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Abstraction and Generalization in Conceptual Design Process: Involving Safety Principles in TRIZ-SDA Environment

Khairul Manami Kamarudin [a,b,]*, Keith Ridgway[a], Napsiah Ismail[b]

[a]*Advance Manufacturing Research Centre with Boeing, The Univeristy of Sheffield, Advance Manufacturing Park, Wallis Way, Catcliffe, Rotherham, England, S10 1G.*
[b] *Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

* Corresponding author. Tel.: +603-8946 4096 ; *E-mail address:* manami@upm.edu.my

Abstract

Abstraction and generalization are the processes of facilitating a specific problem to help designers solve problems efficiently. Abstraction and generalization reduce complexity and increase creativity. Both abstraction and generalization guide designers to focus on the key factors of a problem towards producing a broader solution perspective. This paper aims to discuss the use of abstraction and generalization in the conceptual design process within the Theory of Inventive Problem Solving (TRIZ) environment, specifically, in TRIZ-SDA (Systematic Design Approach), which was developed to increase the understanding of safety principles in the conceptual design process. In addition, the aspects of abstraction and generalization advantages, their implementation in the design process, safety constraints and comparisons between abstraction and generalization are also reviewed. A case study of an aircraft component is used as the example in conducting abstraction and generalization in the safety approach.

Keywords: Abstraction; generalization; TRIZ; conceptual design; constraints.

1. Introduction

The ability to abstract and to generalize problems is an essential part of any intellectual activity [1]. Many studies support that the use of abstraction and generalization can actually help designers think of problem solutions more clearly and creatively [2, 3, 4]. Abstraction and generalization give more freedom in idea construction than using a specific problem solving approach. Both are very useful tools to enable designers to initiate early moves in generating many possible ideas for problem-solving.

This paper aims to discuss the use of abstraction and generalization in the conceptual design process of artefacts with the safety approach within the Theory of Inventive Problem Solving (TRIZ) [5] environment. The paper's structure consists of several sections; section 2 provides the background of abstraction and generalization, and their roles, the differences between them and their benefits. Section 3 explains the methodology. In section 4, the topic scenario and various gaps in the existing literature are discussed together with a conclusion before closing with the references and acknowledgements.

Previous research on the hybridization of TRIZ and the work of Pahl and Beitz' Systematic Design Approach (SDA) called TRIZ-SDA [6] developed an improved CDF (Appendix A.1) and a compatibility table (Appendix A.2). There are eight steps in the conceptual design process of TRIZ-SDA and three important applications within the CDF; FAM (Functional Analysis Model), SDA Safety Principles, and Constraint Diagnosis.

This paper focuses on the second process of the CDF – *Abstract/generalize to identify the essential problems* – with further discussion and insights, how it is perceived, and implemented. The paper deals with questions such as:

- How are the abstraction and generalization used in the TRIZ methodology?
- How to integrate safety principles into the abstraction and generalization process?

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Abstraction and generalization will be applied on the object of the case study to prove that they are particularly suitable for the construction of the conceptual design, especially with safety features. The findings are evidenced by modelling the problem and formulating solutions based on TRIZ Engineering Contradiction (EC) and Physical contradiction (PC).

Nomenclature

TRIZ	Theory of Inventive Problem Solving
SDA	Systematic Design Approach
CDF	Conceptual Design Framework
39-P	39 parameters
40-IP	40 inventive principles
MLG	main landing gear

2. Background

2.1. Definitions

In most dictionaries, the term abstraction is defined as a *quality, generality,* and *ideas.* Dictionary source [7] defines abstraction as *"the act of considering something as a general quality or characteristics, apart from concrete realities, specific objects or actual instances"*. Abstraction is the process of initial concept formulation and generalization of ideas by extracting common qualities from specific examples. Other definitions of abstraction related to generality are *"a general idea or quality rather than an actual person, object, or event: an abstract idea or quality"* by [8], and *"the quality of dealing with ideas rather than events"* by [9]. These definitions all summarize abstraction as the act of *generalizing something* by taking out only important points from the detailed characteristics of a problem.

In design science, the term *theorizing* complements abstraction [10, 11], because a theory is developed from several layers of abstraction process, apart from identification of the core relationships between findings and propositions [12]. They also acknowledge us that theorizing operates in instance domain where instance or particular solution addressing particular problem, and an abstract domain, where abstract solution addressing abstract problem. Previous researcher [13] found that working within abstract domain often build explicit, novel, and interesting outcome. Another finding by [14] suggests that theory development acquires several abstractions, and reflection process to be able to develop a design theory.

2.2. The role of abstraction and generalization

Abstraction is important in the stage of conceptual design process because it reduces complexity. A product of study (later referred to *prototype*) consist of a number of components, functions, constraints, requirements, performance and parameters which is too in-depth to be included at the initial steps of conceptual design process. It also helps in guiding the designers to focus on several important factors towards producing a broader selection of solutions. If a specific problem goes direct to specific solutions, designers might experience psychological inertia and mental block.

Generalization is usually in domain representation, a set of elements or common characteristics of an elements rather than individual or specific element. Generalization is a broadening of an application to encompass a larger domain of objects of the same or different type. For example, the meaning of "parameter generalization" is to classify the problem's parameters into a generic understanding.

2.3. Abstraction in TRIZ

As mentioned in many TRIZ related journals, proceedings, courses and training materials, the use of abstraction is often in the representation of a Four-Box Scheme (Fig. 2). The four-box scheme studies originated from the work of Mann [15, 16] and are widely disseminated in many TRIZ based methodologies. Nakagawa [17], who extended the four-box scheme into a Six-Box Scheme, stated that after a well-defined specific problem, a generalized problem follows. The generalized problem of the six-box scheme is about understanding the present system (objects, attributes, functions, space, and time) as well as understanding the ideal system (artefact).

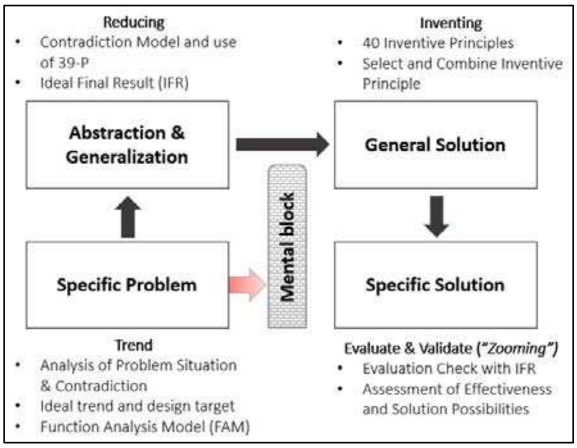

Fig. 1: The TRIZ Four-Box Scheme [15].

Another TRIZ abstraction approach, is done by Khomenko [18, 19] with the development of *Hill model* (Fig. 2), an abstraction-synthesis procedure. The model is part of TRIZ-OTSM which describes the level of problem solving starting with abstraction model (lower curve line), then to specific process (higher curve line) and back to abstraction to complete the problem-solving process. The orange nodes are the earlier stage of problem-solving, requiring the abstraction and generalization of the problem. The green nodes indicate that the candidate solutions are at hand and brought forward to abstract and generalize back.

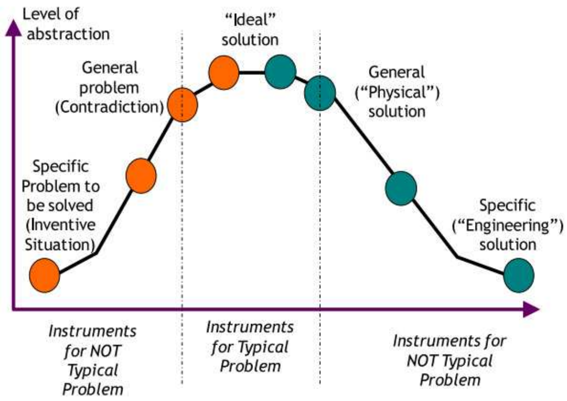

Fig. 2: The "Hill model" from the OTSM-TRIZ method [20] (source from [21]).

Abstraction should be in the middle, between simple and complex. Too simple an abstraction will miss the important information, while, too complex, will make it difficult and confusing to use. TRIZ uses abstraction for the use of 39-P to represent a contradiction in a problem. This is because the solution for the problem are still vague and ambiguous, similar to the condition in the left side of the hill model. The determination of improving and worsening parameters (hereafter referred to as responding variables) is the key. A prototype's EC usually consists of one manipulative variables and contradicting responding variables [22].

2.4. Abstraction vs. generalization

Although many definitions of abstraction refer to generalizing a problem statement, generalization is quite a different entity in TRIZ language. The differences between abstraction and generalization in the context of TRIZ can be understood through the following brief explanation:

- Abstraction is the reducing activity, the reduction of complexity by selecting several important elements and hiding irrelevant details. Abstraction focuses on the main structure of the prototype and its goal setting (IFR) for precise problem modelling [23]. The example of a flower (Fig. 3) as an object (prototype) is presented in a sketch of several petals and the center (consisting of stigma, ovary, ovule, receptacle and pollen tube) in just a simple shape of circle. Only a focus of change or improvement of the prototype is highlighted.
- Generalization, on the other hand, is the construction of problems containing multiple entities, and having similar functions within a single construct. As shown again in Fig. 3, there exist many types of flower but they all are assembled as a single construction, flowers. The same goes for one of the TRIZ inventive principles, *the other way around*, for example. It consists of invert action, moving a fixed object, rotating, and turning it upside-down – but still in a representation of *the other way around*. In the TRIZ problem-solving process, the generalization is important, as it will help in choosing the right parameter from the TRIZ 39-P.

The abstraction requires that the designer simplifies the statement of the prototype, in which simplifies means to only adapt and formulate a few key factors to ease the abstraction formulation and achieve a concept solution. Generalization is the step used *after* abstraction, as a guidance for the selection of 39-P and 40-IP. To proceed to converting a specific problem into an abstract problem, one must identify the *objective* or *goal* of the problem solution. The abstraction process may also include safety principles to excite designers to formulate the conceptual design with a safety approach.

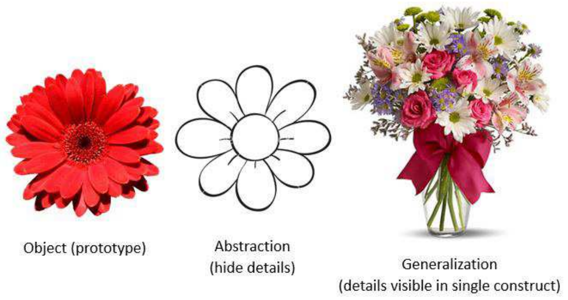

Fig. 3: The differences between the understanding of the actual object, abstraction and generalization (inspired by [24])

2.5. The benefits of abstraction and generalization

Through abstraction and generalization, the designer will choose priorities concerning which main element and other related elements should be taken forward, while the less important can be manipulated. The selection of abstraction and generalization can lead to focusing on the solution. A different focus leads to a different solution. Therefore, the final quality of the artefact reflects the abstraction and generalization used during its design process. According to Hoover and Rinderle [25], abstraction and generalization are a result of a cognitive decision when choosing the focus of change in the design.

3. Methodology

3.1. Abstraction and generalization in selecting the right parameter

Abstraction helps in the decision-making of design change. The level of design change can be from the smallest refinement, optimization, the increase or decrease in performance up to bigger performance change. The important factors to consider while constructing the abstraction of a prototype are the problem's resources, the problem causes, the objective of this problem-solving, the goal, the principles used in the current prototype, and the constraint imposed. For engineering design conceptual design process, abstraction and generalization fall in the second step of CDF, after requirement list.

Abstraction and generalization are easier to visualised in a sketch or model representation. The example of abstraction and generalization model (Fig. 4) shows a simple structure with adequate information to demonstrate the understanding of both processes. On the far left, the abstraction space consists of several selected key points of the prototype's current situation – the advantage, disadvantage, goals, working principle and constraints. The selected abstraction "B" is brought next into the generalization process where the understanding of *many components* is generically translated into complexity. There are three possible 39-P related to complexity projected: 26-quantity of substance, 33-ease of operation and 36-device complexity. Referring back to the way of the component complexities operated, it might help in selecting the right one between the three.

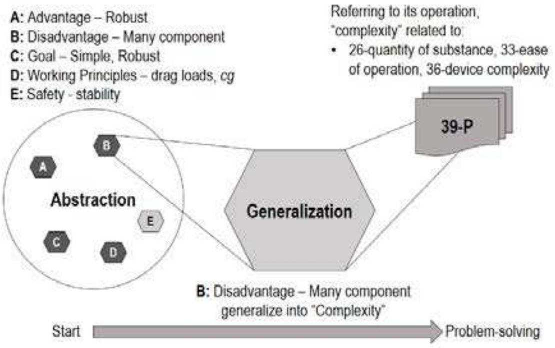

Fig. 4: The model above demonstrates the differentiation between abstraction and generalization process.

3.2. Abstraction and generalization with constraint involvement

When processing the abstraction, the problem's constraint should be included at the initial step. This is because the presence of constraints in the prototype are known and understood when other information details are still blurry. Often TRIZ consider the constraints as the term contradiction of the problem. But, contradiction is something that can and needs to be eliminated while constraints are still remained in the prototype's system. Only the amount and the level of constraints are reduced. Choosing the right inventive principle requires the understanding on constraints, so that the solutions are focused on the optimization of the constraints. The relationship of constraints involves multiple design parameters that are to be reduced to a smaller constraint model.

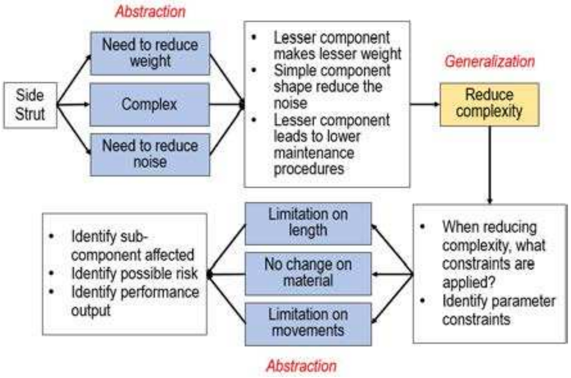

Figure 5: The abstraction activity with constraints input of the MLG Side Strut prototype.

Usually when a constraint is identified, the ideal result [26] [27] or goal is set to contradict the constraint. Fig. 5 demonstrate the abstraction and generalization process inside the idea generation involving constraints. Throughout the process, the selection of 40-IP is based on several generic goals, related components and the characteristics of the prototype's constraints.

Another way to formulate solution ideas involving constraints, particularly for safety, in the abstraction and generalization stage, is by using a compatibility table, Safety Principles - 40-IP table (Appendix A.2). The table was constructed in a study of TRIZ and SDA hybrid methodology (TRIZ-SDA), specifically for safety related conceptual design methodology. Often constraints are optimized when the prototype is firstly changed, since concentrating directly on constraints cannot help in radical design change.

3.3. Generalization and idea development

Proceeding to final stage, before selecting 40-IP, generalization from all the abstraction activity above, resulted to the side strut design contradictions as:

- Improving parameter: The current side strut is sturdy, withstands loads and is stable. To generalize: side strut has advantages in *strength* (39-P number 14).
- Worsening parameter: The current side strut has unwanted weight while in flight mode. The component assembly complexity also contributes to noise. It shows that the complexity of the component structure resulted to increase in weight and noise. To generalize: the problem is *complexity* (39-P number 36).

When 40-IP solution is selected, once again an abstraction and generalization on safety concerns is then conducted. The inventive principles of the formulated responding variables should be: 2-Taking out, 13-The other way around, 25-Self-service, and 28-Mechanic substitution. Assuming the selected principle is 25-Self-service, and referring to Appendix A.2, the safety principle Direct Safety: Safe-life applies. The new side strut artefact should withstand more load types, and should not experience breakdown or malfunction.

Let's generate the solution ideas for the inventive self-service principles. In order to redesign the prototype, any changes require proven principles and calculations, determination of the limits of safe operation, the understanding of the component's operating conditions and environmental factors. At the abstraction process, the inventive principle self-service has two branches of solution approach. They are:

1. Make an object serve or organise itself by performing helpful auxiliary functions.
    - Self-adjusting the side strut so it can withstand loads even greater.
2. Use waste resources, energy or substances
    - Manipulate the loads received. This means when the side loads impacted the side strut the loads are diverted to the area where loads are needed.

To generalize these ideas, the first one are pertaining the positioning and the second is about diversion or movements. Again, the abstraction process happens. When involving the positioning of the side strut, there are restrictions on the connection of side strut to upper and lower link. The area that can only be changed is around the side strut. The body around side strut, for example, can have shapes that can withstand and use the diversion approach - divert loads. The safe-life principles usually applied for parts with high risk or the consequence of failure causes serious threat or accidents [28]. The idea of changing the shape around side strut must comply with the safety standards of the design.

4. Discussion and conclusion

Based on the examples executed in the previous section, it is proven that the use of abstraction and generalization is an absolute advantage in the conceptual design process. Generalization is very potent in the problem-solving steps and stimulates many ideas from different prototype's field. The abstraction activity in Fig. 6 for instance, shows a very generic process. The inventive principles obtained after the abstraction and generalization activity makes designers aware and begin to formulate solutions that are more focused, and the direction concerning what to do becomes clearer.

After referring to the figures and tables presented in this paper, and the abstraction and generalization activities, they provide an avenue to illustrate and modify the existing design. The results strengthen the fact that systematic measures, including abstraction and generalization, guide the design process smoothly.

There is no doubt that an experienced and skilful designer will resolve the design problem straight to specific solution. However, sometimes problems with the prototypes vary. The major challenge of the conceptual design process and problem-solving would be the psychological inertia [29]. A person with psychological inertia favours more familiar ideas and within their scope of interest, rather than exploring a new solution approach. They will work on the solution that is most appealing to them and rely on experience-based problem-solving.

Design is the transformation from the abstract to a concrete description of the design. It is proposed that abstraction and generalization are used as essential steps in the design process. This is to promote creativity, inventiveness, and critical thinking while handling design projects. A designer who is careful in problem formulation by using abstraction and generalization is actually working systematically. Ultimately, the solution for a prototype comes from many critical decisions by the designer themselves, reflecting their capabilities, knowledge and resource management.

As a conclusion, from the study of the abstraction and generalization examples, the review of the literature and the researcher's own experience, the implications for abstraction and generalization in the conceptual design process is an exciting field of design science. This research also complements both TRIZ and SDA methodology in an effort to promote creative and systematic design in many engineering fields. We hope to see this research output and its continuous development contribute to the world of the design community, particularly industrial designers and TRIZ specialists. Finally, we would like to further investigate the improvement of the conceptual design of abstraction modelling, especially concerning the subject of constraint and safety modelling.

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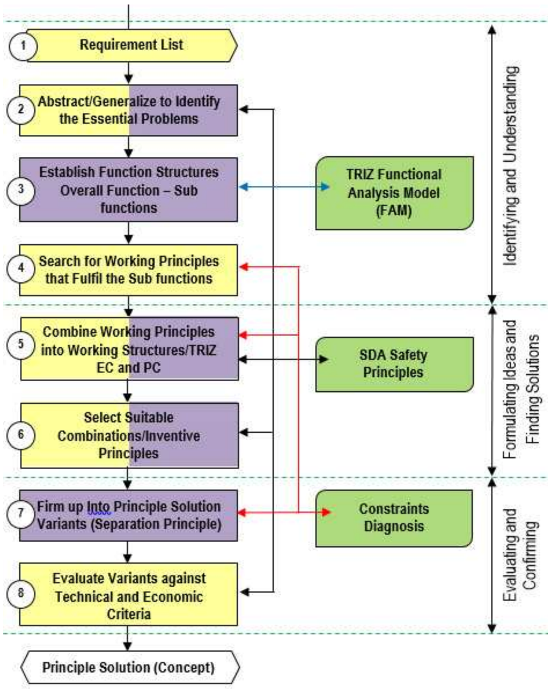
Appendix A. Previous research on TRIZ-SDA

A.1. TRIZ-SDA conceptual design framework (CDF)



The TRIZ-SDA Conceptual Design Framework (CDF) consisting of eight steps [6].

A.2. The compatibility table, Safety Principles – 40-IP.

The Safety Principles - 40-IP compatibility table. The table arranges compatibility and similarity between SDA safety principles and TRIZ 40-IP (updated).

SDA Safety Principles	TRIZ 40-IP	Information
Direct Safety; Safe-Life	3, 6, 8, 9, 10, 11, 14, 17, 20, 22, 25, 28, 31, 35, 36, 37, 40	Operate without breakdown or malfunction throughout lifecycle
Direct Safety; Fail-Safe	2, 3, 4, 5, 6, 8, 10, 11, 12, 16, 19, 32	Signal of any impairment from main function.
Direct Safety; Redundancy	1, 2, 3, 4, 5, 7, 10, 11, 15, 19, 23, 26, 29, 33, 34, 38	Superfluity or excess. Allow transmission losses, hence safeguard the system
Indirect Safety	4, 9, 11, 13, 16, 18, 24, 30, 32, 39	Use of special protective systems and protective devices (when direct safety inadequate).
Warnings	1, 2, 9, 11, 15, 19, 21, 23, 24, 27, 32, 33	Pointing out dangers and indication of the danger area.

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