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INNOVATION ENGINEERING METHODS FOR CONCEPTUAL ENGINEERING DESIGN – A REVIEW

Ivan MAŠÍN[1]

[1]*Department of the Design of Machine Elements and Mechanisms, Technical University of Liberec*

Abstract
This review deals with the description of innovation engineering methods that enable effective course of the initial steps of the innovation process, which aims to generate the best concept of innovated technical product.

Key words: *concept generation, methods, function analysis, creativity*

INTRODUCTION

Conceptual design differs from other phases of the design process (e.g. detailed design, design for assembly). The conceptual phase concerns the problem of coming up with new ideas or new solutions to problems. The goal of conceptual design theory is to understand the processes which lead to innovation and to create or describe techniques and engineering methods which generate proper changes in function in an systematic and repetitious basis (*Pahl, Beitz, Feldhusen & Grote, 2007; Pugh, 1991; Eversheim, 2009; Hubka & Eder, 1988; Eder & Hosnedl, 2010; Baxter, 1995*). Many of these sources, however, do not sufficiently described or underlined the importance of methods of so-called innovation science and systematic creativity, which has been dynamically developing over the last decade.

METODS OF INNOVATION ENGINEERING FOR INITIAL PHASES

Innovation engineering is one of the youngest engineering disciplines. This engineering field can be defined as an "interdisciplinary field, which deals with the effective process of the whole innovation process and the rapid transformation of the primary innovation idea into an innovative product applied in the market. For this purpose, he uses both specific industry methods as well as methods and knowledge from other engineering disciplines, from natural and social sciences, as well as knowledge from management theory. "

A very important role is played by methods for the initial phase of the innovation process. During this phase the concept of innovative products is generated and designers decide on the success of the product on the market, regardless of how well the subsequent engineering activities (modeling, prototyping, testing, etc.) are performed. Overview of these methods is given in the Table 1.

Tab. 1 Overview of methods for conceptual design phases

Innovation process phase	Innovation engineering methods
Innovation and technological forecasting	Technology Road Mapping Directed Evolution (DE) WOIS
Customer needs transformation	Thinking aloud protocol Quality Function Deployment (QFD) Innovation Situation Questionary (ISQ) Main Parameter Value analysis (MPV)
Problem decomposition and innovaton problem definition	Function analysis Trimming RCA, RCA+ Cause Effects Chain Analysis (CECA) Function Analysis System Technique (FAST)

Information search in cyberspace	Function Oriented Search (FOS) Function Behavior Oriented Search (FBOS)
Analysis of competing products	Reverse engineering
Creative concept generation	Morphological table 9 windows 40 inventive principles TRIZ Axiomatic design Bio-mimetics
Product architecture	Design Structure Matrix (DSM) Modular Function Deployment (MFD)
Concept evaluation and selection	Evaluation tables (Pugh) Analytical Hierarchy Process (AHP) Weighted Rating Method

FUNCTION ANALYSIS

Function is an action performed by one material object to change or maintain a parameter of another material object. Technical systems are created to perform functions, and those functions are realized through a set of specific components. Function analysis is an analytical tool that identifies functions, their characteristics, and the cost of the system and the super-system components. (*Litvin, 2010*) The main goals of function analysis are:

- To provide a functional representation of technical system.
- To identify functional disadvantages of the components of technical system.
- To rank the functions for further trimming.

The outcome of function analysis is the model of technical system in tabular or graphical forms. Function model is a model of the technical system that identifies and describes the functions performed by the components of the system and its super-system. Functions are characterized by category (useful or harmful), quality of performance (insufficient, normal and excessive), cost level (insignificant, acceptable and unacceptable) and cost of corresponding components. Function analysis is significantly powerful approach. It opens many new innovation possibilities by developing a function model of the system. This leads to multiple design options that significantly increase our ability to improve the system

CAUSE-EFFECT CHAIN ANALYSIS

There are a lot of methods for causal analysis. At traditional process improvement programs we can see many activities promoting one or another technique. For instance Lean Manufacturing and Industrial Engineering tend to process-oriented analysis, modern TRIZ toolkit contains function analysis where the problem is described as a chain of interactions or functions. Failure-analysis techniques promote fault tree, root-cause methods usually promote fishbone diagram and so on. Each of these forms of causal analysis has their place. They help to describe the problem and give us insights into what is causing it.

TRIMMING

Trimming is an analytical tool for reducing the number of components and simplifying the technical system. During trimming problem solvers or innovators remove certain components and redistribute their useful functions among the remaining system or super-system components. The outcome of trimming is a function model of the technical system as it would exist in the future after trimming. It also contains a set of trimming problems (questions) to solve. Trimming is driven by a set of rules defining how to redistribute useful functions of eliminated components. Maximum improvement of a technical system is achieved when a function is performed without any surplus components. This tool yields new, more effective problem statements and also points toward impactful solutions.

FUNCTION ORIENTED SEARCH

To dramatically improve a technical system, new solutions must be found. However, new solutions are not easy to implement, and many problems have to be solved before changes can be successfully implemented. Function-Oriented Search (FOS) or Function/Behaviour Search (FBOS) changes the paradigm by searching for existing solutions rather than inventing new ones (*Montecchi & Russo, 2015*). Once a solution is found in another industry, it becomes an adaptation problem, which is much easier to overcome than inventing new solutions. Adapting existing technologies is easier, more reliable, and requires fewer resources (manpower, capital, and time) than inventing new technologies and their applications. FOS or FBOS remove the industry-specific limitations of a potential solution, and uncovers possibilities, regardless of the source industry. It allows capitalizing on investments made in other industries. FOS also breaks psychological barriers for acceptance of new technologies, because there is already detected proof that the recommended solution will work. FOS is based on a generalization of functions, using a critical, two-prong approach: by action, and by object. This structured approach allows expanding the search for applicable technical solutions.

9 WINDOWS

Nine windows (or multi-screen diagram of thinking) is a creative tool originally introduced by G. S. Altshuller (*Altshuller, 1973*) for extracting opportunities in a systematic way by exploring changes which transformed the past generation of a system to its current generation. This tool specifies that any specific system (product, technology, organization, etc.) can be viewed at least from three layers: system, its subsystems and super-system. Nine windows help to analyze the system evolution deeper by taking into account relationships of the system with system environment and help with prediction of further evolution. According to G. S. Altshuller, this way of thinking is a feature of outstanding inventors who create new innovative ideas by seeing the whole world by system thinking.

TREND OF TECHNICAL SYSTEMS EVOLUTION

Trends of technical systems evolution are statistically proven directions of technical systems development. (*Zouaoua, 2015*) They describe the natural transition of technical systems from one state to another. These directions are statistically true for all categories of technical systems. Trends result from the general laws of technical systems evolution originally defined by G. S. Altshuller. According to Ikovenko we currently differentiate these trends:

- Trend of S-curve evolution
- Trend of increasing value
- Trend of transition to the super-system
- Trend of increasing completeness of system components
- Trend of increasing degree of trimming
- Trend of optimization of flows
- Trend of elimination of human involvement
- Trend of Increasing coordination
- Trend of uneven development of system components
- Trend of Increasing controllability
- Trend of increasing dynamicity.

INVENTIVE PRINCIPLES APPLICATION

Inventive principle is an abstract model that provides generalized recommendations for modifying a system to solve a problem formulated as a technical or physical contradiction. (*Rantanen & Domb, 2007*) A technical contradiction is a situation, in which an attempt to improve one parameter of an technical system leads to the worsening of another parameter. A physical contradiction is two justified opposite requirements placed upon a single physical parameter of an object. These requirements are caused by the conflicting requirements of a technical contradiction. G. S. Altshuller studied the engineering problems and their resolution by analyzing thousands of patent documents (*Altshuller, 1988*). He generalized 40 typical solutions to typical contradictions that work successfully in most situations and called them inventive principles. Those general recommendations must be translated into specific technical ideas that solve the initial technical contradiction.

CONCLUSIONS

Engineering methods were and are certainly an important factor in the development of human society. These methods have arisen either as a necessary response to the needs and pressure of the environment, or as a systematization or generalization of procedures used in successful technical solutions. The sophistication of engineering practices has grown and increased with the increasing pressure of the business environment, the growth of competition, and ultimately the complexity of engineering tasks or products. The application of innovation engineering methods during the conceptual phase of innovation process does not deny or diminish the quality, experience, specialization, and sometimes intuition of individuals or entire innovation teams. Conversely, innovative concepts will be generated through the synergy of individual skills, systematic teamwork and advanced creative skills.

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Corresponding author:
Doc. Dr. Ing. Ivan Mašín, Department of the Design of Machine Elements and Mechanisms, Faculty of Mechanical Engineering, Technical University of Liberec, Studentská 2, Liberec, 46117, Czech Republic, phone: +420 602 439 258, e-mail: ivan.masin@tul.cz.