CROSS-FERTILIZATION BETWEEN TRIZ AND THE SYSTEMATIC APPROACH TO PRODUCT PLANNING AND CONCEPTUAL DESIGN

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ABSTRACT

Creative problem solving is a key factor to successful innovation and, therefore, to the survival of organizations that plan and design products. TRIZ is a very useful methodology for creative problem solving. However, planning and designing products involves complexity (multiple requirements, multiple functions, multiple contradictions), while TRIZ problem solving methods are effective for single problems. Hence, the use of TRIZ in product planning and conceptual design must involve transformation of complex into simple problems. In this paper, a prescriptive model for creative problem solving in product planning and conceptual design is presented. The systematic approach proposed by Pahl & Beitz (1988) is used as the prescriptive model framework. The model is completed with inclusion of basic TRIZ concepts and with elements from different creative problem solving methods, specially TRIZ problem solving methods.

KEYWORDS

TRIZ, Design Methodology, Conceptual Design, Product Planning, Creative Problem Solving.

1. INTRODUCTION

During the 1980's and 1990's, special attention was paid to the business function of manufacturing. Most companies have developed a quality system, mainly to assure final product or service conformance to specifications. Few companies have also focused on improving their product development processes, to provide better products faster than the competitors. As competition becomes stronger, satisfying the customer is a standard, and business strategies must be directed to innovation. Innovation can only be achieved by strong product development and by the concurrent actions of all business functions.

This paper is related to technical innovation in the business functions of marketing and engineering design - and inside these functions, the paper focuses on the processes of product planning and conceptual design.

This paper presents a prescriptive model for problem solving in product planning and conceptual engineering design that is based on ideas derived from the systematic approach of Pahl & Beitz (1988), TRIZ (Altshuller, 1984), and other methods.

Initially, we describe the bibliographic and electronic (e-mail) research about use of TRIZ in product planning and engineering conceptual design and the foundations of our prescriptive model. Then, the prescriptive model is presented. Finally, a short report on practical application of the model is presented.

2. THE SYSTEMATIC APPROACH AND TRIZ IN PRODUCT PLANNING AND CONCEPTUAL DESIGN

The systematic approach to product planning and engineering design proposed by Pahl & Beitz (1988) is a well proven design methodology, valid for component design as well as complex systems design.

TRIZ, the Theory of Inventive Problem Solving, was developed by Altshuller (1984). It includes some very useful elements that are not included in the traditional systematic approach to engineering design. Although TRIZ is based on knowledge from all technical areas, its scope is narrow, directed to specific problems.

As soon as we became acquainted with the original approach to creativity proposed by Altshuller, we recognized its great value. Nevertheless, some questions arose: how could TRIZ be effectively used in systematic product planning and conceptual design? Could it be used in design of complex systems? How?

To find answers to the questions, we have conducted bibliographic research on the subject and an e-mail survey. The main results are described below.

The e-mail survey produced answers from following TRIZ researchers and practitioners: León-Rovira (1998), Terninko (1998), Domb (1998), and Savransky (1998a).

According to León-Rovira (1998), TRIZ concepts of ideality, contradiction and use of resources could guide the whole design process. TRIZ problem solving methods could be used for removing contradictions when they are identified, regardless of the design phase.

In agreement with León-Rovira, Terninko (1998) argues that TRIZ problem solving methods are selected according to the problem, not according to the design phase.

Terninko (1998) and Domb (1998) suggest combining TRIZ and QFD. QFD should be used to identify conflicts between requirements, that could be resolved with TRIZ.

Savransky (1998a) suggests using TRIZ methods in the upfront of the development process, for obtaining innovative concepts. Traditional engineering methods should then be used for further concept development. The same procedure could be used to redesign systems.

The bibliographic research resulted in identification of two approaches to integrate TRIZ with the traditional product planning and engineering design: the unification approach proposed by Malmquist et al. (1996) and WOIS (Linde & Hill, 1993).

Malmquist et al. (1996) performed a comparative analysis of TRIZ and the systematic approach of Pahl & Beitz. As a conclusion of their research, Malmquist et al. suggest that unification of TRIZ and the systematic approach would result in a powerful methodology for engineering design. They further suggest that the resulting, unified methodology should "use the systematic approach as an underlying design process model while integrating TRIZ elements at certain points. This is because the systematic approach has a wider scope as a design process model, covering the whole process from task clarification to detail design and component as well as systems design, while TIPS focuses on solving the inventive part of a design problem, and provides some tools towards this end (laws of engineering systems evolution, principles, standards) that are not included in the systematic approach."

WOIS is the German acronym for Contradiction-Oriented Innovation Strategy). It is an attempt of unification between TRIZ and German design methodology. Linde & Hill (1993) report that it has been successfully applied in many collaborative projects between German companies and Coburg Technical Institute.

We agree with most points made by interviewed authors, but we disagree in leaving the decision on using TRIZ concepts and methods to be made by the product development team (PDT) alone - "when necessary, regardless of the design phase". It is desired, and even necessary, that the PDT has some kind of guidance on "what method to use when".

The guidance could be provided by a prescriptive model (Blessing, 1994) of systematic product planning and conceptual design. The systematic approach by Pahl & Beitz (1988) is a complete prescriptive model. In agreement with Malmquist et al. (1996), we propose to use Pahl & Beitz approach as a framework and include in this framework TRIZ main concepts and problem solving methods. Besides that, we have two other concerns:

- to enhance reuse of design knowledge available in catalogs of conceptual solutions, patent fund, and other sources;
- to prompt the PDT to use the most appropriate method for each type of problem. Use of effective but difficult (and not widely known) problem solving methods is proposed only after trying to solve problems with simpler methods.

3. PRESCRIPTIVE MODEL

The prescriptive model for problem solving in product planning and conceptual design is described below.

The main concepts incorporated in our model were originally developed by Pahl & Beitz (1988), Altshuller (1984), Linde & Hill (1993), and Horowitz & Maimon (1997).

The model is presented in the Appendix. It is a two part model. The first part is the main one, composed by product planning and conceptual design steps with incorporated TRIZ concepts of ideality, contradiction and use of resources. The second part is composed by SIT - Systematic Inventive Thinking - method (also considered by some a TRIZ method), TRIZ problem solving methods and ARIZ (Algorithm of Inventive Problem Solving).

The first part of the model is based on intuitive, systematic and oriented methods. The second part is based on oriented methods. The second part is to be used or not according to the problem difficulty and to the need to find original working principles. There are preparation, execution and decision steps, described in detail below.

Step 1 - Market and requirements analysis

In the first step it is suggested that the PDT identify customer needs and translate those needs in technical requirements.

Many tools could be used to find customer needs. Some examples are questionnaires (Andrade, 1991), interviews, simulation, focus groups (Urban & Hauser, 1993), checklists like the one shown in Table 1 and analogies with market and technology trends like those presented in Tables 2 and 3.

Table 1 - Checklist for identifying customers needs (adapted from Linde & Hill, 1993)

Questions	Needs	
	Generic	Specific
Why bother with the problem?		
Who is involved with the problem?		
What are the expected results?		
When does the need happen?		
Where does the need happen?		
What is the need currently satisfied with?		
How is the need currently satisfied?		
Why has not the need been satisfied yet?		
What are the trends related to the problem?		

Table 2 - Social and economical trends (adapted from Neumann & Linde, 1992)

↑ Life expectancy	↑ Need for illusion
↑ Living standard	↑ Flexible relationships
↑ Self-fulfillment	↑ Self-organization
↑ Exposition	↑ Need for identity
↑ Need for differentiation	↑ Need for effectiveness
↑ Need for comfort	↑ Health care
↑ Need for taste	↑ Self-conscience
↑ Need for safety	↑ Need for education
↑ Need for reliability	↑ Need for leasure
↑ Need for hygiene	↓ Physical work
↑ Technology content	↑ Need for quality
↑ Information content	↑ Mobility
↑ Concern about environment	↓ Local involvement
↑ = increase , ↓ = decrease	

Table 3 - Economical and technological trends (adapted from Neumann & Linde, 1992)

↓ Use of materials	↑ Energy transformation
↑ Recovery of materials	↑ Use of information
↑ Diversity of materials	↑ Refinement of information
↑ Refinement of materials	↑ Preparation of information
↑ Diversity of materials	↓ Necessary space
↑ Use of ceramics	↑ Avail of time
↓ Energy consumption	↑ Organization degree
↑ Energy recovery	↑ Avail of energy
↑ Energy density	↑ Self-organization
↑ = increase , ↓ = decrease	

After compiling a complete list of customer needs, it is necessary to translate them into technical requirements. The PDT can accomplish this by using the house of quality (Hauser & Clausing, 1988). Using the house of quality is specially important for finding contradictions between technical requirements (in the house's roof).

Step 2 - Preliminary generation of working principles

During step 1, while analysing customer needs and establishing technical requirements, PDT members usually have some ideas on how to address those needs and requirements. In step 2, it is suggested to document existing ideas and to use intuitive methods (brainstorming, lateral thinking, brainwriting) to build on these ideas. Some interesting working principles and whole conceptual solutions can be found at this point.

Step 3 - Definition of overall function and subfunctions

The PDT starts step 3 by describing the system's functioning, i.e. the processes that happen or should happen inside the system. After understanding the system's functioning, it is suggested that the PDT abstract, in order to identify essential system's problems (Pahl & Beitz, 1988) and to formulate the overall function of the system. The multiscreen matrix presented in Table 4 (adapted from Altshuller, 1984) can be used for helping the PDT in identifying the systems, connections and contradictions involved.

Table 4- Multiscreen matrix (adapted from Altshuller, 1984)

		Past	Present	Future
Super-system	Elements			
	Connections			
	Contradictions			
System	Elements			
	Connections			
	Contradictions			
Sub-system	Elements			
	Connections			
	Contradictions			

After proper problem definition, functional analysis or synthesis is to be used. The former is used for redesign, while the latter is used for developing new concepts. The decision on using or not a formal approach to functional analysis and synthesis is left to the PDT, but it is essential to list the functions. Procedures for building functional structures are found in the literature (Back, 1983; Pahl & Beitz, 1988; Hundal, 1990; Roth, 1982; Ullman, 1992; Koller, 1994; Rodenacker, 1982 and Ulrich & Eppinger, 1995). If contradictions between necessary functions arise, these should be documented.

Step 4 - Search and selection of available solutions

With the overall function and subfunctions defined, the PDT is able to conduct a search for solutions. Main references for this search are design catalogues (Roth, 1982), commercial catalogues, books, magazines, the patent fund, and the internet. It is suggested to first look for solutions related to the overall function of the system. If ready solutions are found, and if they are available, acquisition or licensing could be the strategy to be chosen (step 5). If ready solutions relate to subsystems, they should be collected in the form of a morphological matrix (Zwicky, 1948), with the subfunctions as parameters.

Step 5 - Decision

If the solutions found for the overall function are available and satisfactory, the PDT can advise senior management to buy or license the solution. If this direction is not chosen, then the PDT should decide between returning to steps 3 and 4 or advancing to step 6.

Step 6 - Analysis of system evolution and resources

In this step, a thorough analysis of the technical system is recommended. The PDT should study the systems' evolution, formulate problems and the ideal final result A – IFRA for each problem, estimate the degree of difficulty of problems, and list resources from the system and surroundings.

The tools to be used during evolutionary analysis are the matrix of generations (Table 5) and the evolution pattern matrix (Table 6).

The matrix of generations is used to map the system's evolution and trends for its further development. The parameters to be considered are on lines and the generations are on columns. Because of limited space, there is only one generation column in Table 5, but as many generation columns should be used as necessary to properly describe the system's evolution. The first generation is the natural system that accomplished the same function or a similar function to the one performed by the system. The headings "nature" and "structure" correspond to the first generation. The headings "need" and "technical possibility" correspond to artificial systems of the second, third, n^{th} generations. The current generation should be described in column n-1. The "trends" column should be completed with corresponding trends from Tables 2 and 3. In the line "contradiction", the PDT should state the main contradiction that causes the need for the next generation of the system.

Table 5 - Matrix of generations (adapted from Linde & Hill, 1993)

	Generation (1^{st}, 2^{nd} , ...)		
Parameter	**Nature / Need**	**Structure / Techical possibility**	**Trends**
Material	Natural system / need to be satisfied	S/TP for material	
Energy		S/TP for energy	
Information		S/TP for information	
Space		S/TP for space+	
Time		S/TP for time	
Environment		S/TP for environment	
Human involvement		S/TP for human involvement	
Contradiction	Improving parameter	Worsening parameter	
Reason for next generation	Reason for next generation	S/TP for next generation	

After completing the matrix of generations, the PDT should look for evolutionary possibilities, based on the evolution pattern matrix (shown in Table 6). The "working principles" column should be left blank until step 7.

Table 6 - Evolution pattern matrix (adapted from Altshuller, 1984 and Salamatov, 1999)

Patterns	Questions	Ev. possibilities	Working principles
Completeness of system	Is the system complete, with the 5 basic elements (engine, transmission, working element, control element and structure)?		
Energy conduction capability	Is there suitable energy flow between subsystem, specially between control element and controlled elements?		
Rhythm coordination	Is there coordination or planned uncoordination between subsystems' rhythms?		
Endless technical development	What development and improvement possibilities can be identified for the system?		
Increased ideality	How can the system become closer to ideal?		
Unequal development of sub-systems	Which subsystems are more developed or less developed? How can the difference be reduced?		
Transition to the super-system	How could the system become a part of a supersystem? What improvement could be achieved with that?		
Simplification	Can systems working principles be simplified or substituted by simpler ones? How?		
Transition from macro to micro-systems	Can systems working principles be improved by transition to the microlevel? How?		
Automation	Can system effectiveness be improved by automation? How?		
Increasing use of Su-Fields	Can system effectiveness be improved by increased use of Su-Fields? How?		

Still in step 6, it is suggested that the PDT formulate the main systems' problems. These problems should be chosen from the ones identified in steps 1 and 3. The ideal final result A (IFRA) - analog, but not the same as IFR1 in ARIZ - should then be stated. The IFRA should be based on economical and technological parameters. There should be one IFRA for each problem to be solved in the system.

With the problems and IFRAs stated, it is suggested that the PDT estimate the degree of difficulty for each problem. This should be done according to the scale proposed by Altshuller (1984). The estimation of difficulty will be used later (in step 12) to define if use of an inventive methodology is necessary or not.

The last activity in step 6 is resource mapping, which can be facilitated by using the matrix for resource mapping (Table 7). The column "resources" should be completed with resources found in the system and surroundings, and the column "working principles" should be left blank until step 7.

Table 7 - Matrix for resource mapping (adapted from Savransky, 1998b)

Kind of resource	Points to be observed	Resources	Working principles
Substance	Waste, air, additives, raw materials, byproducts, system elements, surrounding elements, surrounding substances.		
Energy	Energy from system or surroundings, mechanical energy, gravitational energy, electromagnetic energy, waste energy.		
Space	Void, porosity, cavities, empty spaces, unused dimensions, unused layouts.		
Field	Gravity, electromagnetic field, thermal field, mechanical field, smell, radiation, sound.		
Time	Before action, during action, after action, pauses.		
Information	Inherent properties, transient information, change of state information.		
Function	Functions that could be fulfilled by the system, transformation of harmful functions.		

Step 7 - Search for working principles

In this step, additional search for working principles should be done.

The PDT should complete the "working principles" columns in Tables 6 and 7, trying to transform evolutionary possibilities and identified resources into working principles.

It is also suggested that intuitive methods be used, again - now with information accumulated from steps 3 to 6.

Step 8 - Decision

Are there enough working principles? If there are enough - both qualitatively and quantitatively - working principles, the PDT should proceed to step 9 (concept generation). If not, the PDT should decide between rework in steps 6 and 7 or advancing to step 12 (definition of inventive methodology).

Step 9 - Concept generation

In this step, it is suggested that the PDT build a morphological matrix (Table 8) and a concept matrix (Table 9).

In the morphological matrix, the parameters are the subfunctions defined in step 3. The working principles to complete the matrix should be collected from those found in all previous steps. Instead of putting all working principles found in the matrix, the PDT can exclude those considered unfeasible.

Table 8 - Morphological matrix (Zwicky, 1948)

	Subfunctions	Working principles			
		1	2	3	...
A					
B					
C					
D					
...					

The working principles compiled in the morphological matrix should now be combined into concept variants. For clarity, the concept matrix (Table 9) can be used for obtaining concept variants. In this matrix, each column corresponds to a concept. For improved visualization, it is suggested to draw a sketch of each concept.

Table 9 - Concept matrix

	Subfunctions	Concept			
		I	II	III	...
A					
B					
C					
D					
...					

Step 10 - Concept evaluation

In step 10, the PDT should use a concept evaluation procedure in order to define the best concept. Because customer's needs and technical requirements were determined (in step 1), it is suggested to use them as parameters for concept evaluation. The absolute evaluation procedure proposed by Pahl & Beitz (1988) or the relative evaluation procedure proposed by Pugh (1990) can be used.

If it is difficult to define one best concept, the PDT can choose to create an additional concept, based on the best ones or decide to keep working with two or three concepts in the embodiment phase.

Step 11 - Decision

In this step, the PDT should decide if the concept(s) selected in step 10 are satisfactory or not. If yes, then it is suggested proceeding to embodiment. If the concept(s) are considered weak, the PDT should decide between rework in steps 9 and 10 or proceeding to step 12 (definition of inventive methodology).

Step 12 - Definition of inventive methodology

This step is reached if there are not enough working principles or concepts (in quantity and/or in quality). In such cases, the use of TRIZ problem-solving methods or SIT (Systematic Inventive Thinking) is recommended. The choice depends on PDT skills and preferences. Use of ARIZ should not be defined at this point.

Step 13 - Problem reformulation

This is the first step of SIT. The original system should be reformulated, the sufficient conditions should be stated and the solution strategy should be defined (Horowitz & Maimon, 1997).

The matrix shown in Table 10 can be used for reformulating the problems stated in step 6. One "identified element" column should be used for each problem.

Table 10 - SIT problem reformulation matrix

Element type	Identified element
System elements	
Surrounding elements	
Problem parameters	
Undesired relations between problem parameters	

After completing the problem reformulation matrix, the QC (qualitative change) and CW (closed world) conditions should be stated, for each problem. Existing relation between parameters 1 and 2 is undesired. The following phrase should be used for problem reformulation: parameter 1 should become unrelated to / decreasing function of parameter 2, with no new elements being added to system elements and surrounding elements.

After redefining problems, solution strategies for each problem should be defined (extension or restructuring).

Step 14 - Problem solving

The idea provoking techniques (Horowitz & Maimon, 1997) to be used for problem solving should be defined according to the solution strategy chosen in step 13. Table 11 can be used for systemizing the process. In the first column, system elements and surrounding elements that will conduct the operations (unification, multiplication, restructuring, increasing variability or reducing) should be listed. The second column should be completed with the necessary operation for each problem. In the third column, working principles identified should be listed.

Table 11 - SIT problem solving matrix

Object that will perform operation	Necessary operation	Working principle

Step 15 - Decision

According to the results of steps 13 and 14, the PDT may choose to stop looking for working principles and proceed to step 9 (concept generation) or advance to step 17 - use of TRIZ problem solving methods.

Step 16 - analysis of technical contradictions

In this step, it is first suggested that the PDT reformulate the ideal final result (which now becomes the IFRB). IFRA involved economical and technological parameters. IFRB should involve only technological parameters. The contradicting requirements should be identified for each problem, and transformed into engineering parameters (Altshuller, 1998).

Step 17 - Solution of technical contradictions

In this step, inventive principles should be used for finding working principles. The contradiction matrix (Altshuller, 1998) can be used to determine inventive principles. The matrix shown in Table 12 can be used to systemize the process of search for working principles. It is suggested that inventive principles be listed in the first column, solution possibilities in the middle column and working principles in the third column. There should be as many matrices as problems to be solved.

Table 12 – Matrix for using inventive principles

Inventive principles	Solution possibilities	Working principles

Step 18 – Decision

In step 18, the PDT should decide if it is necessary to proceed refining the contradictions and looking for working principles or not. If there are enough working principles, the PDT should start generating concepts (step 9). If not, the PDT should proceed to step 19.

Step 19 – Analysis of physical contradictions

If proper solutions to the problems were not found at the technological level, it is necessary to proceed to the physical level. The problems should be reformulated, as physical contradictions. Also the IFRC should be stated, in terms of contradicting parameters that the same object should fulfill.

The PDT should also build Su-Field models of all problems (Altshuller, 1984).

Step 20 – Solution of physical contradictions

In step 20, solutions to the physical contradictions stated in step 19 should be found. The PDT should use the principles for elimination of physical contradictions and the standard solutions (Salamatov, 1999).

A matrix similar to the one shown in Table 12 could be used for finding working principles with the standard solutions, with “inventive principles” in the first column being replaced by “standard solutions”.

Step 21 - Decision

From step 21, there are four possible paths for the PDT to follow: generate concepts (step 9) – if there are enough working principles; revise steps 20 and 21; use the SIT method (if it was not used before) or; use ARIZ.

Step 22 – Use of ARIZ

Using ARIZ is only recommended as the last attempt to solve difficult problems, that could not be solved with previous methods.

4. CURRENT RESEARCH

We are currently evaluating the prescriptive model in projects with agricultural equipment. Some results of using the model in practice are:

- a procedure for defining problems should be included in the first part of the model;
- a better integration between functional synthesis and analysis and TRIZ concepts should be sought in the first part of the model;
- the second part of the model should be modified, in order to avoid parallelism between SIT and TRIZ.

CONCLUSIONS

In this paper, a prescriptive model for

creative problem solving in product planning and conceptual engineering design of complex products was presented.

The prescriptive model uses the systematic approach proposed by Pahl & Beitz (1988) as a framework, which is permeated by TRIZ concepts and problem solving methods.

The prescriptive model is being applied in design of agricultural equipment and some necessary modifications were identified.

BIOGRAPHICAL SKETCHES

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APPENDIX 1 - PRESCRIPTIVE MODEL FOR CREATIVE PROBLEM SOLVING IN PRODUCT PLANNING AND CONCEPTUAL DESIGN