

---

# Guidelines for Reverse Engineering Process Modeling of Technical Systems

Ivo Rodrigues Montanha Junior<sup>a,1</sup>, André Ogliari<sup>b</sup> and Nelson Back<sup>b</sup>

<sup>a</sup> Graduate Student in Mechanical Engineering, UFSC, Florianópolis-SC, Brazil.

<sup>b</sup> Professors of the Mechanical Engineering Department, UFSC, Brazil.

**Abstract.** In spite of the process of conception generation being essential to promote product innovation, it has not been effectively carried out by designers, due to the abstract nature of this activity. In order facilitate this process, Reverse Engineering (RE) has been suggested as a way to formalize the processes of identifying, purchasing and modeling design information in terms of functions and solution principles, in a continuous and systematic way. This paper presents a literature review of technical systems conception processes and of RE. The results of a technical visit to a leading RE company, and a preliminary methodological proposal for RE process modeling for technical systems, are also reported. This proposal is intended to support the concept generation process of technical systems. Finally, guidelines are proposed for the final version of the methodology.

**Keywords.** Conceptual design, Reverse engineering, Innovation, Product development, Function analysis

## 1 Overview

In methodological terms, Brazilian companies have made little effort to promote innovation, in a systematic way [7]. This indicates the need to provide better support to companies, in terms of the obtention of information and an understanding of their products and technologies.

Many authors consider the process of conception generation as essential to innovation, because it uncouples the design problem from the known solutions by an abstraction process. This leads to more possibilities for innovation. In spite of its importance, this process is not effectively carried out by designers. Partially, this happens due to the abstract nature of its activities – mainly in the functional modeling – and the difficulty to manipulate generically valid functions (basic operations) to represent the product.

---

<sup>1</sup> Graduate Student in Mechanical Engineering; Federal University of Santa Catarina (UFSC); NeDIP – Núcleo de Desenvolvimento Integrado de Produtos; Departamento de Engenharia Mecânica, Bloco B, Campus Universitário, Caixa Postal 476, Florianópolis-SC, Brazil; Tel: +55 48 37219719; E-mail: ivojr@nedip.ufsc.br; <http://www.nedip.ufsc.br>

In this process, standardized functions are suggested to guide the designers in the product functional structuring process, together with the “solution principles catalogues”, related to the basic operations. This promotes mechanisms to make the product conception and its innovations easier [2, 8, 13, 14].

Thus, it is recognized that there is a need for methods and tools related to the process of analysis and synthesis of functions. These favor the addition of innovations to the product function tree, by the insertion, combination and removal of standardized functions. Thus, Reverse Engineering (RE) is suggested, as a way to model the processes of identifying, purchasing and modeling design information – functions and solution principles – in a continuous and systematic way.

This paper presents a literature review of Technical Systems (TS) conception processes and of RE. The results of a technical visit to a leading RE company, and a preliminary methodological proposal of RE process modeling for TS, are also reported. Finally, guidelines are proposed for the final version of the methodology.

## 2 Literature Review

### 2.1 Conception Process of Technical Systems

In the conceptual design phase, the TS conceptions are developed through the activities: functional modeling, solution principles and product conceptions generation. The main functional modeling approaches are: functional deployment [13]; axiom-based synthesis [18] and the function-means tree [17].

When the function structure of the TS is defined, the process of generation of solution principles starts, where the functions are usually listed in a morphological matrix. Solution principles are proposed for each function and, after that, the solution principles are combined, generating the product conceptions.

The conception process demands a significant capacity of abstraction and an accurate definition of the functions. In order to support the acquisition of this information the use of RE is proposed, as shown in the next section.

### 2.2 Reverse Engineering for Technical Systems Design

From some definitions [4, 5, 12], RE can be understood as a “process of information getting and analysis from existent systems, in order to optimize systems being developed.” It is intended to understand how a TS works from RE analysis, not a copy of technical solutions. In this context, methodologies have been suggested to formalize a part of, or the entire, RE process for TS [11, 12, 16].

Methods and tools were suggested by [15] to develop the TS function tree through the functions analysis. Three methods are highlighted: FAST (Function Analysis System Technique), SOP (Subtract and Operate Procedure) and Force Flow. Another approach to functions analysis was proposed by [6], where physical principles and functions of a system are identified, through an abstraction process.

According to [12], one important process of RE is the Product Teardown (technical disassembly). The TS is disassembled in order to estimate costs, identify materials and manufacturing processes, estimate technology trends, forecast the TS specifications, etc. This is presented in the next section.

### **2.3 Product Teardown**

A teardown process of competitors TS is carried out by many companies, focusing on RE. Their goal is to verify the market technologies and to find technologies to optimize the system [9]. However, this process is commonly informal, aiming at the solution of specific problems. They consider neither the reasons why the concepts were introduced into the TS, nor the functions and solution principles.

However, the teardown must be formal and consider the entire TS, in its normal conditions of use (as purchased). After that, the TS should be disassembled, to analyze each subsystem and component, in order to identify the inter-relationships among them, their functions and solution principles. This favors the identification of the functional structure of the TS being analyzed, and its solution principles.

In order to carry out the teardown, several methodologies have been suggested. In [12] the practical procedure was emphasized but not the functional modeling; in [1] the identification of the TS functions is clear and logical. In the latter study the TS is disassembled and the Bill of Materials is defined. Then, the TS mechanisms and structure are analyzed, where the functions are identified, considering the levels of global, partial and elemental functions tree. The mechanisms used to satisfy the functions and the force flow diagram, are also defined.

### **2.4 Support Methods Related to Reverse Engineering**

An important method related to RE is Value Analysis (VA) [2], because it identifies important attributes of the TS, which are to be prioritized in the analysis and redesign. The AHP (Analytic Hierarchy Process) method [3] can also be used to analyze the attribute value of the TS.

In order to identify the connections between the physical components or processes of a TS, Interface Diagrams can be used [15]. The nodes of the diagram are the TS components, and the lines connect the nodes and show the interfaces. The functionality of each component is deduced by observing the physical interfaces among the components.

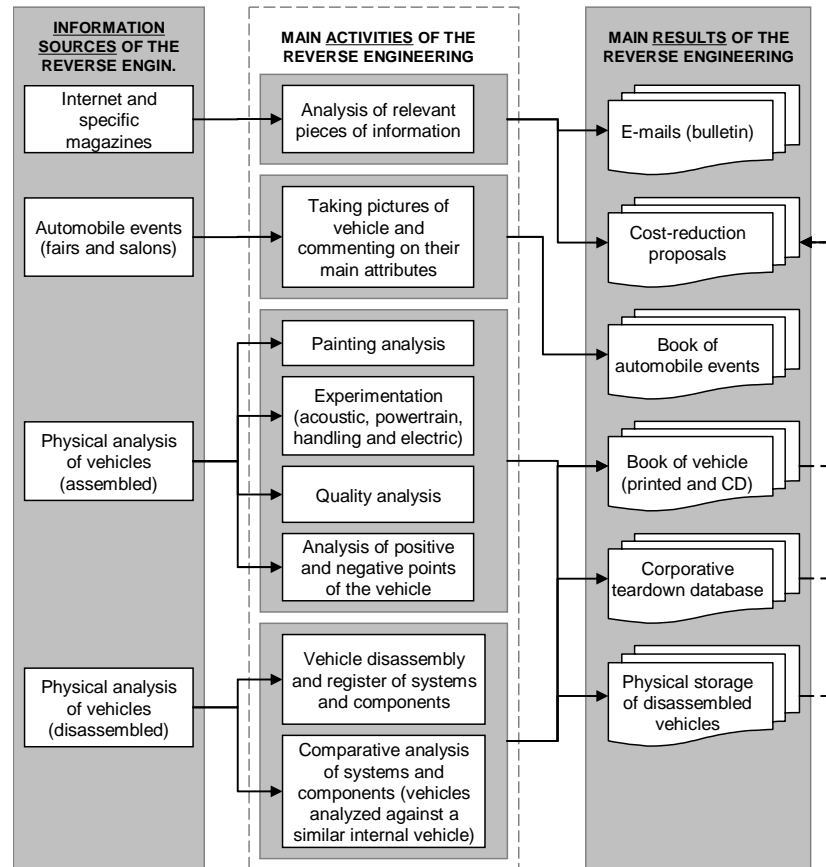
Beyond these approaches, the assembly analysis methods are presented, according to the DFA (Design for Assembly) approach [15]. Three of them are: the AEM method (Hitachi Co.), Boothroyd-Dewhurst method and Lucas method.

In a general way, even though the literature proposes formal methods to implement the RE in TS, they are not integrated into a methodology. They also do not consider specific mechanisms to facilitate the identification of functions and solution principles, both important to the conception process. In order to understand better the RE process, the next section presents the main results of a technical visit, carried out in a leading RE company, in the automotive sector.

### 3 Technical Visit to a RE Leading Company

The selected company is an automotive assembler, of a multinational group. The European head office designs the new vehicles, and the Brazilian unit (visited) makes complementary studies and technical adaptations for the Brazilian market.

One information source that helps in the planning and implementing of technical adaptations and redesigns is the RE process. Its analysis is carried out by professionals from the engineering and quality sectors. One very important sector for the RE process is the teardown, where the analyzed vehicles are disassembled. Figure 1 presents a synthesis of their RE process.



**Figure 1.** General view of the reverse engineering process of the visited company [10]

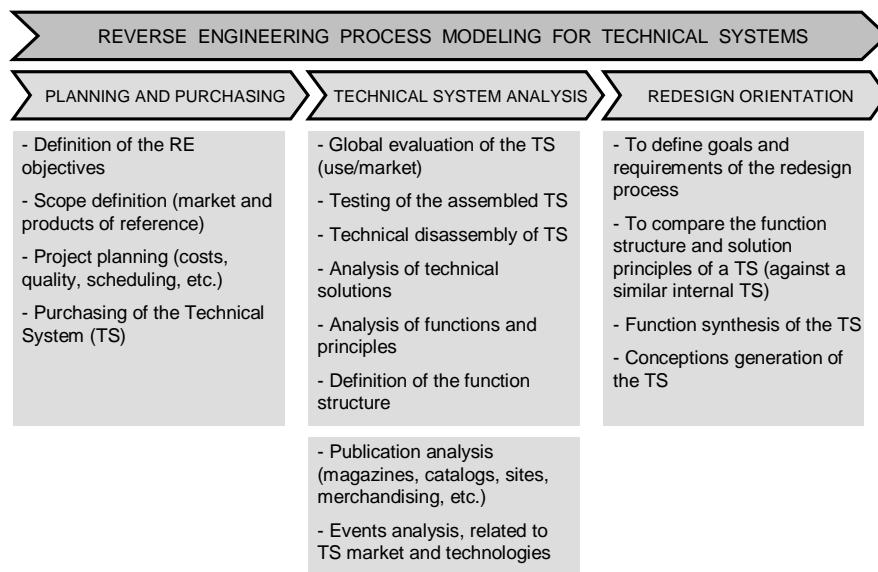
The left side of Figure 1 presents the main information sources of the RE process in the RE company. The RE activities are essentially related to information analysis from the Internet, events, tests of assembled vehicle (as purchased) and analysis of the disassembled vehicle (teardown).

From the sources and activities, the results of the RE process are generated (right side of Figure 1). One important publication is the book of the vehicle, which is a report with all the results of the entire RE process, and this information is inserted into the corporative teardown database. The main information of the RE process is introduced into the cost-reduction ideas database of the company, in order to optimize the design and redesign of the company's vehicles.

In spite of the visited company having a formal and well understood procedure of RE – which is not seen in most Brazilian companies – the vehicle functions are not considered in the TS study. The functions should support the planning of new versions, because the designers can find new ways to satisfy the functions, increasing the innovation possibilities.

#### 4 Proposal of the Reverse Engineering Process Modeling

The modeling of the RE process of Technical Systems (TS) aims, among other aspects, to obtain, represent and make available information about functions and solution principles, which can be used to support the TS innovation (Figure 2).



**Figure 2.** Preliminar modeling of the RE process for technical systems [10]

The RE model (Figure 2) is composed of three macro-phases: planning and purchasing, technical system analysis, and redesign orientation. It seems to be similar to the automotive model (Figure 1), but only here the TS functions are considered, in order to identify opportunities of innovations since its function structure. It is the main original contribution of our methodology.

The goal of the Planning and Purchasing phase is to plan the activities of the RE process, and to orientate the designers to purchase the right TS to be analyzed. The main results of this phase are the project plan of the RE process and the TS purchasing. The Technical System Analysis phase aims at the analysis of the purchased TS, in order to obtain information which can be used in future designs and redesigns. The main results are: a list of components and materials, TS description and information about technical performance.

Another differential result of this research, is the proposition of means to identify the TS function structure, with their respective solution principles. These means are based on the methods of section 2.2 (FAST, SOP, Force Flow and the [6] approach), and the support methods for the RE process (section 2.4 – value analysis, AHP method, interface analysis, etc.).

For example, in [6], a TS is analyzed from its technical drawing, highlighting its mechanisms and principles. After that, the main functions carried out for the TS are identified, as well the energy, material and signal flows. Then, the main functions of the TS are represented in a block diagram, in a systematic process of abstraction, from the real system to its functions.

From the identification of the functions of the TS under analysis, alternatives for the function structures can be suggested. The designers can innovate in the insertion, combination and removal of functions, as well as in the proposal of alternatives for the solution principles for each TS function. In this phase, parallel activities of publications (books, magazines, websites, etc.) and events analysis are also considered, both being related to the market and technologies of the company.

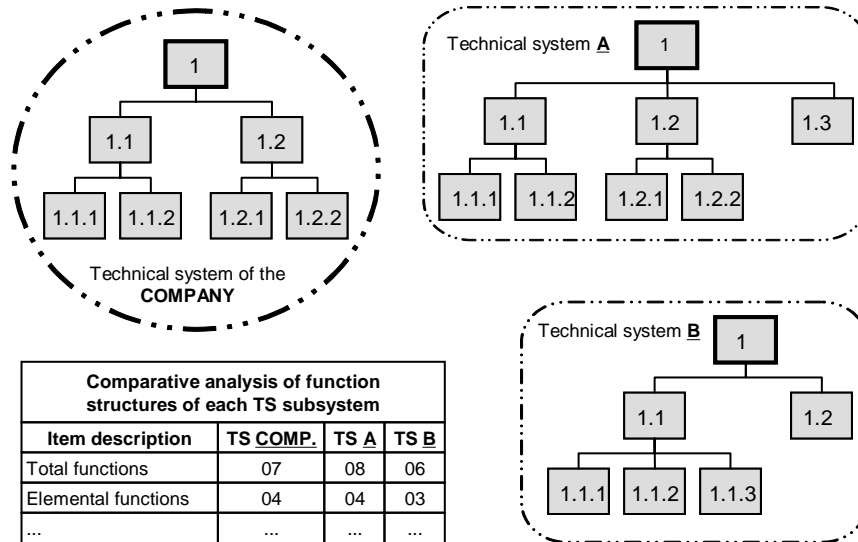
Finally, in the Redesign Orientation phase, the goals and requirements of the TS redesign are defined, indicating which subsystems should be optimized. Then, orientations and means are proposed to compare the TS function structures, against its similar competitors, guiding the function synthesis process (Figure 3).

The objective of such comparison is to visualize the function structures of the TS, seen as a reference for the TS redesign. The function structure of the TS must be deployed in subsystems, where each subsystem can be analyzed (internal against competitors similar), considering: its total of functions; how they are connected (ways of interaction); the sequence of operations/processes of the TS, represented by the functions; flows of energy, material and signal among the functions; etc. From this, the RE team can optimize the function structure to be considered in the design. Adequate methodological approaches were not identified for this application and will be developed in this research study.

The optimized function structure is inserted into the morphological matrix for the generation of new conceptions. The main results of this phase are: the redesign of goals, a comparative analysis of the function structures, the optimized function structure of the TS and the attributes of the new versions of the TS conceptions.

In order to support the suggested RE activities, a database is to be developed, which will be based on the “design catalogues” approach and consider the information structure of the TS functions. Since this research is now in a preliminary stage, the methodology and the database need some guidelines, in terms of RE process modeling, as seen in the next section.

However, this methodology is been developed. For this reason, practical results in companies still have not obtained, but they will be done until this year’s end.



**Figure 3.** Comparison of the function structures of technical systems

## 5 Guidelines for the Reverse Engineering Model

Firstly, processes of functional modeling will be studied in order to define the information structure needed to describe the TS functions, considering the function deployment levels (global, partial and elemental) and the right technical language. A method for TS function analysis will then be implemented, to help designers to identify and describe the functions and solution principles of the physical objects, considering such a structure of information.

It is also to be developed a method for the comparative analysis of TS function structures, considering the functions of each subsystem, the interaction among functions, types of flows, types of transformations, etc. The innovation opportunities in the TS redesign will then be identified by insertion, combination (and modularization), or removal of TS functions.

In computational terms, the database structure will permit the comparison of similar functions, as well the registration of functions and solution principles from many areas. Information from other areas – mechanical, electrical, optical, bionic (analogy with nature), and others – allows the insertion of functions and solution principles into the TS to satisfy the design needs. However, the structure of the description of function – mentioned above – must be used in order to permit the effective insertion of such information into the design.

## 6 Final Considerations

In this paper, the importance of RE process formalizing was highlighted, in order to allow the identification of TS functions and solution principles. A comparative analysis between the technical systems studied and an internal TS can then be carried out, favouring an improvement in the TS.

By utilizing the RE process as a source of knowledge for innovations in TS, companies can develop TS solutions in a faster way and with less uncertainties, in relation to a project without comparison parameters. This requires less validation effort regarding the concepts and technologies implemented in the TS solutions.

## 7 References

- [1] Abe T, Starr P. Teaching the writing and role of specifications via a structured teardown process. *Journal of Design Studies*. 2003, 24, 475-489.
- [2] Back N. Metodologia de projeto de produtos industriais. R.J.: Guanabara Dois, 1983.
- [3] Chen L-C, Lin L. Optimization of product configuration design using functional requirements and constraints. *Research in Engineering Design*. 2002, 13, 167-182.
- [4] Chikofsky EJ, Cross II JH. Reverse engineering and design recovery: a taxonomy. *IEEE*. 1990, 13-17.
- [5] Eilam E. Reversing: secrets of reverse engineering. Wiley Publishing Inc., 2005.
- [6] Höhne G. EMC 3241: projeto de instrumentos. Internal publication. Graduation course of Mechanical Engineering at Federal University of Santa Catarina (UFSC), 1990.
- [7] IBGE. Pintec: pesquisa industrial inovação tecnológica 2003. Rio de Janeiro, 2005.
- [8] Koller R. Konstruktionslehre für den maschinenbau. Berlin: Springer-Verlag, 1985.
- [9] Montanha Jr. IR. Sistemática de gestão da tecnologia aplicada no projeto de produtos: um estudo para as empresas metal-mecânicas de micro e pequeno porte. M.Sc. thesis in Mechanical Engineering. Federal University of Santa Catarina (UFSC), 2004.
- [10] Montanha Jr. IR. Sistematização do processo de engenharia reversa de sistemas técnicos. Qualify (Ph.D in Mechanical Engineering). UFSC, 2006.
- [11] Otto KN, Wood KL. A reverse engineering and redesign methodology for product evolution. Proceedings of the 1996 ASME Design Engineering Technical Conferences and Design Theory and Methodology Conference. 96-DETC/DTM-1523. Irvine, USA.
- [12] Otto KN, Wood KL. Product design: techniques in reverse engineering and new product development. New Jersey: Prentice Hall, 2001.
- [13] Pahl G, Beitz W. Engineering design: a systematic approach. Berlin: Springer-Verlag. 2nd Ed., 1988.
- [14] Roth K. Konstruieren mit konstruktionskatalogen. Berlin: Springer-Verlag, 1982.
- [15] Sousa AG. Estudo e análise dos métodos de avaliação da montabilidade de produtos industriais no processo de projeto. M.Sc. thesis in Mechanical Engin. UFSC, 1988.
- [16] Tay FEH, Gu J. Product modeling for conceptual design support. *Journal of Computers in Industry*. 2003, 48, 143-155.
- [17] Tjalve E. A short course in industrial design. London: Butterworth, 1979.
- [18] Tomiyama T, Yoshioka M, Tsumaya A. A knowledge operation model of synthesis. In: Chakrabarti A. Engineering design synthesis: understanding, approaches and tools. London: Springer Verlag, 2002, 67-75.