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A Method of R&D Electronic Product for Application by Independent Engineers, Designers and Inventors

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Abstract

This paper describes a method for research and development (R&D) of electronic product for use by independent engineers, designers and inventor. The method was under continuous development and optimization from 1980 to 2008 and the concept is based on the analysis and synthesis of 13 product development methodological models. The method was originally proposed to suit the needs of a small company engaged in research, development and production of industrial electronic audio processing products for Radio Broadcasting Stations. The method was optimized with the assistance of Researchers from the Center of Technological Innovation of the Vale do Paranhana – one of a series of such Centers established by the Program of Technological Innovation promoted by the Government of the State of Rio Grande do Sul in Brazil. As a result, a method was obtained particularly suitable for utilization by independent engineers, designers and inventors to facilitate the creative process and increase efficiency in the design of new products, and especially to ensure that the incorporation of these elements results in more innovative and competitive products.

Keywords: *Product Design, Product Development, Innovation, R&D*

Introduction

Is necessary that professionals working on product designs select an adequate methodological model for research and development - R&D of new products bearing in mind the type of application and the size of the manufacturing facility (Zirger and Hartley, 1996; Rosenau, 1999; Bonner, Ruekert and Walker, 2002; Tennant and Roberts, 2003). However, the the standard approaches for product design are often complex, and call for different methods in accordance with the individual views of the authors and market application involved (Pahl *et al.*, 2005; Back *et al*. 2008).

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When independent engineers, designers and inventors try to use the existing methods for R&D developing new products they often run into application difficulties (Bonner, Ruekert and Walker, 2002). These involve the requirements of the methodological structures, especially with regard to the investment in human, financial and technological resources needed for utilization of that particular methodology (Andreasen and Hein, 1987). Adapting an existing method for R&D product design to a specific situation calls for expertise, time and money, all of which may be hard to come by independent professionals (OECD, 2008). The manner in which people are conditioned to think by the current teaching processes, by the cultural context, and by the reference models determines the practical day-to-day actions on the individual plane (Jordan, 1974). Thus, when the use of an existing traditional method of product design is out of the question for a variety of reasons, people tend to invent empirically their own methods. Usually these are constructed by trial and error and might conduct to over time, increased costs, reduction of profits, and loss of competitivity (OECD, 2008).

Frustration at the lack of means to use external methodological models may also negatively affect creativity (Collins and Amabile, 1999) and block generation of new ideas (Feldhusen and Goh, 1995). This happens because creative production cannot be attributed only to the individual's possession of a certain skills or personality characteristics, but may also be subject to the influence of the environment in which the designer lives or works (Henessey and Amabile, 1988). The use of methods for product design that are adapted to the peculiarities of a specific manufacturer may represent a competitive advantage in the short term and allowing that manufacturer to progressively implement other methodological phases as the company and its personnel mature in design management (French, 1999). The existence of methods that are adequate for the realities of operation of independent professionals, and are designed for specific technological applications, would facilitate the creative processes, increase the efficiency of design of new products, and most importantly, ensure that the introduction of these elements results in more innovative, economical and competitive products (David, Hall and Toole, 2000).

This paper describes a R&D method of electronic product for use by independent engineers, designers and inventors. In this work these types of professionals is considered not act in companies. This method has been undergoing continuous development, utilization, evaluation, and optimization since 1980. The structure of the method was based on a study of principles and methodological stages proposed by Asimow (1962), Pahl and Beitz (1977), Bonsiepe (1978), Back (1983), R&D model by Kline and Rosenberg (1986), Park and Zaltman (1987), Suh (1988), Wheelwright and Clarck (1992), Dickson (1997), Prasad (1997), Kaminski (2000), Ulrich and Eppinger (2000), Pahl *et al*. (2005) and Rozenfeld *et al*. (2006).

Conception of the Method

The method was developed and enhanced during a 28 year period extending from 1980 to 2008 and was based on the analysis and synthesis of 13 product design

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methodological models during that period. The 28 years may be divided into four phases each of which had considerable influence on the continuous optimization of the method. This was originally proposed to suit the needs of a small company engaged in research, development and production of industrial electronic audio processing products for Radio Broadcasting Stations.

The first phase, 1980 to 1985, involved the basic delineation of the method to meet initial necessities of the pilot company, viz, (i) only a small team of 2 product engineers was available for research and development; (ii) this same engineers would have to do the design, construction, evaluation and optimization of the prototype in order to specify the productive processes; (iii) also to analyze similar products already on the market and create new and different products; (iv) the product design process had to be simplified. In this phase, four product design models were studied and their methodological phases classified and analyzed for consideration during the initial construction of the method by: Asimow (1962), Pahl and Beitz (1977), Bonsiepe (1978) and Back (1983).

During this first stage, the structure of the method was strongly influenced by the models proposed by Asimow (1962), Pahl and Beitz (1977) and Back (1983) who emphasize engineering in product design. Another important contribution came from Bonsiepe (1978) - the inclusion of the analysis of similar products in an early stage of the method. We performed four different analyses: (1) synchronous; (ii) functional; (iii) structural and (iv) morphological. In this stage we concentrated on developing new products by identifying weak points and deficiencies of competing products and with a simplified structure based on three phases: (i) identification and analyses of requirements; (ii) Detailed design; and (iii) Construction and testing a prototype.

At the second step, from 1985 to 2000, we introduced the concept design phase, divided it into two other parts: the Electronic Design Concept and the Mechanical Design Concept. The models studied in this second phase that served as the basis for optimization of the method were: Kline and Rosenberg (1986), Park and Zaltman (1987), Suh (1988), Wheelwright and Clarck (1992) and Prasad (1997). In the second phase, the model proposed by Suh (1988) indicates that a structure of functions needs to be used, especially during the "Conceptual Electronic Design" process. Among the models we studied at this stage we find that Asimow (1962), Wheelwright and Clarck (1992), Park and Zaltman (1987), Prasad (1997) make this point also. Suh further contributes to the optimization of the method when he states that in the initial stages of any method a social requirement should exist and be identified. For this reason, we saw the necessity of including instruments capable of identifying new requirements by means of more intense interaction with the prospective consumers. In this phase, the method was expanded to include certain functions - such as feedback between the stages – which gave the method greater circularity (non-linearity) by contribution of the R&D method of Kline and Rosenberg (1986).

In the third phase, 2000 to 2006, the method was studied and improved by researchers from the Center of Technological Innovation of the Vale do Paranhana.

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This is one of a series of such Centers established by the Program of Technological Innovation promoted by the Government of the State of Rio Grande do Sul in Brazil. These Centers are promoters of innovation and are found in most regions of the State of Rio Grande do Sul, Brazil. The Program was created by partnerships between a number of public and private Institutes of the State of Rio Grande do Sul and integrates human, financial and technological resources into a statewide system for the development of science, technology and innovation. Implemented by the Office of the Secretary of State for Science and Technology of Rio Grande do Sul, in 1989 the Program for the establishment of Centers of Technological Innovation is today the largest R&D network in the State (Jung, Caten and Ribeiro, 2007).

Another important contribution to the structure of the method was the inclusion of the "Control and Operation Areas Definition" stage after the "Mechanical Structure Definition" stage. This new stage added Ergonomic principals to the "Conceptual Design". In this third phase, we studied the methodological structures of the models by: Kaminski (2000), Ulrich and Eppinger (2000) and Pahl *et al*. (2005).

In the third phase the standards and precepts of Visual Ergonomics were used in the Conceptual Design stage by the introduction of the "Convergence and Generate Alternatives Process", stage - which had previously been cited by Kaminski (2000), Ulrich and Eppinger (2000) and Pahl *et al*. (2005) - with the objective of combining sub-solutions into alternatives, generating alternatives, evaluating alternatives and selecting a solution (conceptual design). Another important optimization of the method was the addition of two steps after the Detailed Design stage, viz; Integrated System Design Analyses, and Electro-Mechanical Design Interconnection.

In the fourth stage, 2006 to 2008, the optimization of the proposed method was incorporated into studies being developed by one of the authors in the Ph.D Program in Industrial Engineering of the Federal University of Rio Grande do Sul, Brazil. The studies carried out up to 2008 resulted in considerable improvements to the method. Furthermore, a study was made of the model proposed by Rozenfeld *et al*. (2006) which demonstrates the need for the method to be adaptable to the peculiarities of the companies or users. In this case, this methodological model (Rozenfeld *et al*., 2006) demonstrated the need to include in the method the "Users and Market" step in order to obtain information from users and market by testing the prototype in real circumstances. The Rozenfeld *et al*. (2006) also motivated insertion of a "New Information from the Market" stage directly connected to the "Convergence and Generate Alternatives Process" stage.

We also studied various sustainability models, such as: (i) Cleaner Production, (ii) Clean Production, (iii) Cleaner Technologies, (iv) Eco-Efficiency, (v) Ecodesign, (vi) Design for Sustainability - DfS, (vii) Design for Environment - DfE, (viii) Pollution Prevention – P2, (ix) Life Cycle Assessment, - LCA (x) Green Engineering, (xi) Cradle to Cradle Design, and (xii) ZERI – Zero Emissions Research Initiative. This study resulted in the inclusion of a sub-stage entitled "Analyses the Use of Sustainable Materials" that proposes options for sustainable methods and materials for the "Convergence / Generate Alternatives Process" phase.

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The process of analyses of the sustainable models for inclusion in the "Analyses the Use of Sustainable Materials" stage was based on principles and concepts derived from Anastas and Warner (1998), Allenby (1999), Billatos and Basaly (1997), Boothroyd, Dewhurst and Knigth (1994), EPA (2001), Keffer, Shimp and Lehni (1999), Van Berkel (2000), McDonough and Braungart (2002) and Pauli (1998).

An important contribution for optimization of the method developed in the Ph.D program of the Federal University of Rio Grande do Sul was the inclusion of the initial step entitled "Discovery of Requirement Through Interaction With User". This stage proposes the utilization of qualitative methods to research user requirements as is also referred to by Shiba, Graham and Walden (1993) as an efficient way to understand user demands when designing a new product.

Description of the Method

In this section we describe the proposed R&D method, Figure 1, by synthesizing the methodological steps of its structure. To make the description easier to understand, one of the products developed with the method – a Broadcast Radio audio console – is used as an example.

Discovery of a Requirement by Interaction with Users

The first stage of the method states that a designer who is considering production of a new product have to interact with a reasonable number of users of similar products to generate new ideas and to determine the problems and deficiencies of the products they now use. This interaction can generate new ideas for resources or operational facilities that could provide a competitive advantage for the new product.

Pahl *et al*. (2005) states that the discovery of the requirement for a product can occur in situations where a group or a collectivity expresses lack of satisfaction with a particular existing product. There are many forms of this interaction that can be classified in the Interaction Level and Environment of Use dimension (Shiba, Graham and Walden, 1993). See Figure 2.

Therefore, the method provides two alternatives for identifying requirements: generate original ideas from: (i) visits to customers with users; (ii) contextual inquiry, (iii) gathering evidence on user behavior, and (iv) ethnography, in addition to the use of techniques for analyzing similar products; or conduct different types of analyses, for instance: (i) synchronous, (ii) functional, (iii) structural, and (iv) morphological.

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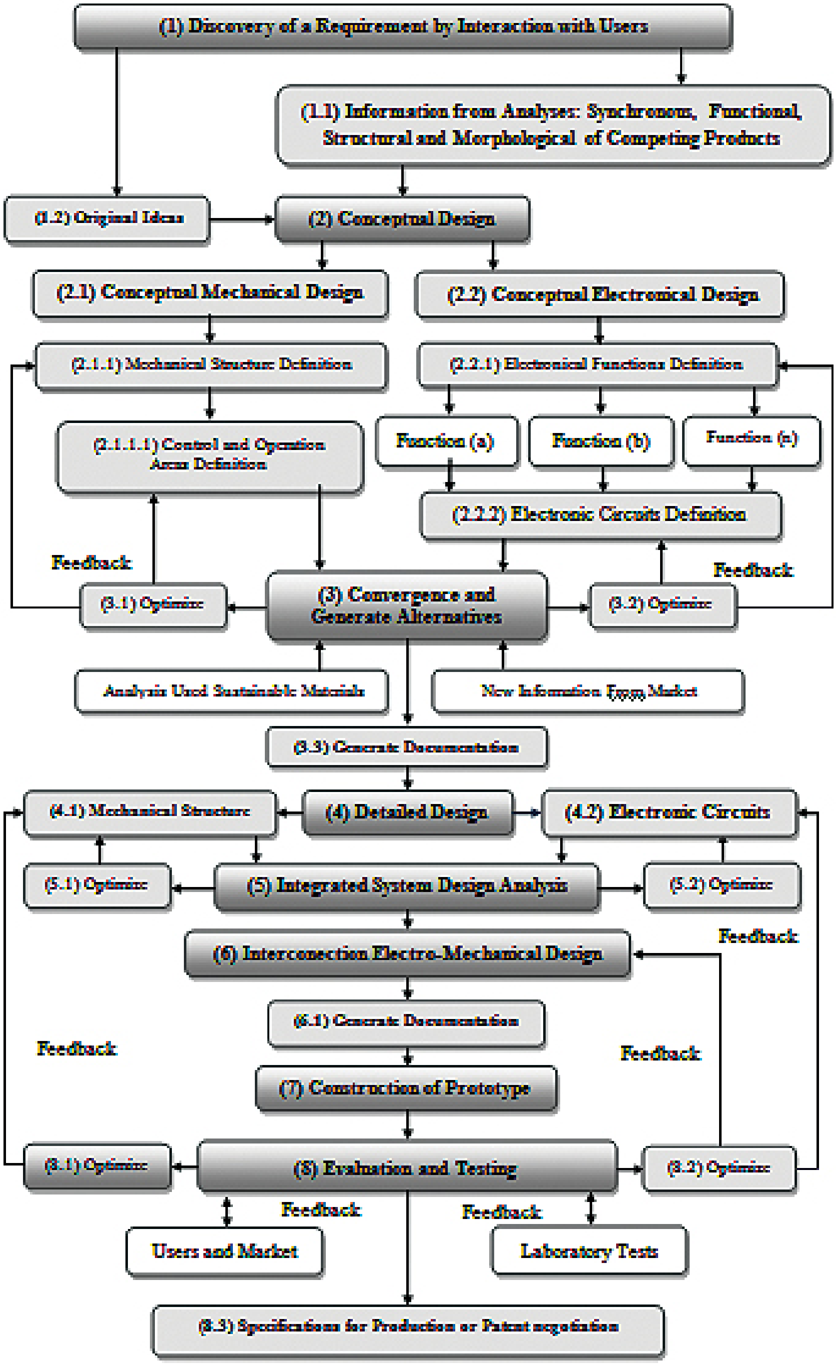

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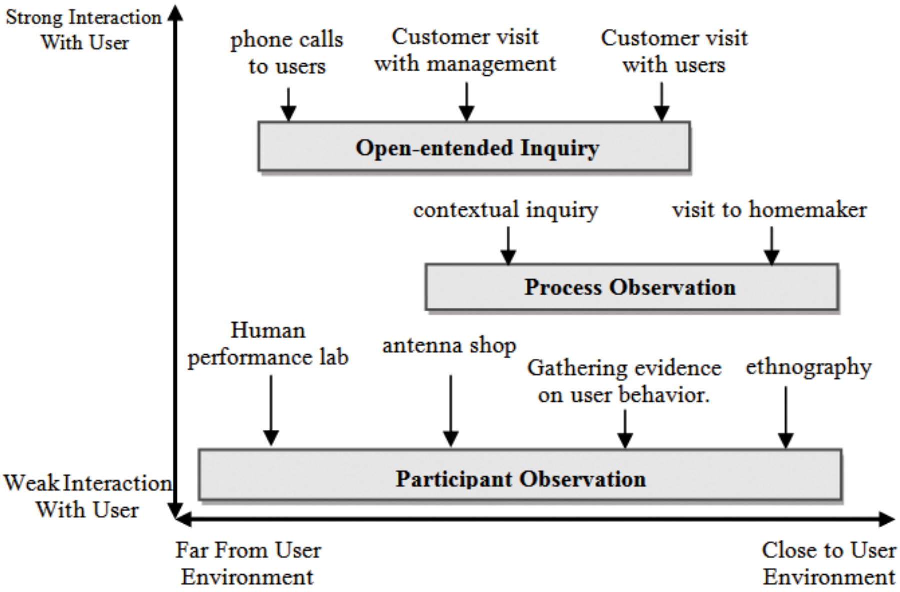

Figure 2 - Interactions with consumers by Shiba, Graham and Walden (1993)

Original Ideas

A great number of new ideas may surface when new information, obtained by observation or experience, obliges reconsideration of older ideas (Bono, 2002). For this to be possible, it is necessary to clearly define the objective(s) to be attained keeping close watch on any external factors that might influence the results.

It is important to assure that one knows what the problem really is and what external influences may worsen or resolve it. It is essential to have a clear definition of the problem. Once the problem is understood, creative techniques for idea generation can be used to propose possible solutions. Later, one should analyze proposed solutions and decide if them can meet the necessities of the users. The positive and negative aspects of the idea should then be analyzed and a subjective evaluation should be made concerning quality and advantages of the chosen approach. Before implementing any solution, it is a good practice to check the reality to verify that the solution is feasible (Birch and Clegg, 1995).

Synchronous Analysis

The object of this analysis is to determine the position of similar products found in the marketplace (Bonsiepe, 1978). Knowing the prices of similar equipments it is possible to estimate the investment that the user must make for his professional activities. The value of the investment reveals the market position of similar product and can establish a parameter that will serve as a reference to evaluate the cost of the

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new product to be developed and consequently, the economic viability (Crawford, 1983). In Figure 3 is presented a suggestion method for synchronous analysis. This method is simplified and can be applied by only one person in potential users.

SYNCHRONOUS ANALYSIS					
PRODUCT: BROADCAST AUDIO CONSOLE					
Values are assigned on a scale from 1 to 3 (importance for the user) (1 = low importance; 2 = mid importance; 3 = important)					
Items considered		**Importance for the user**	***The product not meets the demand = 0**		
Level One	**Level Two**		Product 1 (value)	Product 2 (value)	Product 3 (value)
Basic Operational Resources	Designed within ergonomics specifications	3	3	3	3
	Have up to eight channels of operation	2	2	0	0
	Have boards printed circuit (PCI) plug-in	3	3	3	0
	Hold level meter digital output	3	3	0	0
	Easy installation requires	2	0	2	2
Basic Structure Specifications	Manufactured with recyclable materials	3	0	0	3
	Have shielding to prevent EMI	3	3	3	0
Design / Complement	Comes in metallic colors	1	1	1	0
	Provided in basic colors	3	3	3	3
Conditions of Sale	Term - 30 days	1	1	1	1
	Term - 30/60 days	2	2	0	2
	Term - 30/60/90 days	3	3	0	3
Warranty Conditions	Three months	1	0	0	0
	Six months	1	0	0	0
	One year	2	2	2	2
	Two years	3	3	3	3
	Option to extend with additional cost	3	0	0	3
Delivery Terms	Free at point of use	3	0	3	3
	To the factory	1	1	1	1
Average Market Value	Above U$ 10.000	1	1	0	0
	Between U$ 8.000 and U$ 10.000	2	0	2	0
	Below U$ 8.000	3	0	0	3
Results (value for the user)		49	31	27	32
Results (value of products)					

Figure 3 - A suggestion method for Synchronous Analysis

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Functional Analysis

The functional analysis reveals the technical/physical characteristics of the systems and sub-systems of competing products and the aspects and relationships of the functions. The starting point for the study is the determination of the key systems utilized in these products.

In this respect, one can discover whether the products possesses distinct systems and if the functions are divergent or convergent. In synthesis, the functional analysis is made to find out how the product operates and why that particular system was developed in that specific way with the resources available, see Figure 4 an example.

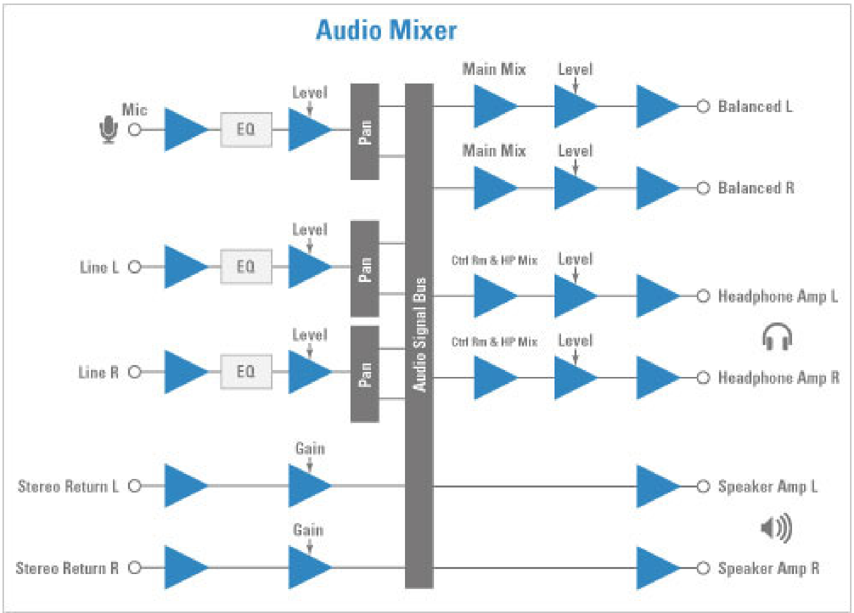

Figure 4 – Block diagram for use in Functional Analysis (NATIONAL, 2009)

Structural Analysis

Consists of a systematic check of the details of the competing product's construction to detect negative or critical points that might be useful in the new design of the mechanical structure, the system of electro-mechanical interconnections, painting, finish, resistance to external impact, portability and protection against external physical/chemical agents. Knowledge of these aspects of competing products can help to avoid repetition of problematic details in the new product. In this analysis, one should also check to see if the structures of the competing products were designed following the principles of Design for Environment (DfE), Design for Assembly - DfA and Design for Disassembly - DfD (Guimarães, 2006), see Figure 5.

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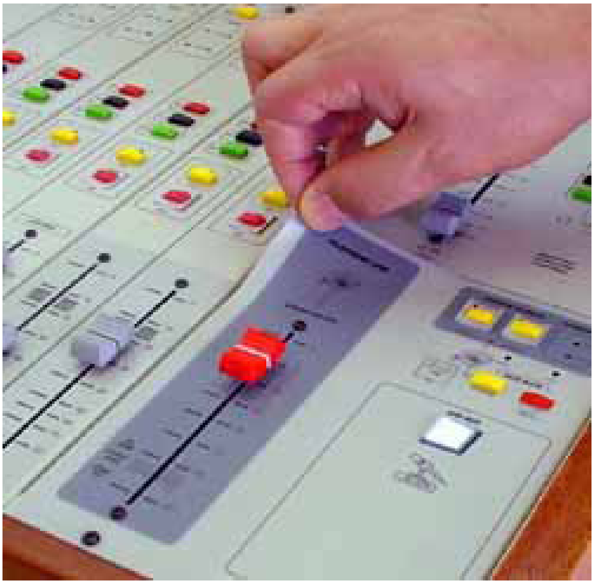

Figure 5 – Detail of the demonstration of Structural Analysis (NJOYFM, 2009)

Morphological Analysis

The objective of this analysis is to understand the formal structure (or concept) of the similar products, and their make-up, starting from their geometrical figures and proceeding to a full understanding of the formal coherence (if any) of the mechanical structure and of the elements for front-panel control and operation. Formal coherence is based on the use of equal or similar elements, geometrically describable, both in the case of the intrafigural (internal) coherence of a product and in the interfigural (external) coherence of a group of products – each one of these elements constitutes a system.

The relevance of the analysis of the systemic relationships between equal or similar elements involves the Theory of Symmetry. For an understanding of the principles of the Theory of Symmetry, Thompson (1969) states that symmetry is a correspondence of position, of form, of measurement in relation to a point, a straight line or a plane between two elements of an assembly. In this case, the analysis should take into consideration the conception of the front panel, the symmetrical arrangements of the disposed components and the relationship between them (interfigural or intrafigural) so as to understand its importance in the design of the new product, see Figure 6.

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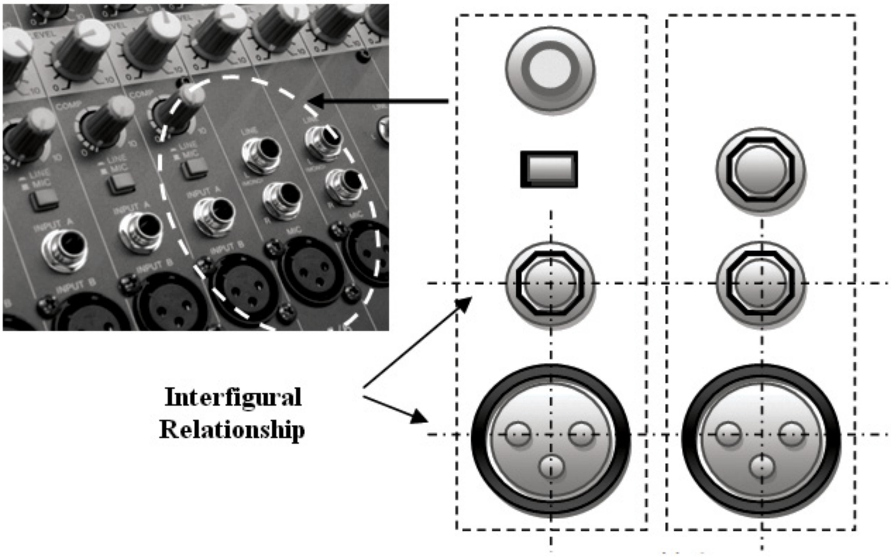

Figure 6 – Example of simmetrical interfigural relationship possible by Morphological Analysis

Conceptual Design

This may be defined as the initial and most abstract stage in the design process and starts with the required functions (what the design is to do without saying how the design is to do it) and should result in the formation of concepts (preliminary system configurations) (Welch and Dixon, 1992). The method proposes an initial division in the formation of product concept - a Conceptual Mechanical Design (2.1) and a Conceptual Electronic Design (2.2). However, during these sub-stages it is important to keep in mind the system as a whole (electronic and mechanical) - that is, details of the mechanical construction should be determined considering the respective electronic systems and their associated external electromechanical controls, and vice-versa. The interaction of the systems is the basic principle that determines the differences between purely mechanical and purely electronic projects.

Conceptual Mechanical Design

The mechanical structure packages the electronic circuits and provides adequate means for control and human interface information necessary to operate the equipment. From these requirements, one can visualize, analyze and create the concept of the mechanical structure and consider the respective ergonomic aspects, see Figure 7.

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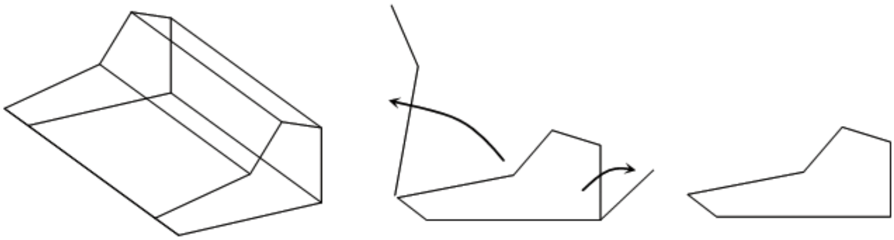

Figure 7 – Example of the concept mechanical structure

Following this, the outline of the final mechanical structure can be drafted in the Mechanical Structure Definition (2.1.1) stage and, in turn, the most functional layout for the operational controls and visual displays determined at the Control and Operation Areas Definition (2.1.1.1) phase, see Figure 8.

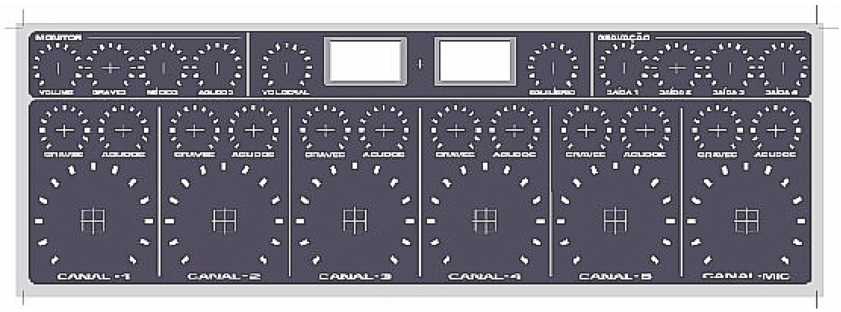

Figure 8 – Conceptual layout of operational controls and visual displays

Conceptual Electronic Design

At this stage, the functions of the new product should be first defined. The Electronic Functions Definition (2.2.1) sub-stage requires that the designer utilize the information obtained in the Synchronous, Functional, Structural and Morphological Analyses of Others Products (1.1) sub-stage. With this information, the designer may add other differential functions to the project. To facilitate the specification of the details it is recommended that a structure of functions be utilized. Proceeding then to the Electronic Circuits Definition (2.2.2) stage, where the electronic circuits necessary for the required functions are determined, see Figure 9.

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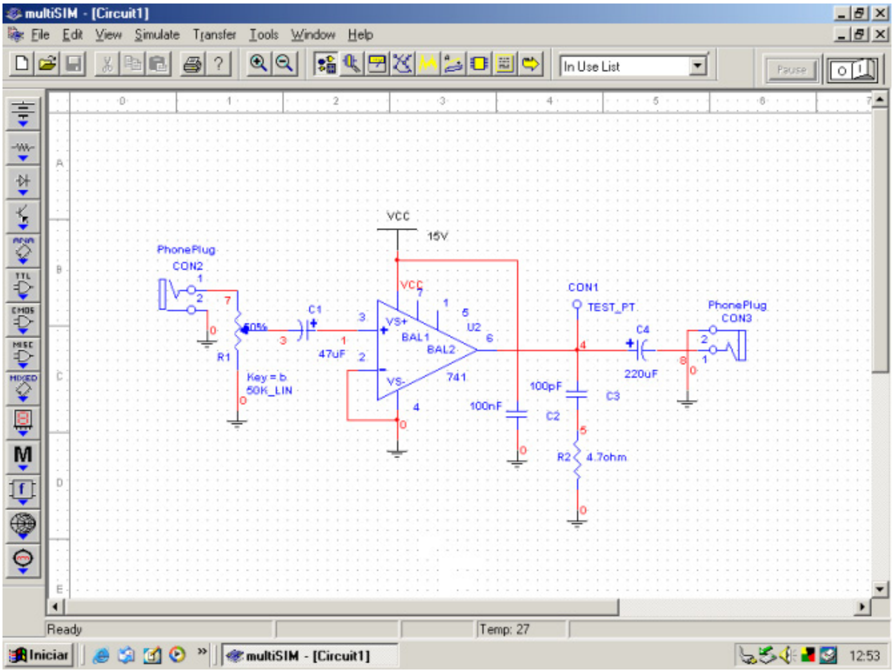

Figure 9 – Example of an conceptual electronic circuit for the functions of the product

Convergence and Generation of Alternatives

For the Convergence and Generation of Alternatives stage, all the information and designs already defined at the Conceptual Mechanical Design (2.1) and Conceptual Electronic Design (2.2) are consolidated. At this point, an advanced concept of the new product exists. The idea of convergence rests on the fact that now the mechanical and electronic systems can be analyzed as one so that the concept as a whole can be used to consider the alternatives.

At this stage, we also consider the possibility of using sustainable materials and alterative power supply sources, Figure 10, (Analyses of the Use of Sustainable Materials sub-stage) as well as introducing new technological and economic information obtained in the market (New Information From the Market sub-stage).

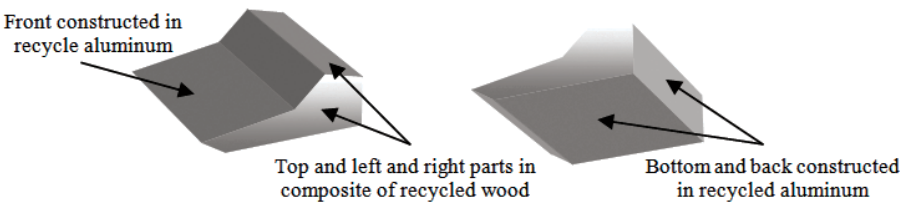

Figure 10 - Use of recyclable materials in product conceptual design

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Detailed Design

The detailed specification of the mechanical and electronic systems is drawn up at this stage. In principle, product design may be divided into two main elements - the Mechanical Structure (4.1) and the Electronic Circuits (4.2). The first concerns detailed design of the external container (as seen by clients), which contains and arranges electronic circuits, mechanisms for control and operation, internal interconnection cable forms, and other sub-systems.

The second involves the design of the electronic circuits that correspond to the functions determined at the Electronics Circuits Definition (2.2.2) sub-stage. Here software tools as CAD (Computer Aided Design) programs should be used. For example, Figure 11, in the development of the audio console for Radio Broadcasting the circuits to be designed are: pre-amplifiers, line amplifiers, phone amplifiers, etc.

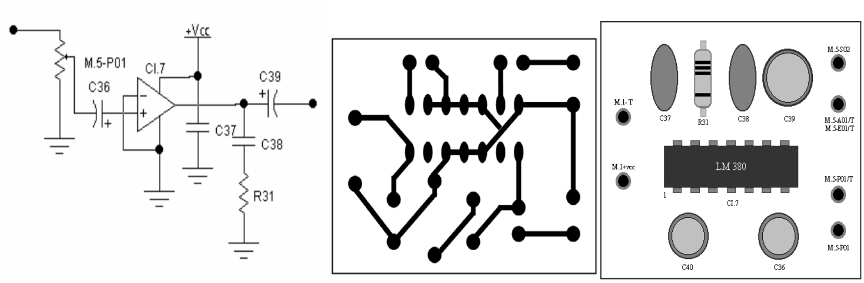

Figure 11 – Stages of development an electronic circuit using Computer Aided Design (CAD)

Integrated System Design Analysis

When details of the design of the mechanical structure and electronic circuits have been completed, the form and process for the integration of these two sub-systems should be analyzed more thoroughly. At the Integrated System Design Analysis (5) stage, one should verify that printed circuit boards (PCB´s) insert perfectly into respective connectors and are not obstructed by any part of the neighboring mechanical structure, see Figure 12.

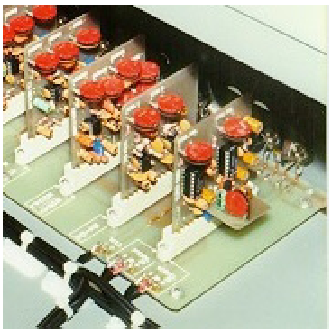

Figure 12 – Example of detail for Integrated System Design Analysis (electronic and mechanical)

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Where necessary, suitable adjustments should be made both in the projected electronic circuit boards and in the mechanical structure. For this reasons, the flow chart (Figure 1) should be used, since it provides feedback between the Mechanical Structure (4.1) and Electronic Circuits (4.2) sub-stages.

Interconnection Electro-mechanical Design

This stage is executed in parallel with the previous one. The designer should proceed to detail in the CAD software the installation and interconnection of external components to printed circuit boards (PCB´s), for example: keys, variable attenuators for signal control, Leds, Connectors.

Also at this time, the design of the connections of internal cable-forms between PCB´s and mechanical components and/or support structure should be completed. Figure 13 presents an internal view of an audio console for Radio Broadcasting, showing the disposition of the electronic circuits over the mechanical structure and the internal cable forms that interconnect the systems.

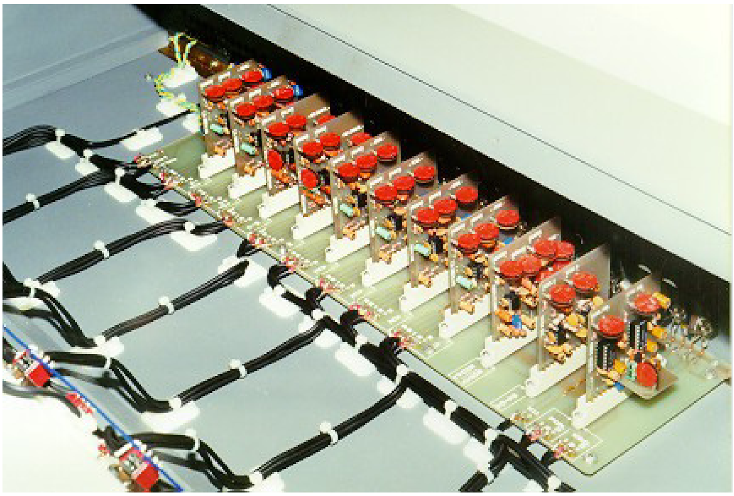

Figure 13 - Internal view of an audio console and the respective interconnection system

Construction of the Prototype

The construction of prototype is conducted by the assembly and integration of all systems involved – electronic, mechanical and electrical. This is essentially practical work and is carried out in three stages; (i) construction and assembly of PCB´s; (2) construction of front panel and adaptation of mechanical structure, and (iii) final assembly and electro-mechanical interconnection of the components. Figure 14 illustrates a prototype of an audio console for FM Radio Broadcasting, model JMR-8CSD, constructed by the application of the R&D method proposed and described in this paper.

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Figure 14 - Prototype of Model JMR-8CSD, designed by the R&D method described in this paper

Evaluation and Testing

With so many possibilities for mistakes or failure it is difficult to achieve results exactly as planned at the first time around (Back *et al*., 2008). Thus, it is vital to verify the operation of prototypes and processes (Pahl *et al*., 2005 and Back, 1983). A careful revision of a project can offer a series of advantages, such as: (i) a demonstration of how well the design meets user's requirements; (ii) provide information on costs and potential profit; and (iii) supply data on product performance and reliability (Bonner, Ruekert, and Walker Jr., 2002).

The test for usability is a formal process that involves the interaction of the user with the product. The results of this test can be used for product optimization or even as a marketing strategy. Feedbacks received from users may help to improve the product, with a reduction of manufacturing costs and sale prices. Therefore, the method proposes that new products should be tested in real operational environment and operated by professionals in order to obtain market and user information about the product directly from those best equipped to judge. Also, detailed analyses in laboratory are important to verify technical characteristics and parameters. These tests generate feedback and may suggest modifications and improvement in the Mechanical Structure (4.1) or in the Interconnection Electro-Mecanical Design (6).

When this stage is complete, documentation and specifications are generated for production or for patent negotiations with companies interested in commercializing the new product.

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Synthesis

The results show that the proposed method has the following main characteristics, see Figure 15.

Methodological	(i) the method starts by applying a technique of qualitative research (is based on discovery of a requirement by interaction whit users); (ii) is proposed four analysis on similar products; (iii) both the conceptual design and the detailed design are divided into two stages. Subsequent proposal is a convergence of results; (iv) in the stage of Convergence and Generate Alternative Process is proposed an analysis of used sustainable alternative materials; (v) the method specifies both the mechanical and electronic transactions in their stages and sub-stages.
Human / Operational	(i) the method can be used by only a mechanical engineer and an electrician, or an engineer, designer or inventor who has both expertises; (ii) the method is applied to engineers, designers and independent inventors do not need a team or industrial infrastructure to obtain the prototype; (iii) the method nurture the research and experimental development of a new product in the form of prototype, to offer an innovation for manufacturing firms or the registration of a patent by the engineer, designer or inventor.

Figure 15 – Main characteristics of the R&D method

Conclusions

This paper described a R&D method for electronic product suited for use by independent engineers, designers and inventors. The method was under continuous development and optimization for 28 years.

The concept of the method was based on an analysis and syntheses of 13 product development models during the period from 1980 to 2008.

The proposed method is made up of 8 stages and 22 sub-stages and uses a non-linear configuration with feedback between the stages and sub-stages so as to optimize product concept and detailed design. The method can be used by only a mechanical engineer and an electrician, or an engineer, designer or inventor who has both expertises.

The method starts by applying a technique of qualitative research (is based on discovery of a requirement by interaction whit users). Is proposed four

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analysis on similar products. Both the conceptual design and the detailed design are divided into two stages. Subsequent proposal is a convergence of results. In the stage of Convergence and Generate Alternative Process is proposed an analysis of used sustainable alternative materials. The method specifies both the mechanical and electronic transactions in their stages and sub-stages.

As a result, a method was obtained that is particularly suitable for utilization by independent engineers, designers and inventors to facilitate the creative process and increase efficiency in the R&D design of new products, and especially to ensure that the incorporation of these elements results in more innovative and competitive products. In essence, this method is intended for product design up to the prototype stage and is not for application in the subsequent processes of production and follow-up of the product in the market.

We feel that it is necessary to continue this research, to further improve this method as new technological and economic information become available and to constantly improve the process of interaction with the user.

References

Allenby, B. R. (1999), Industrial ecology: policy framework and implementation. New Jersey: Prentice-Hall.

Anastas, P. and Warner, J. (1998), Green Chemistry: Theory and Practice. New York: Oxford University Press.

Andreasen, M. M. and Hein, L. (1987), Integrated product development. Bedford: Springer-Verlag.

Asimow, M. (1962), Introduction to design. New Jersey: Prentice-Hall.

Back, N. (1983) Metodologia de projeto de produtos industriais. Rio de Janeiro: Guanabara Dois. (in Portuguese)

Back, N.; Ogliari, A.; Dias, A. and Silva, J. C. (2008), Projeto integrado de produtos: planejamento, concepção e modelagem. Barueri: Manole. (in Portuguese)

Billatos, S. B. and Basaly, N. A. (1997), Green technology and design for the environment. Washington: Taylor & Francis.

Birch, P. and Clegg, B. (1995), Criatividade nos negócios: um guia para empresários, gerentes e administradores de empresas. São Paulo: Clio. (in Portuguese)

Bonner, J. M.; Ruekert, R. W. and Walker Jr., O. C. (2002), "Upper management control of new product development projects and project performance", Journal of Product Innovation Management. Vol. 19, No. 3, pp. 233-245, New York.

Bono, E. D. (2002), O pensamento lateral. Rio de Janeiro: Nova Era. (in Portuguese)

Bonsiepe, G. (1978), Teoria y práctica del deseño industrial. Barcelona: Gustavo Gili. (in Spanish)

Brazilian Journal of Operations & Production Management
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Boothroyd, G.; Dewhurst, P. and Knigth, W. (1994), Product Design for Manufacture and Assembly. New York: Marcel Dekker Inc.

Collins, M. A. and Amabile, T. M. (1999), Motivation and creativity. In: Sternberg, R. J. (Org.), Handbook of creativity. New York: Cambridge University Press.

Crawford, C. M. (1983), New product management. Burr Ridge: Irwin.

David, P. A.; Hall, B. H. and Tool, A. A. (2000), Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. Vol. 29. Research Policy. Elsevier.

Dickson, P. (1997), Marketing management. Forth Worth: The Dryden Prees.

EPA - U. S. Environmental Protection Agency. (2001), An Organizational Guide to Pollution Prevention. Cincinnati: EPA.

Feldhusen, J. F. and Goh, B. E. (1995), "Assessing and accessing creativity: an integrative review of theory, research, and development", Creativity Research Journal, Vol. 8, No. 3, pp. 231-247.

French, M. J. (1999), Conceptual design for engineers. 3 ed. Harcover: Springer.

Guimarães, L. B. M. (2006), A ecologia no projeto de produto: design sustentável, design verde, ecodesign. In: Guimarães L. B. M. (Org.), Ergonomia de produto: evolução dos objetos, funções do produto, design ergonômico, design sustentável. Vol. 2, 5ª. ed., Porto Algre: FEENG. (in Portuguese)

Henessey, B. A. and Amabile, T. M. (1988), The conditions of creativity. In: Sternberg, R .J. (Org.), The nature of creativity. New York: Cambridge University Press.

Jordan, N. (1974), Temas de psicologia especulativa. Buenos Aires: Troquel. (in Portuguese)

Jung, C. F., Caten, C. S. ten and Ribeiro, J. L. D. (2007), Inovação em produtos e processos a partir da parceria entre o setor público e o privado: o Programa de Pólos Tecnológicos do RS. In: VI Congresso Brasileiro de Gestão de Desenvolvimento de Produto. Belo Horizonte. (in Portuguese)

Kaminski, P. C. (2000), Desenvolvendo produtos com planejamento, criatividade e qualidade. Rio de Janeiro: LTC. (in Portuguese)

Keffer, C.; Shimp, R. and Lehni, M. (1999), Eco-Efficiency Indicators and Reporting: Report on the status of the project's work in progress and guideline for pilot application. Genebra: WBCSD.

Kline, S. and Rosenberg, N. (1986), An overview of innovation. In: Landau, R.; Rosenberg, N. (orgs.). The positive sum strategy. Washington, DC: National Academy of Press.

Brazilian Journal of Operations & Production Management
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McDonough, W. and Braungart, M. (2002), Cradle to Cradle: Remaking the Way We Make Things, New York: North Point Press.

NATIONAL SEMICONDUCTORS. High performance audio application diagrams. Available: http://www.national.com/analog/audio/hp_diagrams. Access: 01 March 2009.

NJOYFM. New audio consoles. Available: http://www.njoyfm.nl/2300xs-compact-modulair-console/product_info.php/products_id/1312. Access: 15 March 2009.

OECD. (2008), Oslo Manual: Guidelines for collection and interpreting innovation data. OECD/European.

Pahl, G. and Beitz, W. (1977), Konstruktionslehre. 1ª ed. Berlim: Springer.

Pahl, G.; Beitz, W.; Feldhusen, J. and Grote, K. (2005), Projeto na engenharia: fundamentos do desenvolvimento eficaz de produtos, métodos e aplicações. Trad. Werner, H. A., 6 ed., São Paulo: Edgar Blucher.

Park, C. and Zaltman, G. (1987), Marketing management. Chicago: The Dryden Prees.

Pauli, G. (1998), Upsizing: Como gerar mais renda e criar mais postos de trabalho e eliminar a poluição. Porto Alegre: Fundação Zeri Brasil – L&PM. (in Portuguese)

Prasad, B. (1997), Concurrent engineering fundamentals: integrated product development. London: Prentice-Hall.

Rosenau, M. D. (1999), Successful product development: speeding from opportunity to profit. New York: John Wiley & Sons Inc.

Rozenfeld, H.; Forcellini, F. A.; Amaral, D. C.; Toledo, J. C., Silva, S. L.; Alliprandini, D. H. and Scalice, R. K. (2006), Gestão de desenvolvimento de produtos: uma referência para a melhoria do processo. São Paulo: Saraiva. (in Portuguese)

Shiba, S.; Graham, A. and Walden, D. (1993), A new american TQM: four practical revolutions in Management. Cambridge: Productivity Press.

Suh, N. P. (1988), The principles of design. New York: Oxford Press.

Tennant, C. and Roberts, P. (2003), "The creation and application of self-assessment process for new product introduction", International Journal of Project Management. v. 21, n. 1, pp. 77-87. Oxford.

Thompson, D. W. (1969), Crescita e Forma. Torino: Boringhieri.

Ulrich, K. T. and Eppinger, S. D. (2000), Product design and development. New York: MacGraw-Hill.

Van Berkel, R. (2000), Cleaner production for process industries: overview of the cleaner production concept and relation with other environmental management strategies. Perth: Curtin.

Brazilian Journal of Operations & Production Management
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Welch, R. V. and Dixon, J. R. (1992), "Representing function, behavior and structure during conceptual design", In: Proceedings of the 3th International Conference on Design Theory and Methodology, New York, USA, ASME.

Wheelwright, G. and Clarck, K. B. (1992), Revolutionizing product development process: quantum leaps in speed, efficiency, and quality. New York: The Free Press.

Zirger, B. J. and Hartley, J. (1996), "The effect of acceleration techniques on product development time", IEEE Transactions on Engineering Management. Vol. 43, No. 2, Newark - New Jersey.

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