the measurement of the waiting time for happy customers and its effect is the same as that in Cases 1 and 4. Moreover, compared to Case 4, it further reduces the measurement error of the waiting time for the unhappy customer (Fig. 7).



Fig. 7. Time plots for Case 5.

3.2 Analysis of the Five Cases

Comparing the five cases clearly shows that adding all of the resources in Model: stage 2 (Case 4) completely renders the correct measurement of waiting time for the happy customers. However, it has no effect on the measurement error of the waiting time for the unhappy customers. This problem can only be mitigated by the additional resources implemented in Model: stage 3 (Case 5). The waiting times are summarized in Table 2.

Table 2. Waiting times for each customer in 5 cases.

	Cus 1	Cus 2	Cus 3	Cus 4	Cus 5	Cus 6	Cus 7	Cus 8
Model: Timer	0	3	3	2	0	1.5	0	0
Model: Default	0	5	5	3	0.5	2	0	0
Model: Stage 1	0	5	4	3	0.5	2	0	0
Model: Stage 2	0	5	4	2	0	1.5	0	0
Model: Stage 3	0	3.45	3.35	2	0	1.5	0	0

From Table 2, it is clear to see the benefit of using proper resources to calculate the waiting times of both happy and unhappy customers. The waiting times of the unhappy customers are marked in red. The waiting times of the happy customers (reasonable times less than 3 s) are in black; whereas, the unreasonable waiting times are marked in blue. As one can see from the first model: timer, there should be only two unhappy customers with six happy customers for the simulation run of 25 s. The waiting time for the unhappy customers is exactly 3 s; whereas, for the happy customers, their waiting times are less than 3 s.

As we proceed to use additional resources to update the waiting time in Model: Stage 1, the measurement error of unhappy customer 3 is mitigated; it is reduced from 5 s to 4 s, even though the inflation problem of waiting times for the happy customers remain the same.

As more resources are used in Model: Stage 2, there are two unhappy customers once more. This is the normal status for the unhappy customers, even though their waiting times are still inflated. As for happy customers, their waiting times become normal and are the same as the ones in Model: Timer.

As one uses the update interval of 0.45 s to update the waiting time in Model: Stage 3, one can see that the inflated waiting times for the unhappy customers are mitigated while the waiting times of the happy customers remain correct, as in the Model: Stage 2. Therefore, one can say that the resource usage in the consecutive three stages gradually improve the waiting times for both the happy and unhappy customers. It is very important to use proper resources with the help of the TRIZ contradiction matrix.

4 Conclusions

4.1 Key Finding

The key finding of this research is that, through the inventive time plots for the queue length, system number, and server busy status, one can clearly see the progressive improvement of the measurement of waiting time in a simple reneging queue. If one only relies on 'common sense' to use the incoming customer to trigger the update of the waiting time in the queue, one will suffer severely misleading information on the waiting times of both happy and unhappy customers. Two unhappy customers will be mistakenly identified as one. Moreover, the waiting time for the unhappy customer is inflated, as well as the majority of the waiting times for the happy customers too.

Fortunately, these problems can be greatly mitigated as one uses more resources via the TRIZ contradiction matrix. In the ultimate version of Model: Stage 3, the waiting times for the happy customers are completely restored to the normal condition. Moreover, the number of the unhappy customers is not only correctly restored to be 2, the measurement error of waiting times is also significantly mitigated.

The time plots for customer ID, marked in the plot, significantly help us to understand what is going on at each moment, dynamically. The question of who is in the waiting line, by which permutation they are in the line and who is being served are crystal clear in the time plots. This is very helpful, especially in the reneging queue problem. Without the customer ID in the time plot, it is difficult to read whether the customer becomes happy or unhappy.

Table 2 reveals that, under the Model: Stage 3, the waiting times for unhappy customers 2 and 3 are 3.45 and 3.35 s, respectively. These are very close to the correct waiting time of 3 s and they have been improved significantly from 5 s in the model: default. It should be noted that, in model: default only customer 3 is treated as being unhappy, while customer 2 is mistakenly identified as a happy customer, even though their waiting time is 5 s, far more than the threshold of 3 s. The waiting times for the happy customers 1, 4, 5, 6, 7, and 8 are 0, 2, 0, 1.5, 0, and 0 s in the Model: Stage 3. They are identical to the correct model, model: timer, and are significantly improved

from the model: default, where the corresponding waiting times are 0, 3, 0.5, 2, 0, and 0 s, respectively. Model: default mistakenly treats customer 2 as a happy customer.

4.2 Practical Implications

Maister [8] reported that extra waiting time causes customer resentment. Knowing the accurate waiting time of a frustrated customer is very important from a managerial perspective; misleading information on waiting times can cause significant problems in retaining potential customers. Thus, when a business system is complex and needs to be analyzed by simulation, proper consideration of the resources is very helpful in obtaining an accurate waiting time for both happy and unhappy customers.

Although the application of resources in the simulation is demonstrated in FlexSim, it does not mean that it cannot be extended to other simulation packages. The significance of applying resources, with the help of the contradiction matrix and inventive principles in TRIZ, is that the proper use of resources can help reduce the measurement error of waiting time. Those resources can escape the notice of a programmer without the concept of TRIZ.

4.3 Research Limitations

The example studied was taken from a tutorial in FlexSim and the empirical data for the inter-arrival times and service times are similar to the work of Beaverstock et al. [4]. We used these data to demonstrate the effect of resources on the waiting time. Our work may be considered as a case study. Future work could focus on the theoretical analysis of how the measurement error is related to the tolerance of waiting time.

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Incorporating TRIZ Methodology into Semi-structured Interviews for Innovative Insights

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Abstract. The article presents a novel approach to problem-solving in the maritime industry by combining the use of TRIZ with Qualitative tool which is Semi-Structured Interviews (SSI) to identify and resolve contradictions between different objectives. First, the SSI were conducted with expert in Tunisian Maritime Ship owner. Second, the results obtained from SSI were analyzed and presented as objective need to be meet. Third, Contradictory objectives will be mapped to contradictory parameters using a System of Contradiction (SoC). Finally, TRIZ Matrix of parameters is used to solve the different conflicts that arise between objectives. It's worth noting that we are studied a non-technical parameter, therefore, fitting between TRIZ parameters and evaluation parameters of the optimized system should be done. As a result, solution principles are proposed.

Keywords: Qualitative Research · Semi Structed Interview · TRIZ · Maritime Transportation

1 Introduction

Research is a vital tool for gaining knowledge and understanding about the world around us. One common research method is Qualitative Research (QR), which involves exploring people's experiences, attitudes, and perspectives through techniques such as interviews, observations, and document analysis. According to [1] the objective of a QR study is to well understand the topic and get closer to the goal. In order to conduct a QR study properly, several techniques are available:

Individual interviews: Its purpose is to gather as much information as possible from the respondents. Individual interviews are made up of three types: (structured interviews, semi-directive, and unstructured interviews). A structured interview is a type of interview in which the researcher asks a predetermined set of questions to each participant

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(example questionnaires). Contrary, unstructured Interview, which give the respondent an opportunity to express himself without specific themes [1]. This type of interview is useful to collect very large data. However, these data will obviously be very complex to analyze. For this reason, the semi-directive interviews come with balance structure that provides an opportunity for researchers to gather rich data from participants while allowing for specific direction. It aims to guide the respondent through a pre-established interview guide whose main objective is to remember that all the topics on the guide interview will be addressed and get as much useful information as possible.

Focus Groups: A focus group is a group discussion in which participants are asked to share their thoughts and experiences related to a specific topic among a group of people.

Observations: Consisting of recording what you have seen, heard, or encountered in detailed field notes.

SSIs (Semi-Structured Interviews) are widely used for collecting data, despite their flexibility. Participants may express contradictory viewpoints or provide inconsistent information due to various factors such as different perspectives, contexts, or experiences. These contradictions can then be used as the starting point for applying TRIZ (Theory of Inventive Problem Solving), which provides a structured approach for identifying and resolving contradictions through innovative solutions. This technic, was originally proposed by Altshuller, and have been predominately applied to technical problems involving engineering of tangible products [2], mechanical design [3] trying to offer innovative product structures by considering different combinations of 40 principles in a $39 * 39$ contradiction matrix. Since there are not only technical problems in the real world (Management process, services, human factors), problems may also contribute to firms [4]. For example, [5] have studied the power of TRIZ in solving different kinds of contradictions that can arise when safety issues are taken into account at diverse stages of the product development process.

The application of the TRIZ method to resolve contradictions within the outcomes of semi-structured interview problems in the maritime transportation sector is one of the outcomes of this research which will be structured as follow: we will review at first the current state of the art in order to assess the applicability of TRIZ with QR methodologies across various non-technical service fields. Second, we will provide an overview of the methodology used in this study followed by a detailed case study of the application of TRIZ and SSI in a Tunisian maritime company.

2 State of the Art

It is crucial to highlight the importance of conducting a comprehensive literature review to evaluate the potential of integrating TRIZ and QR methodologies, such as semi-structured interviews or similar, in improving processes, product and service in various context as shown in the Table 1.

We will focus specifically on service industries where non-technical problems have been addressed using TRIZ and QR methodologies, and we will review relevant literature in these areas to determine the potential benefits and limitations of this approach. Based on the data in Table 1, it is evident that TRIZ can be a valuable addition to QR methods.

Table 1. State of the art.

Field	QR tool + TRIZ	The main contribution of the article	References
Transport	Focus Group	Use Soft Systems Methodology and TRIZ to engage stakeholders and resolve conflicts in infrastructure megaprojects, using a focus group as collected data tool	[6]
	Questionnaire, observations, focus group	Elaborate TRIZ techniques to resolve service quality contradictions in an airline, based on passengers' feedback	[7]
	Questionnaire	Combine the SERVQUAL and TRIZ methods to improve airport passenger services, through initial collecting Data (questionnaire)	[8]
		Use TRIZ method approach with the QR method (questionnaire) based on SERVQUAL's five dimensions to measure customer satisfaction	[9]
Project Management	Questionnaire	Identify the impact of TRIZ) and close-ended questionnaire in reducing the delay in construction projects	[10]
Healthcare services	Questionnaire + Observation	Propose a novel service design model incorporated TRIZ with qualitative and quantitative methods (AHP + FMEA) for New Healthcare Service Conceptualization	[11]

(continued)

Table 1. (continued)

Field	QR tool + TRIZ	The main contribution of the article	References
	Questionnaire	Develop a methodology to improve the quality of health-care service using questionnaire and SERVQUAL scale parameters to TRIZ	[12]
		Identify and resolve the conflict between patients' expectations and the timely provision of services using TRIZ and feedback gathering	[13]
Tourism	Questionnaire	Use the TRIZ concept to formulate an expert questionnaire and then analyzed it with the DEMATEL matrix	[14]
		Provide a questionnaire alongside an AHP-TRIZ framework to identify various factors affecting tourists' decision-making behavior and businesses' desire to make profits	[15]
Banking	Observation technics	Demonstrate the impact of usage of Lean Six Sigma with TRIZ methodology in the banking sector through observation techniques	[16]
Teaching	Questionnaire + SSI	Solve language-teaching problems using QR construct teaching quality determinants that correlate with the TRIZ 39 parameters	[17]

However, it is important to acknowledge the limitations of these findings. Specifically, there is currently no evidence supporting the use of TRIZ with non-technical contradictions in the maritime transportation service through SSIs. Only one study has been found that utilizes TRIZ with SSIs, but it focuses on technical contradictions in the design domain [18]. To address this research gap, this study aims to investigate the integration of TRIZ with SSIs in the maritime domain to address non-technical contradictions and enhance processes and services.

3 Methodology

To generate TRIZ contradictions, it is necessary to gather data and analyze the existing process to identify the underlying problems and contradictions that need to be resolved using the TRIZ methodology. As shown in (Fig. 1) we employed a four steps approach that aims to apply TRIZ method to a subset of qualitative results.

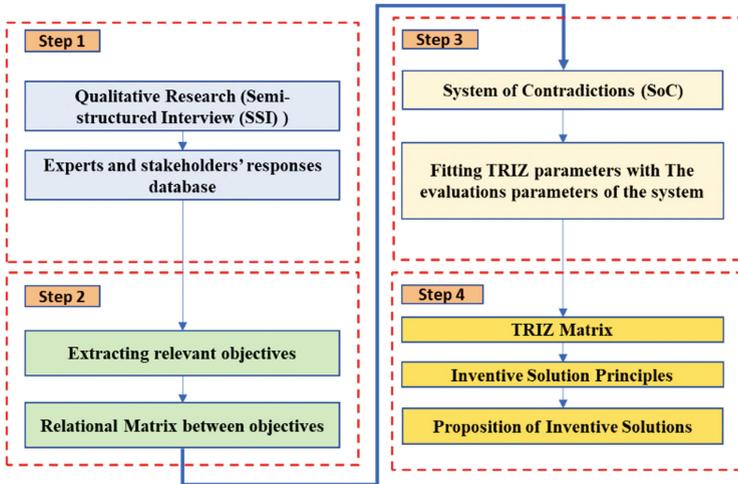


Fig. 1. Methodological framework.

Step 1: Qualitative research (Semi-structured interview frameworks):

As QR tool, we use SSI framework for extracting and analyzing expert answers.

Step 2: Objective extraction and relationship mapping:

These answers are transformed into objectives that need to be reached. Once the objectives are identified, it is essential to identify the relationship between them.

Step 3: Identifying Contradiction Parameters:

The objectives that present the contradiction between them are then represented by a System of Contradictions (SoC) to highlight the conflict between them.

Step 4: Inventive Principles and Solutions Using TRIZ Matrix:

Once the contradictions are identified, we can use the TRIZ 39 * 39 matrix [18] to propose inventive principles. Based on these inventive principles, potential solutions can be generated that should aim to resolve the contradictions identified in our process.

4 Tunisian Maritime Case Study

The case study will be conducted in accordance with the methodology section, which outlines the steps to be taken. The shipowner is already using DMP (Decision Making Process), but with the exploitation of additional type of vessels, it no longer meets their requirements for personnel allocation.” We should note that Data and results were provided by a shipowner of a maritime company in Tunisia.

4.1 Qualitative Research: Semi-structured Interview Frameworks (Step 1)

The SSI were conducted with intention to guide the respondents' answers around various themes that were predetermined by the interviewers in an interview guide.

Sample Selection. As presented in (Table 2) 8 interviews were conducted, with varying levels of experience and expertise in the maritime industry, belonging to different using interviews that last from 1 to 1.5 h.

Table 2. Interview information number.

Interviewer	Stakeholders / Qualification					Duration (min)
	Senior management employee	Armament Director	Pilot	Head mechanical-Engineer	Syndical agent	
1	X		X			78
2	X					65
3	X					73
4		X	X			82
5		X	X			76
6			X		X	67
7				X		62
8					X	58

Conducting and Analyzing Interviews Using the Interview Guide. Themes previously defined by the interviewers and recorded in an interview guide.

Topic 1: Need for a new decision support tool for seafaring staff scheduling:

What are the reasons behind the need for a new decision support tool?

- All of the interviewees (100%) affirmed that expanding the fleet and operating vessels with different categories (car ferries with maximum length 93.5 m) requires a new decision support tool with new constraints and objectives.
- The DMP used does not take into account aspects relating to Human resources management (qualification, replacement of personnel during periods of leave, illness, etc.) (50%).

What kind of information and parameters should be taken into account during the assignment process?

- Vessel category to be assigned in order to meet human resource requirements based on manning visa (75%).
- Identify the position(s) which each employee could get (75%).

What measures have been taken to face unforeseen circumstances?

- Some dock personnel are qualified to work on ships for various positions. In case of need, these employees can be assigned (88%).

Topic 2: Expectations and challenges of the new decision support tool for seafaring staff scheduling:

What is the assignment process that is used for assigning the staff member?

- The DMP that is already proposed take into consideration regulation constraints (working hours, rest hours, day-off, workload fairness), but could not meet the new requirements to meet decision maker challenges (100%).

Are there any changes of objectives, constraints related to the assignment process?

- Try to keep a fixed structure composed of the captain, chief mechanic and team leader (50%).
- Try to keep the constraints and objectives that are already considered in the current decision-making process (100%).
- keep, as much as possible, a homogeneous and stable composition of teams.
- Ensure the rotation of personnel on different vessels to enhance competences (38%).
- Respect the requirements of the captain and the chief engineer for the selection of other crew members (e.g., mechanics and greasers) (63%).
- Ensure that the right worker with the specific qualification is assigned to the right type of vessel (88%).
- The level of experience (trying to ensure a balance between the different teams) (63%).

Are there any other aspects should be considered in the scheduling process?

- Respect, as much as possible, the preferences of employees (25%).
- Propose an online version that allows different employees to access to indicate their preferences or request permutations (with validation by their superiors) (25%).

Topic 3: Stakeholders' interaction, and personnel involved throughout the allocation process:

Who are the stakeholders in the new assignment process and what are their roles?

- The employees that each captain could refuse to include among the members of his sailing team (75%).
- Chief mechanics and maritime team leader can also restrict the levels of their subordinates (75%).
- The HRM (Human Resources Manager) is the person who defines the position(s) that each employee can fill (50%).
- The director of armament who define the ship allocation schedule (50%).

Topic 4: Do you have any additional information to provide?

Propose a DMP for the assignment of dock staff (13%).

4.2 Objective Extraction and Relationship Mapping (Step 2)

In this Step, will be transformed the extracted answers of participants (from SSI results), into specific objectives. We are committed to maintaining the same objectives of the current decision support system, that are used in the maritime company, concerning regulatory constraints such as working hours and rest time, as well as objectives related to workload fairness. Those results are derived from [19]. We should note that the future decision-making process will be built upon these results and incorporate new objectives and constraints that are extracted from SSI. Therefore, there are two sets of objectives and constraints to consider: the existing ones from the previous DMP, and the newly identified objectives and constraints from the latest SSI results

Extracting Relevant Objectives. With multidisciplinary meeting, we have extracted the most important objectives (according to the shipowner) that should be meet (Table 3).

When multiple objectives are pursued simultaneously, conflicts can arise between them. Therefore, it is crucial to carefully analyze the relationships between them to identify any contradiction and determine how best to address them.

Relational Matrix. Achieving those objectives might appear challenging when studying relation between them (Fig. 2).

Some of them could present correlation (blue color); it means that one objective moves in the same direction as the other one. However, contradiction (red color) means that the objective is in reverse direction of the others. Finally, when two objectives are not related (grey color), it means that they are independent and have no direct correlation

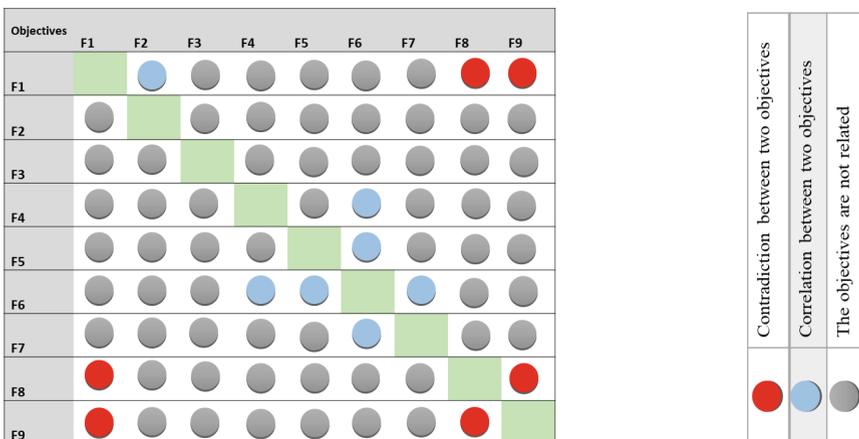


Fig. 2. Objectives Relational Matrix.

Table 3. Combining Previous and New Objectives and Constraints for Decision Making Process (DMP).

Current DMP		Latest DMP	
F1:	Maximize affinity/minimize conflicts	F7	Respect employee preferences
	The shipowner aims to promote positive relationships between members to minimize any conflicts that may arise, through a stable team composition and an extended periods of working together		The company should strive to take into account the employee's preferences, such as their preferred working hours or job assignments
F2	Respect the working hours set by the government	F8	Maintain a certain level of competences
F3	Respect rest day/periods		The company should ensure that each team has a certain level of expertise required for different type of vessels
	Ensuring that employees are given adequate time to rest between shifts, as well as their days off	F9	Maintain a certain rotation of employees between all the ships
F4	Equity in the number of posts	F9	Since the types of ships are different, the shipowner must rotate employees among different ships to ensure that each employee has acquired all the necessary competences for each type of ship. It should be noted that in the transport sector, generally the promotion of employees in this regard to positions is done with the number of hours exercised and the type of equipment used
	Ensuring a fair distribution of posts between employees		
F5	Equity in the type of post		
	The company has three shift types (regular, special, reinforcement), and equal opportunity should be provided equally to all employees		
F6	Equity in terms of salary bonuses		
	The company should ensure that workers are rewarded fairly for their work		

or influence on each other. According to our context, we will focus on conflicting objectives, and we will solve these contradictions using TRIZ Matrix by proposing Inventive solutions.

4.3 Identifying Contradiction Parameters (Step 3)

In this step, we will elaborate the (SoC) concept to identify conflicts that may arise between objectives. It's worth noting that we are studied non-technical parameters, therefore, fitting between TRIZ parameters and evaluation parameters of our system should be done.

Construction of the System of contradiction (SoC). Our proposed (SoC) (Fig. 3) will be applied to the objectives that are in conflict with each other in (Fig. 2): F1, F8, F9.

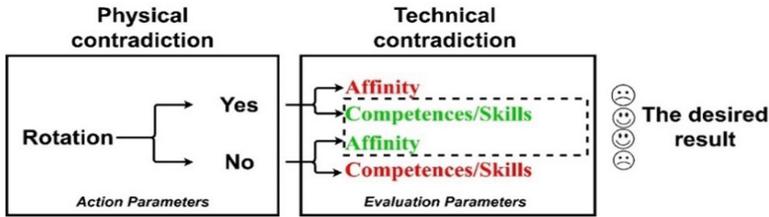


Fig. 3. The System of Contradictions (SoC).

We should note that every type of boat requires a specified set of skills. Therefore, the shipowner often wants to ensure that their crew members have the necessary experience and skills to work on various types of ships (F8). This can be achieved by rotating team members among different types of vessels (F9).

However, it's important to note that frequent rotation could make it difficult to maintain a stable team and can decrease affinity and familiarity among employees and their coworkers (F1).

The rotation of employees among different ships can be considered as an action parameter because it is an action that can be controlled and adjusted positively or negatively to achieve certain objectives of our system. Affinity and competences can be taken as evaluation parameters in relation to rotation as action parameters because they are directly affected by the existing of employee rotations. Once contradictions were established, we need to move to resolve them. However, we need to wonder if any two of the objectives are in contradiction, how to use the technical TRIZ matrix to solve a non-technical problem?

Fitting between TRIZ Parameters and Evaluation Parameters of the System. In our initial study, we discovered contradictions between two distinct parameters. It is important to note that these contradictions can be classified as “technical contradictions” rather than physical contradictions. To analyze and address these contradictions, we employed the matrix of contradictions along with relevant guiding principles.

Therefore, TRIZ parameters need be translated into non-technical terms that are relevant to the case study. Table 4 shows the adoption of TRIZ parameters to evaluations parameters of the system based on brainstorming with TRIZ experts.

4.4 Inventive Principles and Solutions Using TRIZ Matrix (Step 4)

The main idea of the inventive principles solution in TRIZ is to identify and resolve contradictions between two or more parameters to a wide range of systems, including non-technical ones in order to generate Inventive solutions (Table 4). According to the above-mentioned contradictions, we propose the inventive solutions as follow:

- *Change of physical and chemical parameters.* In this case we propose to change the degree of flexibility of the system, it means the possibility of creating a pool of employees who are trained in multiple skills, allowing for more flexibility in assigning them to different boats and roles.

Table 4. Fitting TRIZ parameters with Evaluations parameters of the system.

	Evaluation parameters of the system	TRIZ parameters
(35) Adaptability or versatility	Competences: the ability to perform a task or job effectively and efficiently, using a combination of knowledge, experience, and abilities	The extent to which a system/object positively responds to external changes. Also, a system that can be used in multiple ways for under a variety of circumstances
(27) Reliability	The degree of connection or attraction among the members of the team	A system ‘s ability to perform its intended functions in predictable ways and conditions

- *Anti-weight* This involves introducing elements flexibility into the system to decrease rigidity and complexity. In our case, it could involve creating a person or platform for workers that allowed to express their preferences for which team they would like to be assigned.
- *Intermediary*. In TRIZ, an “intermediary” resolves conflicts by finding a compromise that satisfies everyone. For our case, an intermediary could be a designated staff member who manages employee assignments and rotations on different boats. They serve as a point of contact for employees with assignment preferences, ensuring a balanced and stable team while addressing individual needs (Table 5).

Table 5. Contradiction matrix of the objectives.

	Improving features	Worsening features	Inventive principles
Senario1	(27) Reliability	(35) Adaptability or versatility	13, 35, 8, 24
Scenario 2	(35) Adaptability or versatility	(27) Reliability	35, 13, 8, 24

5 Conclusion

Our study followed a three-step process: conducting semi-structured interviews with a Tunisian shipowner, presenting the results as conflicting objectives in a Relation Matrix, and mapping contradictions to parameters in the TRIZ Matrix to propose inventive solutions. This approach identified several solution principles to address the conflicts between the objectives. Overall, our study highlights the potential of TRIZ and non-technical

parameters in qualitative research for tackling complex challenges in the maritime company that could be applicable for other industries regarding that scheduling of staff is crucial in every single organization.

The results of the semi-structured interviews will be used in a mathematical model for human resource allocation and distributed among objectives and constraints. The solutions generated by TRIZ will also be considered as objectives or constraints within the model to effectively meet the needs of the shipowner.

As a limitation, TRIZ does not provide guidance on prioritizing contradictions, necessitating the use of a Multi-criteria decision-making (MCDM) tool to evaluate and assign weights to contradictions based on their relative importance. Future research could explore this aspect further.

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Dilemma or False Dilemma: A Sequence of Steps to Avoid the Trolley

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Abstract. This paper explores the concept of false dilemmas, which are problems that seem to have only two bad options but have at least one hidden third option. However, whether such an option exists cannot be known unless an alleged dilemma is properly tested. To conduct such a test, Altshuller's Algorithm for Solving Inventive Problems (ARIZ-85C), a method for finding creative solutions to dilemmatic problems, is being applied to the famous trolley dilemma. The trolley dilemma is a moral dilemma where people must choose between killing one person or five people by a runaway trolley. The paper shows that the trolley dilemma is a false dilemma that can be solved without any deaths by using the steps defined by ARIZ-85C. It also reports the results of a survey that tested the perceived morality of this solution compared to the standard options. The overwhelming majority of survey respondents opted for the third option. Overall, the paper argues that the sequence of steps of ARIZ-85C can be used as a tool to expose and solve false dilemmas in various domains.

Keywords: Trolley Problem · Trolley Dilemma · ARIZ · Ethical Decision Making · Creative Problem Solving

1 How to Know if a Dilemma is Real?

When faced with a dilemma, decision makers must choose between two bad options. Whatever they choose, there will be negative consequences. Making a choice in a dilemmatic situation is difficult and notorious for causing stress and anxiety in leaders [1]. Therefore, framing a problem as a dilemma can be a rhetorical device to make choices seem justified [2]. A good example of this is the famous trolley dilemma. People must choose between letting five or one person die by a runaway trolley. Most people choose to sacrifice one person to save the lives of the other five by switching the trolley to the track of the one person. But what if their choice is based on a fallacy?

The mistake of presenting a problem as a dilemma that could be solved without the supposed negative consequences is called a false dilemma or pseudo dilemma. Recognizing a dilemma as a pseudo dilemma is the same as finding an unexpected solution to a

This paper is to a large extent a translation of a section of the still unpublished synopsis of the German version of my cumulative dissertation.

problem that seemed to have no good solution. Exposing dilemmas as false dilemmas – that is, falsifying dilemmas – therefore requires creativity and is the core of Altshuller’s *Theory of Solving Inventive Problems* (TRIZ [3]).

The aim of this paper is to introduce Altshuller’s *Algorithm for Solving Inventive Problems* (ARIZ-85C [4]) as a test to tell apart real dilemmas from false dilemmas. It will be shown that the famous trolley dilemma is a false dilemma that can be solved without any deaths. The subjective perception of the morality of the solution has been tested in a survey and most people choose this suggested solution over the two standard options (see the Sects. 3.3 and 3.4).

2 Falsifying Dilemmas

How can we tell if a dilemma is real or not? [5] suggests considering the options that different participants might have to find solutions. However, there is no clear method for how to generate those options systematically. Without a systematic approach, it is uncertain whether all possible options have been explored. [6], whose decision-making guide focuses on moral dilemmas, proposes a sequence of nine steps. This sequence is well defined and includes various tests. The test that corresponds to solving a dilemmatic situation creatively is step number 7, and it involves looking for a third option:

“Is there [...] a third way through this dilemma? Sometimes that middle ground will be the result of a compromise between the two rights, partaking of each side’s expansiveness and surrendering a little of each side’s rigidity. Sometimes, however, it will be an unforeseen and highly creative course of action that comes to light in the heat of the struggle for resolution” [6].

What Kidder calls a *highly creative course of action* could also be called *the least obvious but most desirable one* or – as [3] would call it – a *strong solution*. This course of action is part of the potential set of options for falsifying the dilemma. This paper will show that there is a way to scan the range of possible solutions (i.e. ways of falsifying the dilemma) with more focus on such strong solutions. To examine the different ways in which formally valid dilemmas can be falsified, we first need to examine its formal structure; [2, 7] identify four types of dilemmas (see Table 1). The *simple* pattern suggests that no matter which of the disjunct options is realized, the consequence will be the same. In the case of the *complex* pattern, the consequence is itself a disjunction of (undesirable) consequences. A dilemma is called *constructive* if the consequence takes the form of an affirmation. It is called *destructive* if its form is a negation.

Formally, their reasoning patterns are valid. If a false dilemma appears behind the form of one of these patterns, the false conclusion can only be hidden in the premises. As shown by the patterns in Table 1, two kinds of premises can be distinguished: The premise stating the disjunction that is so characteristic for dilemmas, and the consequentialist premises with “if ..., then ...” statements. Only if all premises are true it can be called a real dilemma (see Table 2).

Thus, falsifying any of the four types of dilemmas distinguished in Table 1 must come with either falsifying the disjunctive premise or at least one of the “if ..., then ...” premises or both.

Table 1. Dilemmatic patterns of reasoning according to [2, 7].

	Simple (only one option in the conclusion)		Complex (several options in the conclusion)	
	Constructive	Destructive	Constructive	Destructive
1	Either A or B	If E, then G	Either A or B	If F, then J
2	If A, then C	If E, then H	If A, then P	If K, then L
3	If B, then C	Either not G or not H	If B, then Q	Either not J or not L
4	So C	So not E	So either P or Q	So either not F or not K

Table 2. Real dilemma versus false dilemma.

	“If ..., then ...” premises are true	At least one if ..., then ...” premise is false
Disjunction is true	Real dilemma	False dilemma
Disjunction is false	False dilemma	False dilemma

2.1 Tenability Criticism

The two types of premises offer two different attack strategies. [2] calls attacks aimed at the truthfulness of the disjunction *tenability criticism*, questioning whether the argument is dilemmatic at all. To challenge the completeness of the disjunction, it is enough to show that there are more options than the binary choice given in the antecedents for constructive dilemmas or in the consequences for destructive dilemmas.

2.2 Active Criticism

If we assume that the disjunction premise is true and no other options exist than the ones stated in the disjunction, disproving the dilemma must depend on targeting the “if ..., then ...” relations. [2] calls this strategy of criticism *active criticism*. According to [2], this approach is harder and “requires some inventive thinking” [2]:

“Usually, it does not focus only on checking the stipulated logical structure of the argument or on checking the evidence that is typically expected to prove the truth of the given premises. Instead, it commonly involves realizing that some information relevant for the argument is missing, but also shows the relevant ways of influencing the initial argument when the new relevant information is added” [2].

Active criticism is challenging because it requires getting into the problem and checking if the problem description in the form of the dilemma is consistent or if information has been deliberately or unintentionally left out to create the dilemma. [2] could not have said it better: Inventive thinking is needed for active criticism. It is not surprising that

Tomić [2, 7] does not propose a method of active criticism, because inventive thinking is usually seen as not formalizable. Thomas Kuhn, for example, writes in his influential book on revolutions in science:

“What the nature of that final stage is – how an individual invents (or finds he has invented) a new way of giving order to data now all assembled – must here remain inscrutable and may be permanently so” [8].

In [9] this claim of Kuhn’s was challenged using the steps of the *Algorithm for Solving Inventive Problems* – or ARIZ-85C [4]. The ARIZ is an elaborate sequence of steps to tackle hard to solve problems and belongs to the *Theory of Solving Inventive Problems* (TRIZ [3]) which aims to make inventive thinking teachable. In [9], the underlying logic of the algorithm, originally developed by [4] for use in engineering, was generalized so that it can be applied to systems in the widest sense. This was shown using one of the most famous scientific revolutions: the shift from the Ptolemaic geocentric worldview to Copernicus’ heliocentric worldview.

In the next sections, the sequence of the generalized logic of the ARIZ will be shown using one of the most debated dilemmas in modern moral philosophy and psychology: *the trolley dilemma*.

3 Test for False Dilemmas

The ARIZ-85C is Altshuller’s final version of the *algorithm for solving inventive problems* and was developed over a period of about 30 years. The first version appeared in 1956 [10] and the last in 1985 [4]. During this period, the sequence of steps changed considerably, and the vocabulary became more general [9]. The next section will introduce the generalized form of the algorithm from [9] as a way to test if dilemmas can be falsified.

3.1 Brief Summary of the ARIZ

The test starts with a system analysis that results in the formulation of a dilemma. After selecting one of the sides of the dilemma, the conflict is further exacerbated either (i) by eliminating the component responsible for the negative effect, or (ii) by exacerbating the conflict by massively increasing the requirements. Both ways of thinking make the system (or its solution) look like an earlier stage of its development. Then, the problem to solve is defined based on this worse situation from the thought experiment. Next, any kind of resources are listed, starting from where the conflict is and going outwards. The task to be solved is now formulated in such a way that a resource is to be found which – if slightly modified – leads to the solution of the previously aggravated problem. One of the resources from the list is then used to ask how it could help solve the problem. If no solution is found, it is asked if the resource needs to have opposite properties to make the solution possible. This step is central and serves to liberate the thinking to look into pathways that seem to be blocked by the law of noncontradiction [20]. If it turns out that conflicting demands on the resource would solve the task, it is suggested to separate the conflicting demands either in time, space, or at different system levels to develop ways

of implementing the conflicting properties. The ideas that come from this are collected before moving to the next resource on the list.

3.2 Detailed Application Example

In order to demonstrate the sequence in detail, the trolley dilemma – a classic dilemma from moral philosophy and psychology – will be tested for its authenticity. We will follow the same steps as in [9].

The Trolley Dilemma. The trolley dilemma is a well-known thought experiment in moral philosophy and psychology that originated from [11] and [12]. It is used to examine when people think it is morally acceptable to sacrifice the life of one or more people. The experiment has become so influential that the search term “trolley problem” has recently gained more interest than the terms “moral philosophy” and “moral psychology” (see Fig. 1. The numbers on the y-axis represent relative search interest compared to the highest value on the graph for the selected region in the indicated period. Where the value is 100, search interest was at a maximum. A value of 50 indicates that the term was searched for only half as often at that time. Where the values are 0, not enough data is available for the term).

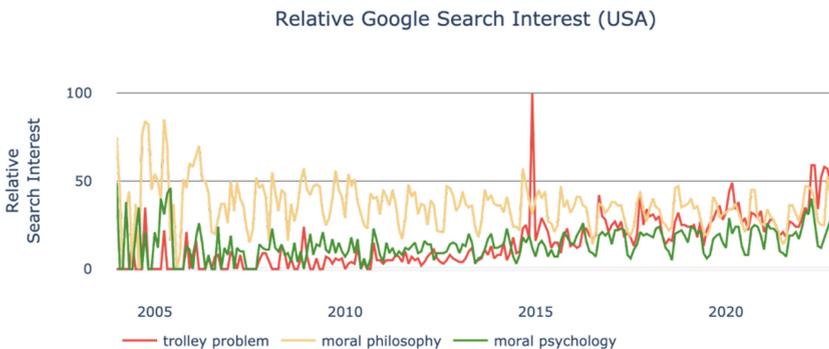


Fig. 1. Relative search interest on Google for the terms trolley problem, moral philosophy, and moral psychology in the U.S. between 2004 and Dec. 14, 2022.

This thought experiment is not only relevant for ethical issues related to autonomous driving (e.g., [13, 14]), but also suitable for surveys (e.g., [15–17]). [17] surveyed 70,000 people from 42 countries in 10 languages about three different trolley scenarios. One of the scenarios is as follows:

“A man in blue is standing by the railroad tracks when he notices an empty boxcar rolling out of control. It is moving so fast that anyone it hits will die. Ahead on the main track are five people. There is one person standing on a side track that doesn’t rejoin the main track. If the man in blue does nothing, the boxcar will hit the five people on the main track, but not the one person on the side track. If the man in blue flips a switch next to him, it will divert the boxcar to the side track

where it will hit the one person, and not hit the five people on the main track. What should the man in blue do?" [17].

The respondents can choose between two options: *Activate the switch* or *Do nothing*. This is a complex-constructive dilemma according to the typology of [2], because both choices result in different negative outcomes.

1. Activating the switch (A) will cause the boxcar to kill one person (P).
2. Doing nothing (B) will cause the boxcar to kill five people (Q).
3. The switch can be either activated (A) or not activated (B).
4. One person (P) or five people (Q) will be killed by the boxcar.

Cross-cultural Survey Results. According to [17], 84% of the 70,000 respondents chose to activate the switch and thus to sacrifice the single person on the sidetrack to save the lives of the five people on the main track. Typically, this finding is interpreted to mean that 84% of respondents believe it is better to sacrifice the life of an uninvolved individual in order to save that of the five others [18]. The remaining 16%, in turn, would be unwilling to sacrifice the life of one individual to save the lives of five others. However, this interpretation may not reflect the moral reasoning of the respondents, as suggested by the survey results obtained when offering a third option (see chapter 3.3).

But can the best choice be found on either of these sides? Before choosing between the two options presented in the survey, shouldn't one first consider whether there is a third option that could avoid any fatalities? If such an option existed, wouldn't then choosing either of the other two options be morally wrong?

Simple Tenability Criticism. Tenability criticism according to [2] aims to attack the completeness of the disjunction premise. Are the only options really just to either activate the switch or to do nothing? For instance, could the man in blue not warn the people on the track to move away? Such objections have prompted the scenario to be refined over time to eliminate such alternative solutions. [19], for example, specifies that the people involved are bound to the tracks.

To increase the degree of difficulty, let us assume that the persons are bound to the tracks and that the disjunctive premise stating that the man in blue can either activate the switch or do nothing is complete. Given these circumstances, is the dilemma real or is there still a way for it to be falsified? According to [2], falsifying this dilemma requires *active criticism*, which in turn depends on inventive thinking: a good opportunity to apply the generalized version of ARIZ (see Fig. 2).

Active Criticism to Test Whether a Dilemma Can Be Falsified.

Step 1 – Understanding the System Conflict.

Step 1.1: What is the primary function of the system?

The primary function of the system used by the man dressed in blue is to save the lives of the five people on the track.

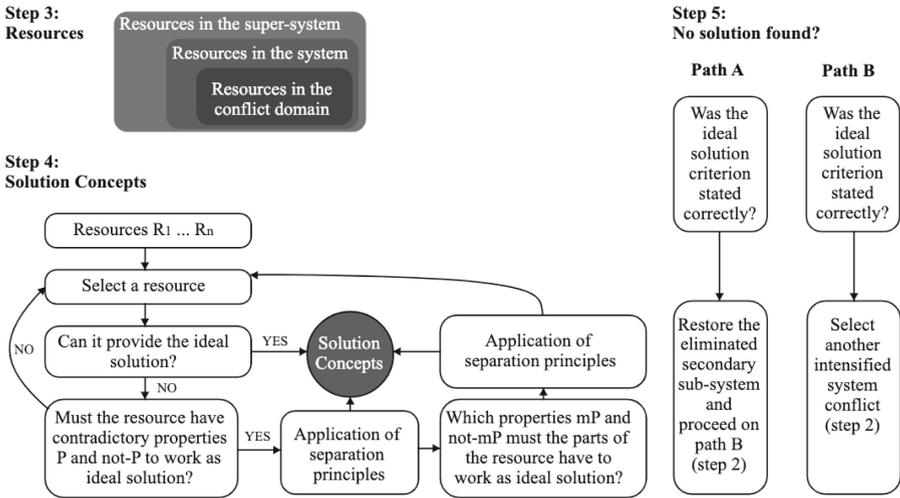
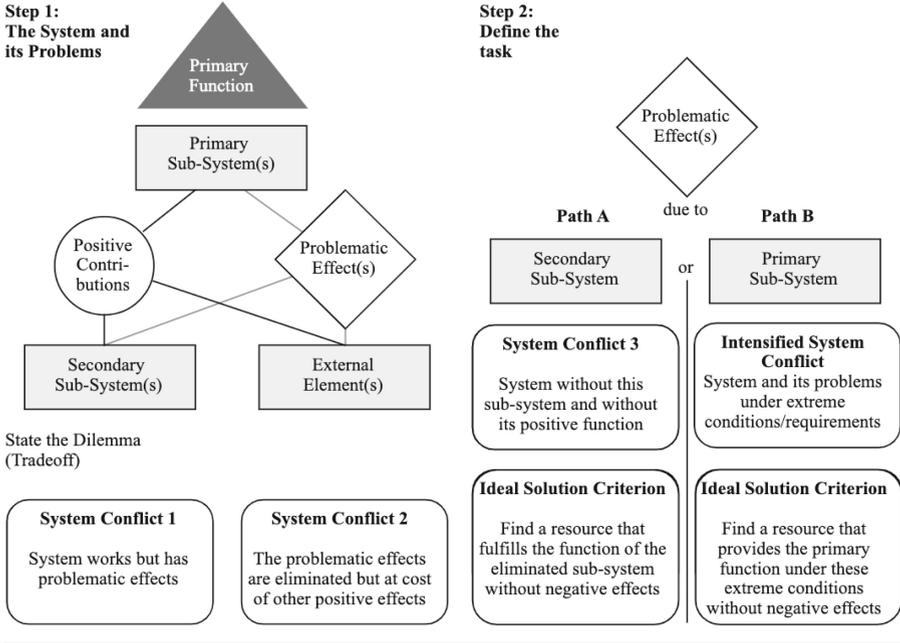


Fig. 2. Step sequence of the generalized ARIZ [9].

Step 1.2: Describe the system in terms of its components and functions.

A boxcar is rolling along a track at high speed. The track positions the wheels of the car on two rails. It runs over a switch in direction A, where five people are standing on the track. By means of two movable tongues, the switch can change the course of the car by forcing its wheels on a sidetrack in the direction of B. A single person is standing on

the sidetrack (direction B). The man in blue controls the switch mechanism and thus the direction of the boxcar. Ultimately, the switch carries the primary function, as it allows the man in blue to prevent the five people from being run over.

- System conflict 1: Five people will be run over if the direction of the car is not changed.
- System conflict 2: The five people will not be run over if the car is diverted. However, the person on the sidetrack will be run over.

Step 1.3: Is it a trade-off/system conflict?

System conflict 1 and *system conflict 2* are systematically related, in the sense that one follows from the other. As established at the beginning, the problem satisfies all formal criteria of a dilemma. Since *system conflict 2* achieves the primary function – ie. to rescue the lives of the 5 people on the main track – and since it seems to be the preferable choice for most people (84% of surveyees select this option), this conflict will be selected for the next step.

Step 2 – Formulation of the Task

Step 2.1: Is the system conflict the result of performing a secondary function?

No, the problem of killing the person on the sidetrack is not due to some secondary function but results directly from the use of the switch. The switch is the primary tool responsible for saving the lives of the five people (primary function). The killing of the individual on the sidetrack is thus a side effect of exercising the primary tool to save the five people on the main track.

If this side effect was the result of a secondary tool that was not directly responsible for the primary function, the recommendation of ARIZ would be to remove that tool and to look at the resulting problem under these newly created conditions (see, for instance, the example in [9]). Since this is not the case, ARIZ recommends to further increase the requirements expected from the solution. In this way, the solution appears to be even less attainable. Both scenarios force the user to abandon the previous path and to explore new pathways.

Step 2.2: What does the system conflict look like after escalation?

To increase the requirements for the solution means to demand that the lives of all six individuals are to be saved. The reformulated task thus states: *Save the lives of the six people in a scenario in which the boxcar is rolling toward the five workers on the main track.*

Step 2.3: Formulate the task in the resource scheme.

To find a solution, the system must be modified. To minimize the extent of the intervention, Altshuller's ARIZ recommends reformulating the task in the resource scheme (see Fig. 2): *Find a resource that, if slightly modified, will ensure that the trolley does not kill a single person.*

Step 3 – Search for Possible Resources that Could Help to Solve the Task.

Create a list of resources.

As the formulation of the task suggests, a possible solution would imply to repurpose a resource or to use unused ones. Only abstract problems can create the appearance of being context-free. Concrete problems, in contrast, are rooted in their own environments. There is more to these environments than the problem statement might suggest. Therefore, Altshuller's ARIZ recommends to list resources that might be useful in developing solutions – starting in the problem zone and progressing from there into the broader environment. In addition to listing the resources, it is recommended to consider time as a resource in its own right and to examine it carefully to identify potentially unused time slots.

For example, starting in the problem zone, the following resources can be considered: the switch including the switching mechanism, the people on the track, the boxcar, the wheels of the boxcar, the rails, the ground on which the rails run, and the air. Further, in the immediate vicinity of the problem zone the station could be searched for additional resources, but because of the abstract nature of the problem in this thought experiment, it appears to be pointless.

Step 4 – Development of Solution Approaches.

Step 4.1: Formulate the problem definition for a concrete resource.

To develop solution approaches for the task formulated in Step 2.3, it is recommended to go through the resource list – entry by entry. The first resource on the list leads to the following formulation: *How could the switch be used such that the approaching boxcar does not run over any of the six track workers?* If the answer to this question were obvious, the problem would probably not be difficult to solve. Nevertheless, the formulation might already trigger the thought of a solution. If not, the problem might lie deeper.

Step 4.2: Could it be that the chosen resource would have to take on contradictory properties (P and non-P) to solve the problem?

This step is perhaps the most unusual aspect of the entire ARIZ. It prompts the user to consider whether the path toward the solution is blocked by an apparent contradiction. To imagine a contradiction runs counter to logical thinking, since logic is based on the theorem of noncontradiction [20]. To counteract the psychological tendency of avoiding contradictions, ARIZ gives the instruction to consciously construct the contradiction in order to resolve it later. This process intends to open a perspective that might otherwise remain hidden to conditioned thinking.

Applied to the switch, we have to look at its key parameter: Positioning the wheels of the boxcar either toward direction A or direction B. Should the task be solvable if the switch was guiding the wheels of the boxcar in direction A as well as in direction B? Executing this step results in the following hypothesis: *If guided in direction A and in direction B, the boxcar will not run over any of the six people.*

In fact, a boxcar that is guided in both directions could not go in either of them. Instead, it would derail. Accordingly, a solution seems possible if the switch could be set for both directions. If this alleged contradiction (positioning toward direction A and not-A) could be resolved and thus transformed into a pseudo-contradiction, a solution might be in reach.

Step 4.3: Application of the separation principles.

In order to resolve an alleged contradiction of the type *X is said to be both P and not-P*, Altshuller's ARIZ recommends the application of three separation principles: *separation in time*, *separation in space*, and *separation on different system levels*. Accordingly, the contradictory predicates can be thought of as states distinguished either in time, in space, or in the system hierarchy. This leads to the following options:

1. *Separation in time*: at time T1 the switch guides the wheels of the boxcar onto the main track and at time T2 it guides the wheels on the sidetrack.
2. *Separation in space*: In the spatial part P1 the switch is set to guide the wheels of the boxcar on the main track, while in the spatial part P2 it is set to guide the wheels on the sidetrack.
3. *Separation between system and subsystems*: As a system, the switch is set so that the boxcar travels in the direction of the main track, while the subsystems are set so that the boxcar travels in the direction of the sidetrack.

The first formulation is immediately obvious: If it is possible to activate the switch when the front wheels of the boxcar have passed the switch mechanism, so that only the rear wheels are diverted, then the switch ensures that the wheels are guided both in direction A (the front wheels) and in direction B (the rear wheels). The car should derail and likely come to a stop. Consequently, the people on the track would not be run over and the goal would be achieved.

The fact that this solution could indeed lead to the goal is shown, among other things, by the case of a derailed ICE in Basel on 17.2.2019. According to the final report of the Swiss Safety Investigation Authority, the derailment was "due to the inadvertent, unauthorized auxiliary disengagement of [one] train route and the subsequent setting of another train route, which caused a switch to be rerouted under the moving train" ([21], translation by J.S.).

Even if the boxcar was a passenger-carrying train, the ratio of fatalities to derailments appears to be relatively low. For the period 1990 to 2021, the U.S. Transportation Department counted 54,539 train accidents involving derailments, resulting in a total of 131 fatalities [22].

The other separation principles could possibly lead to other solutions, but separation in time seems most intuitive and can be controlled directly by the switch. Furthermore, for each of the separation principles, the ARIZ recommends thinking about the contradiction at the level of the smallest subsystems (molecules, atoms, and smaller) to arrive at deeper and presumably even less obvious approaches to the solution. For this example, however, the solution appears to be satisfactory.

Step 4.4: Repetition of the fourth step.

To explore all possible solutions, the same process from the fourth step is repeated for each resource on the list. As mentioned before, the history of the trolley dilemma reveals that people who faced the dilemma often tried to avoid killing any of the workers. The most obvious solution seemed to be to warn the workers to move away from the tracks. However, in some versions of the scenario, the workers were tied down, making the dilemma more unrealistic and inescapable. But even when a problem is framed as hopeless, there might still be a way out, as shown by this use case.

Step 5 – What if no Solution Can Be Found?

If no solution can be found, the ARIZ recommends going back to Step 2 to see if the problem can be formulated differently. The fewer constraints imposed on the solution, the wider the realm of possible solutions. The step of listing resources makes it clear that the realm of possible solutions could, in principle, be extended well beyond the boundaries of the problem zone. If we acknowledge that, logically speaking, we could also use resources from the edge of the universe, we can see that real dilemmas should be rather rare.

3.3 Survey: Trolley Dilemma With Derailment Option

Using the sequence of steps of Altshuller's ARIZ, it could be shown that the classical trolley dilemma is a false dilemma and that the following premise is incomplete: *Activating the switch (A) will cause the boxcar to kill one person (P)*. Rather, it should read: *Activating the switch (A) will cause the boxcar to kill one person (P), unless the boxcar is passing the switch at the moment of activation. In this case, the boxcar derails.*

To test what percentage of people would select the option of activating the switch at this particular moment in time, the same question as in [17] was posted online on SurveySwap with the additional third option: *Flip the switch at the moment when the boxcar passes the rail switch, such that its front wheels and its back wheels get on different tracks, derailing and thus stopping the boxcar.*

Between November 3, 2022, and February 1, 2023, 97 responses were collected (see collected data in [23]). The percentage of respondents choosing to do nothing was 15.5%. 75.2% chose to attempt to derail the car, while 9.3% indicated that they would try to activate the switch to move the car onto the sidetrack, killing the single person. The most popular option was thus the derailment solution obtained by following the steps of the ARIZ (see Fig. 3).

It is surprising that adding the third option does not significantly change the percentage of those who choose to do nothing (p-value 0.89). Doing nothing is often seen as a way of not favoring the lives of five people over the life of one person. This view is challenged by the finding that the same proportion of respondents makes this choice, even when offered a third option that might save everyone's life (see, e.g., [18]).

The main finding of this survey, however, is that a large percentage of respondents think it is morally right to derail the boxcar (75%). To be able to see this option at all, the dilemma – becoming responsible for either killing one person or killing five people – had to be falsified. This suggests that it is a moral requirement to check whether a dilemma can be falsified before picking one of the undesirable options.

It has been shown that Altshuller's ARIZ can serve as a test of falsifiability of dilemmas. The process of iterating through alternative resources is equivalent to what [2] calls *tenability criticism*, since it checks for options that are not mentioned in the disjunctive premise of the dilemma. By exploring even the allegedly contradictory ways in which those resources might be able to solve the situation, causal mechanisms that remain hidden in the formulation of the dilemma can be discovered resulting in rather less obvious solutions. In this way, Altshuller's ARIZ provides a method to systematize what [2] calls *active criticism*.

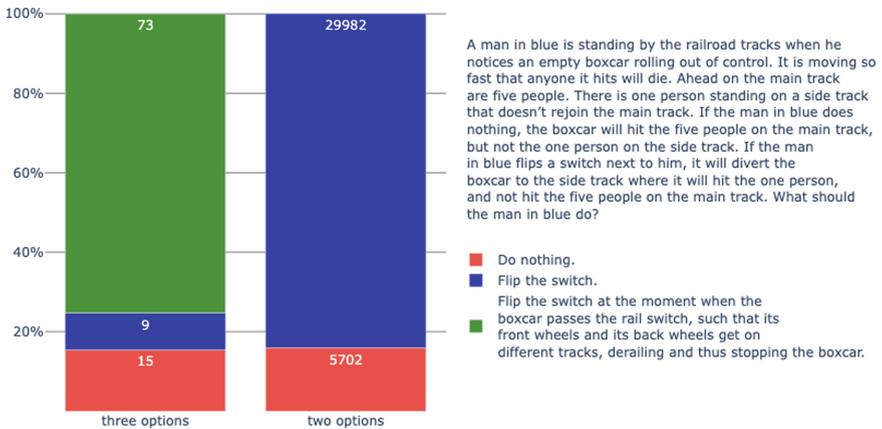


Fig. 3. Survey results from [17] (right) and results from a survey adding a third option to the original question (left) [23]. Most respondents choose to try not to kill any of the people. Surprisingly, the proportion of respondents choosing to do nothing (and thus have the five people be likely killed) is the same in both surveys (15.4% vs. 16%, p-value 0.89). The code underlying the analysis can be found in [24].

3.4 ChatGPT: Trolley Dilemma with Derailment Option

On January 13, 2023, I asked ChatGPT twice what option it would select using the exact same text as in the survey. In both cases, ChatGPT selected the option to flip the switch, sacrificing the life of one person to save the lives of the five people on the main track. About four months later, I asked the same question again using both OpenAI's gpt-3.5-turbo API and the older version gpt-3.5-turbo-0301. Gpt-3.5-turbo selected 68 out of 69 times the option of derailing the boxcar. Gpt-3.5-turbo-0301 selected this option 18 out of 19 times [25]. In both cases, the option to flip the switch resulting in the death of the person on the sidetrack was selected only once. To do nothing was not selected by any of the models. This suggests that OpenAI's model has learned since I asked it the first time in January. The code for reproducing the experiment can be found here [26].

4 Conclusion

By applying the steps of the generalized version of Altshuller's ARIZ-85C it could be shown that the trolley dilemma is a false dilemma since at least one option exists to avoid killing any of the people on either of the tracks. The overwhelming majority of respondents selected this option as the best available choice. This raises the question whether exhaustive testing of dilemmas should not be integrated into standard practices of ethical decision-making. When facing an ethical dilemma, the sixth step of [6]'s sequence for ethical decision making suggests applying three resolution principles: "Do what is best for the greatest number of people", "Follow your highest sense of principle", and "Do what you want others to do for you". As the example of the trolley dilemma shows, this should only be done if the dilemma is real. To know whether it is real or false,

it needs to be tested appropriately. Therefore, it is recommended that the ARIZ-based test precedes the application of [6]’s resolution principles.

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TRIZ-Based Approach in Remodeling Invasive Glucometer

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Abstract. Diabetes Mellitus is a serious clinical condition. If left unchecked the increased blood glucose level may predispose to cardiovascular disease, damages in nerves/veins, blindness, limb amputation and kidney disease. Utilising TRIZ based models such as Functional analysis and Su-field, we are able to model the problem appropriately by highlighting the key disadvantages for design improvement. Engineering and Physical contradiction models enabled us to address the problem effectively and provide an excellent case study for enhancing the present tool used in determining the blood glucose of a diabetic patient. A prototype model of the device has been developed and preliminary experiments are done to validate its efficacy. The potentials for further refinements can be expanded by addressing secondary problems that we have identified. We believe that noninvasive smartphone glucometer will be useful and a safer option in determining the blood glucose level.

Keywords: Invasive · Glucometer · TRIZ

1 Introduction

The need for a noninvasive method of detecting the presence of glucose in a person's body will be useful. The widely used mode of detecting glucose in a person's body is via blood sampling. Blood glucose detection is usually done by glucometer. Since it is an invasive method we shall address it as Invasive Glucometer (IG).

According to the International Diabetes Federation (IDF), as of 2021, approximately 537 million adults (aged 20–79) worldwide have diabetes, with type 2 diabetes being the most common form [1]. Diabetes is a leading cause of death globally, with approximately 4.2 million deaths in 2019 attributed to the disease. Low- and middle-income countries tend to be disproportionately affected by diabetes, with 80% of people with diabetes living in these countries. Diabetes prevalence is increasing globally, and it is

estimated that by 2045, approximately 783 million adults worldwide will have diabetes [1]. Diabetes is a major contributor to blindness, kidney failure, heart attacks, stroke, and lower limb amputation [2, 3]. It is not surprising therefore that the World Health Organisation has identified diabetes as one of the top ten global public health threats. Diabetes is also becoming a global public health epidemic [4].

Type 1 diabetes and type 2 diabetes are both chronic diseases that affect the way the body regulates blood sugar levels. However, they differ in several key ways. Type 1 diabetes occurs when the body's immune system attacks and destroys the insulin-producing cells in the pancreas, resulting in a lack of insulin in the body. This usually develops in children and young adults, but can also occur at any age. The individual will then require insulin therapy for life to regulate blood sugar levels and this condition cannot be prevented [5]. Type 2 diabetes occurs when the body does not use insulin properly (insulin resistance) or does not produce enough insulin [6]. Is often associated with lifestyle factors such as obesity, physical inactivity, and unhealthy diet. This typically develops in adults, but can occur in children and adolescent as well. The condition may be managed through lifestyle changes which include healthy eating and exercise, and may require medications and insulin therapy if blood sugar levels cannot be controlled through lifestyle changes alone. The consequences of the disease can often be prevented or delayed through lifestyle changes. In summary, while both types of diabetes affect blood sugar levels, Type 1 is an autoimmune disease that requires insulin therapy for life, while Type 2 is often associated with lifestyle factors and can sometimes be managed with lifestyle changes alone.

To diagnose diabetes, measurement of blood glucose is required. Therefore, to measure blood glucose we can use invasive or non-invasive techniques. An invasive procedure is a medical procedure that involves inserting instruments or devices into the body or cutting into the body's tissues or organs. The purpose of an invasive procedure is usually to diagnose or treat a medical condition. Invasive procedures carry a higher risk of complications compared to non-invasive procedures. However, they may also provide more accurate and definitive diagnoses or treatments for certain medical conditions. The decision to perform an invasive procedure has to be made by a healthcare provider after considering the potential risks and benefits.

Diabetes patients tend to have slower level of wound healing process and in extreme cases impaired wound healing that may lead to amputation [7]. In general, anyone will feel pain during an invasive process. IG process will also cause wound in order to measure blood glucose. The current available IG is useful and reliable but it has its disadvantage. The end users who are diabetic patients generally will complain of it being cumbersome, expensive and a painful experience to do blood glucose detection using IG. This obvious contradiction suggests an inventive problem [8]. The technical and physical contradiction in this particular problem allowed us to use TRIZ to better understand and discover a solution for the existing problem. Furthermore, by utilising the Su-field modeling technique we were able to conceptualise the product better. Using TRIZ we were able to come up with a Smartphone Glucometer (SG) solution. SG will stand out as a solution for not only diabetic patient but also for general population to detect their glucose level in their body. This paper delivers the use of TRIZ in conceptualising the

essence of the problem and using Engineering and Physical Contradictions plus Su-field modeling to elicit a probable TRIZ based solution for glucose measuring in humans.

2 Research Methodology

The application of a systems approach with functional analysis has been explored as a means to characterise the problem of Invasive Glucometer (IG). The lack of proper tool to screen, detect and monitor non-invasively an ongoing global epidemic problem has been adopted as the target problem. This problem requires an immediate practical solution.

The IG was studied and this was followed by the formulation of the Function Analysis. Figure 1 shows a typical IG. Then system analysis and contradictory analysis were used to conceptualize the problem [9]. The tools rendered insights into the nature of the problem. To understand in further clarity Su-field modeling was employed. The overall methodology of the SG project is illustrated in Table 1.

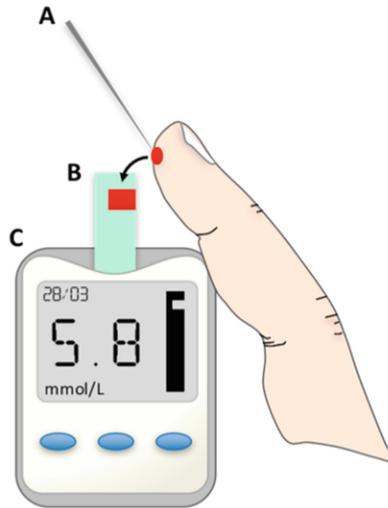


Fig. 1. General Invasive Glucometer adopted from Bruen et al. [10]. A. Invasive lancet needle; B. Blood sample on test-strip; C. Glucose meter displaying glucose concentration in mmol/L.

2.1 Function Analysis

The initial analysis shows the main useful functions as an engineering system of IG is depicted in Fig. 2. IG's main function is to hold test strip, sensor unit, display unit and power unit. A lancing device is required for IG. In a nutshell an IG is able to detect blood glucose level in a person. The preliminary component analysis (see Table 2) indicates that the system is composed of the Glucometer. This system interacts directly with the super system which is subject to spatial and temporal changes, which in return will affect

Table 1. Overall concept methodology of the project.

Research Methodology	Tools
Review of Related Work	Review covered articles with “glucometer” in reliable databases
Problem Modelling based on Function Analysis	Function Model was formulated to model domain knowledge
System Analysis as inventive problem solving model	Engineering Contradiction as a Triz knowledge based approach was utilized to elicit directions
Contradictory Analysis as a deep knowledge model of inventive solution Su Field Modelling	Physical Contradiction served as an instrument for deepening our understanding Su-field modeling was used to represent elements and interactions in order to characterize the behavior of our technical system
Designing Smartphone Glucometer	Utilising designing tools to work out a practical model of Smartphone Glucometer. Ongoing discussion with the end user of Smartphone Glucometer for feedback and further enhancements

and influence the IG device. The product in our component analysis is the Glucose. IG subcomponents are test strips, lancing device, glucose sensor, display unit and power unit. This analysis showed that the application of a systems approach by using of function model was informative.

In brief the role of the main components of IG is highlighted. Lancing device: A tool used to puncture the skin and collect a small blood sample. Test strip: A small strip of material used to collect the blood sample and measure the glucose level. Glucose meter: A device that reads the glucose level on the test strip and displays the result. Lancet: A small, disposable needle used to puncture the skin and collect the blood sample. Electricity/Battery: A power source that allows the glucometer to function. Display unit: A screen that shows the user their glucose level and other important information. Memory function: A feature that allows the glucometer to store and recall previous test results.

2.2 Engineering Contradiction

Based on the initial analysis the following Engineering systems were formulated.

- a. **IF** blood is used in an invasive glucometer **THEN** blood glucose is measured **BUT** glucometer user feels pain. The improving parameter was selected as 39: “Productivity”. The invasive glucometer is functional as it becomes productive with ability to measure the patient’s blood glucose level. On the other hand, the worsening parameter

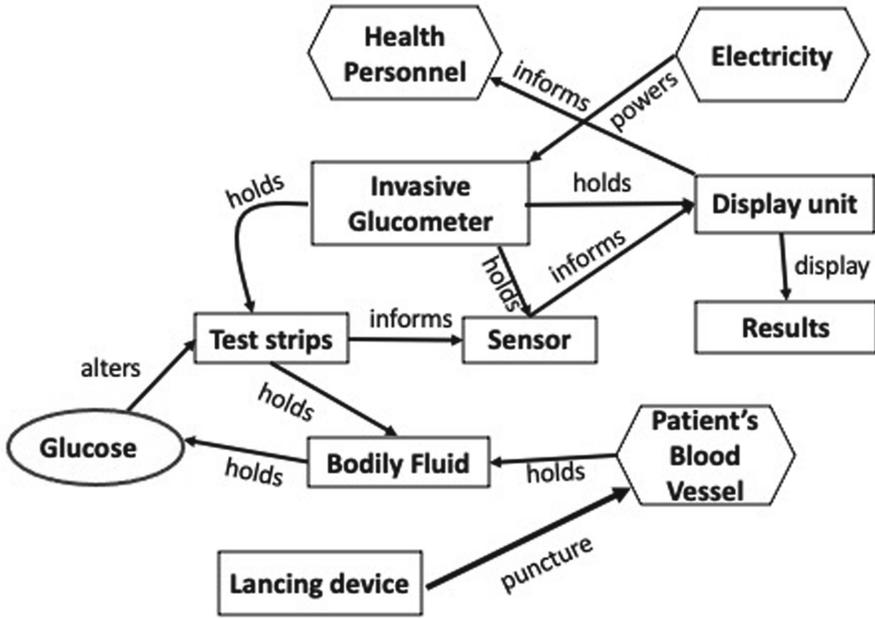


Fig. 2. Function Model for Invasive Glucometer.

Table 2. Preliminary Component Analysis.

Components	Super System	System	Product
Items	Environment Electricity User Health Personnel	Glucometer -Test Strips -Glucose Sensor -Display unit -Lancing device	Glucose

was selected as 30: “Object-affected harmful effect”, which suggest that the invasive glucometer may render a health hazard to the end user in the form of pain.

- b. **IF** an invasive glucometer is used regularly **THEN** blood glucose can be monitored frequently **BUT** the user has to get more resources. The improving parameter was selected as 39: “Productivity”. The invasive glucometer is functional as it becomes productive with ability to monitor the patient’s blood glucose level. On the other hand, the worsening parameter was selected as 31: “Object-generated harmful effect”, which suggest that the invasive glucometer forced the end user to use more resources therefore losing valuable material.

The inventive principles provided an insight in the modelling of smartphone glucometer by suggesting intuitive strategy in designing and modelling a purposeful yet

safer glucometer for end user. Based on this model, the possible approaches are listed as shown in Tables 3 and 4.

Table 3. Engineering contradiction based on Smartphone Glucometer (SG) with considering the improving parameter as “39: Productive” and the worsening parameter as “30: Object-affected Harmful Effect” were contemplated and its possible solutions postulated.

Inventive principles	Possible solutions
13 The other way around	Currently we are sampling blood which is required in our body, instead of this we sample a bodily fluid that is not required in the body
22 Blessings in Disguise	The procedure for monitoring glucose level will not be a painful experience
24 Intermediary (Mediator)	The gold standard for glucose level in the body is measuring the blood glucose, instead now we can measure something else to correlate to the gold standard
35 Parameter changes	Instead of looking for glucose in an important fluid of the body, we can be flexible in looking for glucose in some other substances of the body

Table 4. Engineering contradiction based on Smartphone Glucometer (SG) with considering the improving parameter as “39: Productive” and the worsening parameter as “23: “Loss of substance” were contemplated and its possible solutions postulated.

Inventive principles	Possible solutions
10 Prior action	Procedure for the SG process will be present in the smartphone for user to refer
23 Feedback	The app present in the smartphone will be used to give feedback to the user
28 Mechanical substitution	Replace the present electrical-electrode system with smartphone based imaging system
35 Parameter changes	Instead of looking for glucose in an important fluid of the body, we can be flexible in looking for glucose in some other substances of the body

2.3 Physical Contradiction

The following physical contradiction can be proposed here, describing a situation which requires one parameter to take opposing values in order to meet contradictory demands to a system:

Glucometer has to be *invasive* to obtain bodily fluid and *noninvasive* to avoid inflicting pain.

2.4 Su-Field Modeling

Su-field modeling was explored where the original problem was formulated as a harmful system. By transforming the solution in considering the Mechanical, Acoustic, Thermal, Chemical, Electric and Magnetic (MATCHEM) as an alternative, we were able to propose the following model using the biological system (see Fig. 3a).

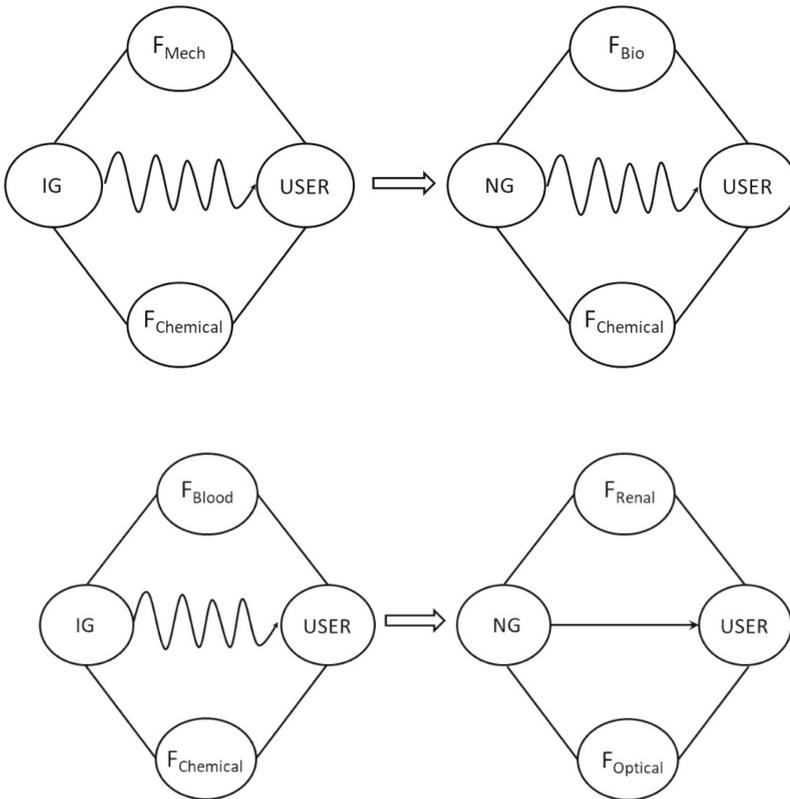


Fig. 3. a. Double Su-field Modeling for Invasive Glucometer problem. $F_{chemical}$: Chemical field, IG: Invasive Glucometer, F_{Mech} : Mechanical field, NG: Noninvasive Glucometer, F_{Bio} : Biological field and USER: Patient or End user. b. Double Su-field Modeling for Noninvasive Glucometer in the Biological System. F_{Blood} : Blood system, IG: Invasive Glucometer, F_{Mech} : Mechanical field, NG: Noninvasive Glucometer, $F_{Optical}$: Optical field, F_{Renal} : Renal system and USER: Patient or End user.

We considered the Biological system (F_{Bio}) due to the nature of our product. Further to this we analysed this model by delineating in detail the main biological body system which are, Blood, Skeletal, Muscular, Nervous, Cardiovascular, Respiratory, Digestive, Renal, Reproductive, Endocrine and Lymphatic. The main issue to address was the invasiveness of the system and keeping this in mind, here is the following Su-field model proposed. We choose the renal system as the sampling of the urine which will not

harm the user. Our next Double Su-field Modeling for Noninvasive Glucometer in the Biological System is depicted in Fig. 3b.

3 Results

In order to validate the concept, our group have built the system design of the noninvasive Smartphone Glucometer. The possible solutions that was proposed is given in Tables 3 and 4. Applying the solutions we have proposed a new component analysis of the noninvasive Smartphone Glucometer, shown in Fig. 4.

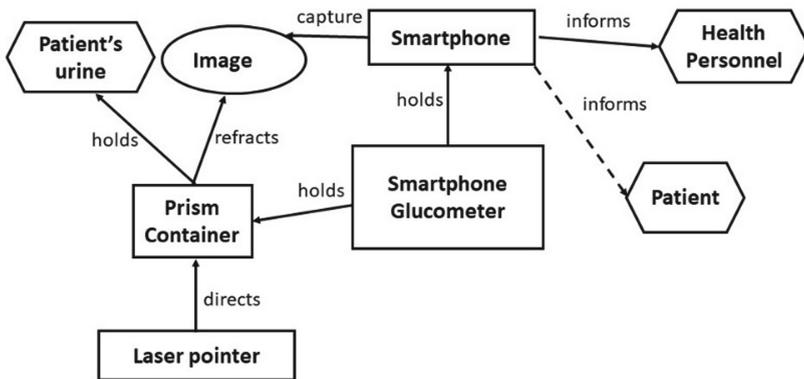


Fig. 4. Function Model for Noninvasive Smartphone Glucometer.

The function modeling in Fig. 4 is captured as a schematic diagram of noninvasive Smartphone Glucometer. The design thinking approach was implemented whereby we engaged an active discussion with the parties of concern, mainly healthcare personnel and diabetic patients. This led us to build a schematic diagram of the new noninvasive glucometer, as shown in Fig. 5, which is called Noninvasive Smartphone Glucometer.

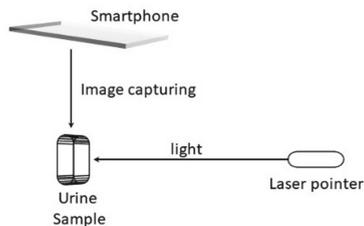


Fig. 5. Schematic Diagram of the noninvasive Smartphone Glucometer.

The application of a systems approach with functional analysis has been used to understand the problem of IG. Figure 6 depicts the isometric view of the noninvasive Smartphone Glucometer system design. The Engineering Contradiction and Physical

Contradiction analysis enabled us to look deeper at the inventive principles proposed by the contradiction matrix based on the improving and worsening parameter analysis.

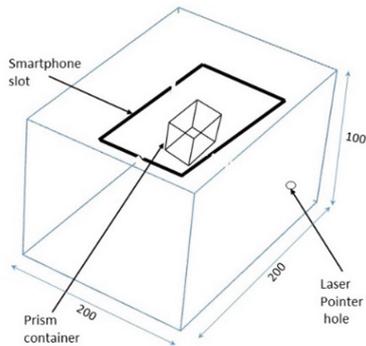


Fig. 6. Isometric View of Smartphone Glucometer System Design (dimensions in mm).

The system design shown in Figs. 5 and 6 are noninvasive Glucometer device. The main components in this system are the laser pointer, prism container and smartphone. As the laser beam is refracted into the prism container containing the noninvasive sample (urine), the refracted image is captured by the smartphone camera. The image captured will be processed using a designated software in an App. Preliminary experiment using refractive index of sugar concentrates versus Glucometer reading of sugar concentrates correlated very well. A regression analysis showed R^2 of 0.98, indicating that 98% of the variance in our data is accounted for by the experiment [11].

4 Discussion

Trimming is a way of increasing system ideality by removing a component of the system. According to Genrich Altshuller, a system's Ideality is affected by Useful Function, Harmful Function and Resources [12]. In TRIZ, Trimming is the way of making a system better by removing things while keeping all the useful functions [8].

Based on Fig. 2, the four major functions of IG have been replaced by 2 functions in Fig. 4. Figure 4 depicts the Function model for noninvasive Smartphone Glucometer (SG). The test strip and lancing device are trimmed and their functions are taken over by the prism container. While the function of the sensor and display units are taken over by the smartphone. Removing the lancing device certainly will have a major impact on the system as it also exerted a harmful effect on the user. The new system, noninvasive Smartphone Glucometer is free of harmful functions.

Two undesirable characteristics of the IG system are removed, they are the inflicting pain on user by the lancing device and the cost of replacing the test strip after each test. Certainly this is leading towards Ideality. The proposed noninvasive glucometer has its limitation such as patients who are on drugs that inhibit the Sodium Glucose Cotransporter 2 protein which enables glucosuria, will not be able to use this system.

Further studies in this cohort of patients using the proposed tool need to be undertaken to validate its usefulness.

Noninvasive SG can be used regularly without inflicting pain on the user. The IG tends to create wound which is not good for diabetic patients, as they tend to have an impaired function of wound healing [7]. The specificity of noninvasive SG test maintained by using urine sample of patient and not an invasive sample such as blood. Since diabetic patients require regular monitoring of blood level which may cost dearly due to the use of fresh test strips. In noninvasive SG, we can continue monitoring regularly without implicating further cost because we are capturing image of diffracted laser beam in urine sample via smartphone. Although frequent urine samples are required with the proposed tool, patients no longer suffer pain and the loss of precious resources.

Lastly, when dealing with a problem that involves multiple goals, TRIZ provides several tools and principles that can help in finding creative solutions. Future problem solving can be enhanced with powerful TRIZ tool such as Function Oriented Search (FOS), Ideal Final Result (IFR), System Operator, Resource Analysis, TRIZ Contradiction-Solving Process and others. TRIZ is a systematic and structured approach to problem-solving, and its tools can be tailored to the specific needs of a problem with multiple goals.

5 Conclusion

An invasive technique is not good because it is expensive and painful. Furthermore, if a diabetic patient requires frequent monitoring of the glucose level, then the constant state of wound is created. Diabetic patients have low wound healing ability. So an alternative method is required. We have proposed a conceptual idea for noninvasive Smartphone Glucometer using urine as the sample. The effectiveness and functionality of urine glucose was proved through the sugar concentration experiment. The refractive index of urine was well correlated with actual blood glucose level measured via Glucometer. Once again TRIZ has enabled us to zoom-in on the key functions to resolve Ideality. Further analysis using higher TRIZ tools will certainly gear us towards an ideal pathway through TRIZ-modelling of Invasive Glucometer.

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