Postprint of: Waris M., Sanin C., Szczerbicki E., Toward Smart Innovation Engineering: Decisional DNA-Based Conceptual Approach, CYBERNETICS AND SYSTEMS, Vol. 47, Iss. 1-2 (2016), pp.149-159, DOI: 10.1080/01969722.2016.1128775

Towards Smart Innovation Engineering: Decisional DNA Based Conceptual Approach

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Knowledge and experience are essential requirements for product innovation. The presented paper proposes a systematic approach for product innovation support using Smart Knowledge Management System comprising Set of Experience Knowledge Structure (SOEKS) and Decisional DNA (DDNA). This proposed system is dynamic in nature as it updates itself every time a new decision related to innovation is taken. Through this system the product innovation process can be performed semi-automatically and efficiently as it stores knowledge of past experiences of innovative decisions.

Keywords: product innovation, product design, set of experience, decisional DNA, innovation management

Introduction and Background

Organizations involved in manufacturing products cannot grow only through cost reduction. For the survival of any manufacturing unit, entrepreneurs need to find new ideas that can be implemented in the products leading to their innovation (Chen and Feng 2009). The reasons are frequent changes in the lifestyle of the users, rising costs of materials and energy, competition in the market at national and international level, and emerging technologies among others. There are three types of possible approaches in solving innovative problem (Sheu et al. 2011): a flash of genius, empiric path, and methodical path. Out of these the methodical path is a systematic approach to solving the innovative problem. The current study employs this systematic approach expanding on our former research on the topic presented in Waris et al. 2015.

Both knowledge and experience are essential attributes of an innovator. They are necessary to find the optimal solution for the changes required to achieve innovation. These changes are based on the innovative objectives reapplied to the established, existing product. Due to the enormous amount of ever evolving and increasing knowledge and rapid changes in the dynamic environment of product design and manufacture, the innovation process is difficult to practice. Innovators not only need to take proper decisions, they have to do this quickly and systematically so that the changes in the product may be implemented at the required time. We try to address this problem by proposing a system that uses a collective, team-like knowledge developed by innovation related experiences in the past.

In our approach past experiences based on innovation decisions are stored in a Smart Knowledge Management System (SKMS) (Sanin and Szczerbicki 2008) and recalled during the innovation problem solving process. Such SKMS provides quick optimal solutions to a particular innovative challenge. This system acts as a group or team of experts required to find a solution for innovative query. Moreover, the decision taken by this system can be quick due to current fast computational abilities.

The proposed SKMS is based on the Set of Experience Knowledge Structure (SOEKS or SOE in short) and Decisional DNA (DDNA), which were first presented by Sanin and Szczerbicki (2005, 2005a, 2006 and 2008) and later enhanced further for a number of dedicated domains (Toro at al 2012, Wang et al 2015). Implementing this system in the process of product innovation enables entrepreneurs and organizations to take enhanced innovative decisions at appropriate time. The system grows and matures with time gaining increasingly more expertise in its domain as it stores information, knowledge, and data related to the past formal decision events.

Product Innovation and its Timing

Innovation is defined as the process of making changes to something established by introducing something new that adds value to users and contributes to the knowledge base of the organization (O'Sullivan and Dooley 2008). Historically, Schumpeter (1934) describes innovation as the use of an invention to create a new product or service resulting in the creation of some new demand. He termed it as creative destruction as the introduction of a new product into the market destroys the demand for existing products and creates demand for new ones. There is a clear difference between innovation and invention. Invention is the creation of something new and does not need to fulfil any customer need. Invention however, can be exploited and transformed into a change that adds value to the customers; thus, becoming an innovation.

Most of the time, organizations fail to predict the proper moment for analysing and applying innovation. They usually start the analysis process at the time when they should be already applying innovation. The most important questions encountered during innovation problem solving are: (i) when to innovate, and (ii) what to innovate? There is some point, a particular time, at which the organization needs to start analysing the innovative objective. Once this point is established, the innovation process can be started for finding optimal solutions, so that the required innovative changes can be implemented into the product on time. There must be clear difference between the point of analysing the innovative objective and the point of applying innovation. The time difference between these two accounts for the complete innovation process, i.e. analysis, innovative solution, design, manufacturing, and finally availability of the innovative product on the market. The recommended time for starting innovation analysis process is shown as a dotted circle in Figure 1 and is called the critical zone (Okpara 2007). This is the point in any Product Life Cycle at which the sales are still increasing but the rate of increase in sales starts decreasing.

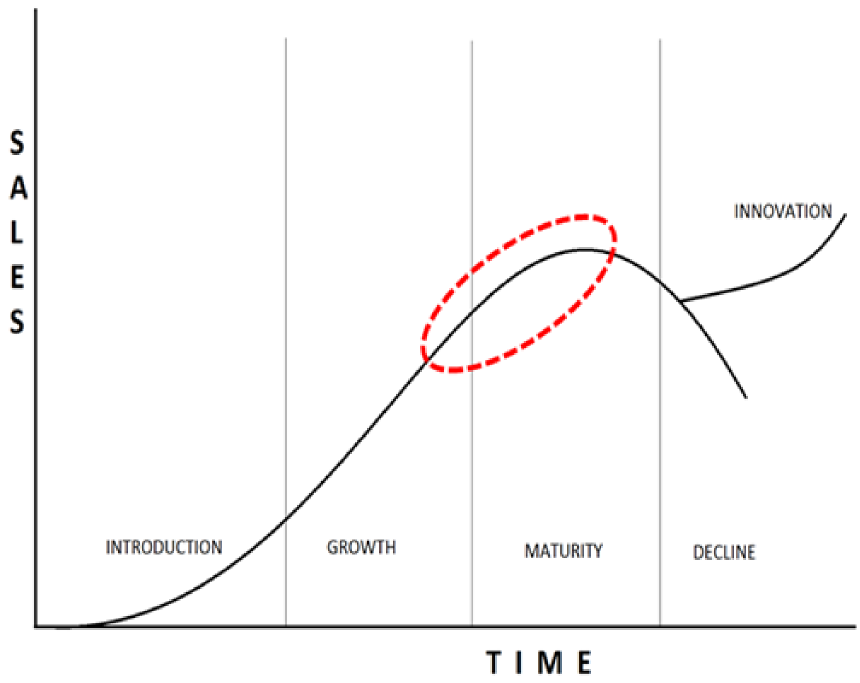

Fig. 1. The Product Life Cycle with the introduction of innovation critical zone

After properly selecting the starting point of innovation analysis the innovative product can be launched into the market at the end of the maturity phase (Figure 1) increasing its sales. This cycle can be repeated.

The above general product innovation procedure enhanced by application of SOE and DDNA will add smartness to the process and make it systematic, portable, and fast.

Set of Experience Knowledge Structure and Decisional DNA

SOE is a smart knowledge structure capable of storing explicitly formal decision events (Sanin and Szczerbicki 2007, 2008a; Sanin et al. 2012). This smart knowledge based decision support tool stores and maintains experiential knowledge and uses such experiences in decision-making when a query is presented in the future. The SOE has four basic components: variables (V), functions (F), constraints (C) and rules (R) as seen in Figure 2 (Sanin and Szczerbicki 2005a).

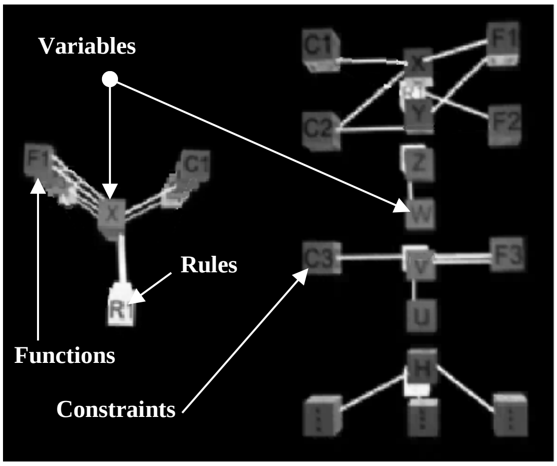

Fig. 2. SOE is combination of four components that characterise decision making actions (variables, functions, constraints, and rules) and it comprises a series of mathematical concepts (a logical component), together with a set of rules (a ruled based component), and it is built upon a specific event of decision-making (a frame component)

SOE variables are considered as the root of the structure as they are required to define other components. Functions are the relationships between a dependent variable and a set of input variables. Functions are used by the SOE for establishing links between variables and constructing multi-objective goals. Constraints are also functions that are used to set the limit to the feasible solutions and control system performance with respect to its goals. Rules, on the other hand, are the conditional relationships among the variables and are defined in terms of If-Then-Else statements. A formal decision event is represented by a unique set of variables, functions, constraints and rules within the SOE. Groups of SOEs are called chromosomes that represent a specific area within the organization and store decisional strategies for a category. Properly organized and grouped sets of chromosomes of the organization are collectively known as its Decisional DNA.

SOE and DDNA have been successfully applied in various fields like industrial maintenance, semantic enhancement of virtual engineering applications, state-of-the-art digital control system of the geothermal and renewable energy, storing information and making periodic decisions in banking activities and supervision, e-decisional community, virtual organization, interactive TV, and decision sup-port medical systems for Alzheimer's diagnosis to name a few (for details see Shafiq et al. 2014). Our research converges on the application of SOE in the development of a systematic smart decision support system for product innovation process.

Product Innovation using SOE and DDNA

Product Hierarchy Structure

Specific details about the geometry and performance of products/components are less important in the early stages of design than the ability to represent its knowledge at a higher level of abstraction (Kusiak et al. 1991). The functionality of products provides a natural framework upon which such abstraction can be built. A methodology for the systematic placements of functionality-based components into a hierarchical ontology was proposed by Bryant et al. (2007). A list of more than 100 distinct generic component terms is provided in Kurtoglu et al. (2005). Centred on this functionality-based hierarchy, one can proceed to select the appropriate product needed for a particular analysis. The extended functional hierarchy shown in Figure 3 is used to arrive at the position of a Screw Jack which is a product selected for initial case study illustrating our approach. This product is considered to be further represented as a Virtual Engineering Object (VEO) (Shafiq et al. 2015, 2015a). The concept of VEO captures the combined virtual/real world exemplification of an engineering artefact.

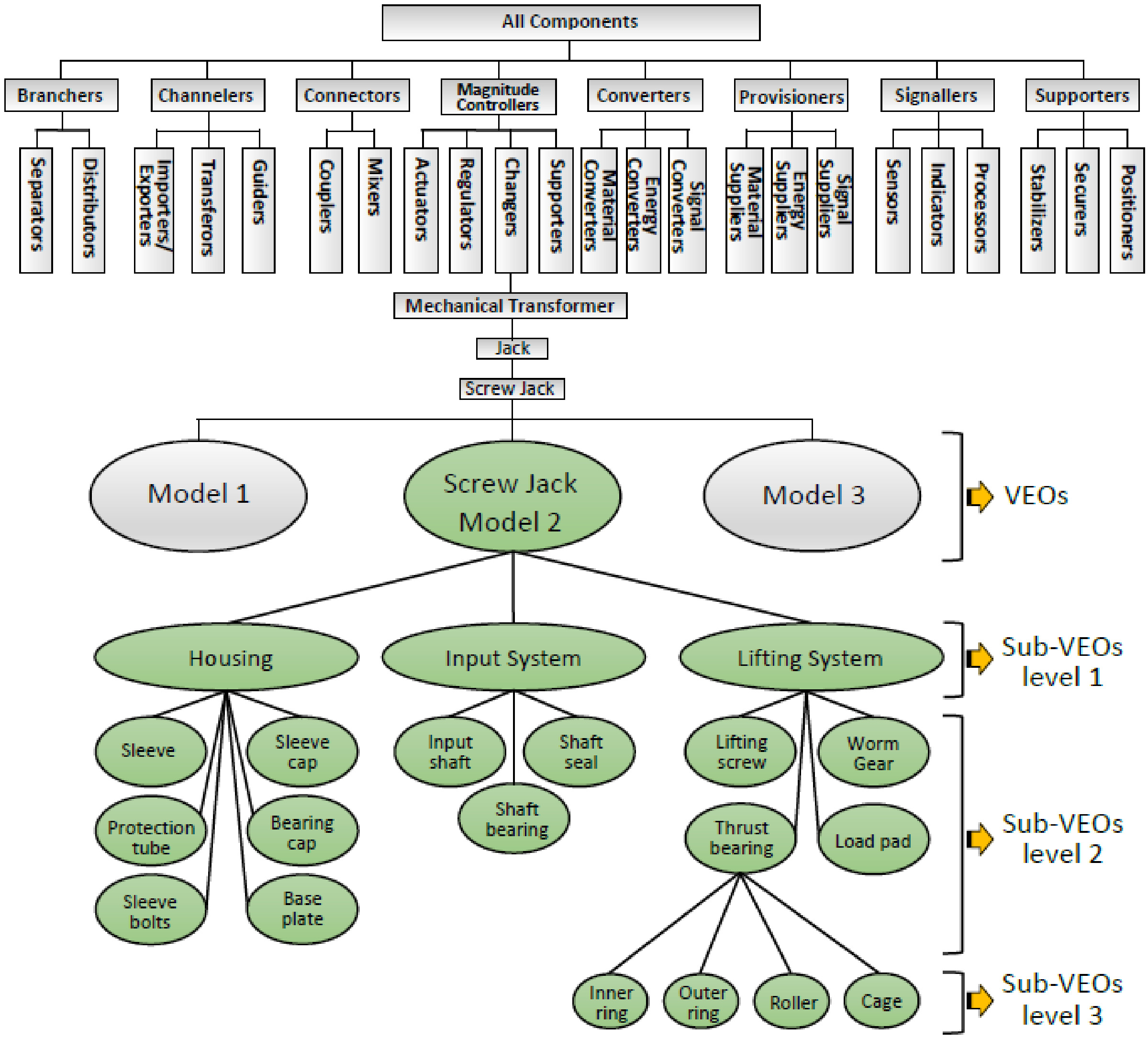

Fig. 3. Function-based hierarchical structure and representation of a Screw Jack as VEO and sub-VEOs.

As shown in Figure 3, first the product under consideration is structured in terms of the hierarchy of nested parts (Murmann and Frenken 2006). Then, its VEO representation (in our case the Screw Jack Model 2) is divided into a number of subsystems performing specific VEO functions, which in Figure 2 are denoted as sub-VEOs level 1. Similarly, sub-VEOs level 1 is decomposed into lover level subsystems shown in Figure 3 as sub-VEOs level 2, which are subassemblies associated with some sub-functions that collectively perform the function at sub-VEO level 1. This nesting continues until the subsystem level reaches the basic element level that cannot be decomposed any further. The example of four level hierarchy is shown in Figure 3. Each level of sub-VEO can be different for any particular VEO functionality of the product and can be decomposed into 10 or more sublevels before reaching the basic element level (Chen et al. 2005).

To illustrate the above concept of decomposition the VEO representation of our case study product Screw Jack Model 2 is subdivided into sub-VEOs level 1 representing *Housing*, *Input System*, and *Lifting System* (Figure 3). As shown in Figure 3, each of these sub-VEOs level 1 are further subdivided into sub-VEOs level 2 and so on. The decomposition continues till the sub-VEOs reach the basic simple element level. For example the *Thrust Bearing* (sub-VEO level 2) is divided into elements *Inner Ring*, *Outer Ring*, *Roller* and *Cage* (sub-VEOs level 3) (Figure 3). As shown in Figure 3 there are logical interrelationships among the VEOs and sub-VEOs which can be defined as the same or cross level associations depending on a particular product design.

Innovation Process and its Decisional DNA

Based on innovative objectives, organizations can establish which features or functions of the product need to be upgraded, which ones may be excluded, and which new features or functions may be added to the product to improve its competitiveness (Ai et al. 2013). In our proposed approach, these features and functions are attributed to the VEO representation of the product. All sub-VEOs at different levels of the hierarchy illustrated in Figure 3 form a structured VEO representation of an engineering product. Innovative changes in a particular VEO can be performed by modifying one or more of its sub-VEOs . These modifications or changes can be introduced at any hierarchy level. In our approach we try to capture experiences related to any past innovation occurrence in dedicated SOEs. The unique SOE combination of variables (V), functions (F), constraints (C), and rules (R) represents experiential formal decisional event related to a given instant of innovation. A group of sets of experience of the same category is called a decisional innovation chromosome. Finally the innovation DDNA is the ultimate collection of decisional chromosomes and encapsulates knowledge for the whole domain in question.

Continuing with our case study illustrative example, a single innovation related decision associated with the *Lifting System* of the Screw Jack represents a set of experience, or decisional gene of the *Lifting System*. Subsequently, a number of such decisions, or sets of experience, associated with *Lifting System* will comprise its decisional chromosome. Similarly many such types of decisional chromosomes, like *Input System* chromosome and *Housing* chromosome will comprise a DDNA of the whole Screw Jack. These knowledge representation structures are never complete as they keep evolving and are upgraded with new decisions that are captured as SOE and added to the knowledge base. In this way the DDNA continues to gain new and updated experiential knowledge which helps it to support and enhance future decisions based on innovative objectives.

The conceptual architecture of the VEO representing product innovation DDNA is shown in Figure 4.

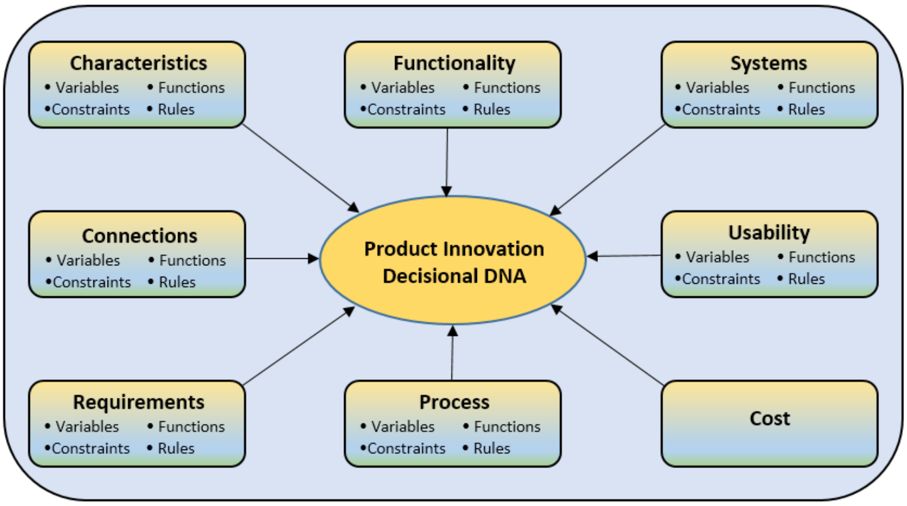

Fig. 4. Architecture of a Product Innovation DDNA

It is the unique SOE based experience representation structure embedded in the VEO that is capable of capturing, storing, adding, improving, sharing as well as reusing knowledge in innovation related processes and decision making in a way similar to an innovator or entrepreneur. The product innovation DDNA contains knowledge and experience related to each important feature of a product. This information is stored in eight basic modules of a product innovation DDNA (Figure 4): Characteristics, Functionality, Requirements, Connections, Process, Systems, Usability, and Cost which are very briefly introduced below.

Characteristics represent the knowledge about dimensions, weight, appearance, etc. of the VEOs as well as the possible concurrency attributes like versatility or ease of operation.

Functionality represents the knowledge about the basic working, input/output of the VEOs, and its operational principles. It also contains the operational knowledge of VEOs such as time consumed and outcome of the process that is performed.

Connections represent the knowledge about relations between the VEOs in conjunction with the manufacturing scenario.

Requirements represent the knowledge about the necessities of the VEOs required for their precise working. It includes the type and amount of power required, space requirements and the extent of user expertise necessary for operating a VEO.

Process represents the knowledge about the manufacturing process/process planning of the VEOs having all shop floor level information including sequence and selection of operations, resources required for its manufacturing. This information helps in transforming a design model into a product in competent and economic way.

The above mentioned five modules can be extracted from the VEO/VEP DDNA developed by Shafiq et al. (2015, 2015a). Three additional modules added to the architecture presented in Figure 4 are Systems, Usability and Cost:

Systems represent the knowledge about the relationships between various sub-VEOs like their hierarchy and dependability so as to embody a complete product structure and its logic. It also stores the past history of VEOs that were used for achieving identical functionalities as well as the possible alternative VEOs that have the potential of replacing the current one. This module is continuously updated with the alternative VEOs used in advanced new products and new technological practices, new inventions, and new advanced materials. This module is crucial for innovation process.

Usability represents the knowledge about the use of a particular sub-VEO of the given product in other products. This helps in assessing its performance in other domains from the perspective of possible application elsewhere. It contains information on which products have stopped using the given sub-VEO, in which products it has been introduced recently, and its effect on the performance, popularity, sales or price of the product.

Cost represents the knowledge about the total cost of each sub-VEO of the product, the assembly cost of a group of sub-VEOs, and any other cost associated with the product manufacture, usage, maintenance etc.

The Working of the Proposed Concept

The query based on innovative objectives is fed into the DDNA system embedded in the product VEO. This query is converted to a SOE containing a unique combination of variables, functions, constraints and rules. The system then looks for the most similar SOE for comparison and based on the similar past innovation related experiences provides proposed possible solutions. For example, the innovative objectives suggest conceivable changes in a set of functions or sub-functions. The system relates this set with some sub-VEOs of the product. Comparing the existing in the DDNA experiences from the past that had common innovative objectives, the system suggests possible solutions. At this point it may be noted that generally innovative changes are incremental and not modular, i.e. changes are done only in some few parts of the product and not in all the sub-VEOs.

The system then compares the suggested possible solution alternatives in the Usability Module (Figure 4). The best solution is chosen and stored in the DDNA of the product innovation as a new SOE that can be used for solving innovative problem in the future. In this way the system gains some additional experiential knowledge with each query. Eventually, it behaves as an expert innovator/entrepreneur possessing knowledge equivalent to a group of experts capable of taking quick, smart innovative decisions.

To illustrate the above working of the proposed concept even further, let’s consider “ease of operation” as one of innovative objective for our case study VEO

(Screw Jack Model 2). This innovative objective is linked to one or more functions/sub-functions of the VEO that affect the operating conditions. Different weights are assigned to each possible connection between innovative objective and corresponding functions. These functions are then connected to one or more sub-VEOs of the analysed product. For example “ease of operation” depends, along with other sub-functions, upon the sub-function “friction” between the sub-VEOs “input shaft” and “worm gear” (Figure 3). The system first looks for the similar queries from the past events and the decisions that were taken. It also collects the related information about the sub-VEOs *Input Shaft* and *Worm Gear* from the modules in the product hierarchical structure. This information is in the form of SOE (Variables, Functions, Constraints and Rules) and may be as follows:

IF lift speed = 400 THEN Power = 0.15

Efficiency = 27% - 34%

IF lubricant = B3 THEN friction = 32

Maximum load = 500

The system then looks for the alternative sub-VEOs from the Systems Module (Figure 4) based on this set of unique information including similar sub-VEOs present in other products, new technological VEOs, inventions, etc., and some top alternative sub-VEOs are selected. Similarly, the system performs the same process for other innovative objectives and selects the other alternative sub-VEOs. The unique final combination of different possible alternative sub-VEOs is proposed based on the priorities set by the user. These priorities can be of the form:

Maximum Cost = 60

Minimum life = 15

The whole above process with the final solution is stored as the new experience into the DDNA of the Product Innovation and can be used in future queries.

Conclusion

This paper introduces the concept of a new approach to solve product innovation problems. The presented concept is called Product Innovation DDNA and it is based on knowledge representation structure that applies past experiential familiarities. The proposed framework for smart product innovation carries the promise to perform the innovation processes quickly and efficiently. It stores the past decisional events or sets of experiences related to innovation issues, which significantly enhances innovation progression. The proposed decision support system is dynamic in nature as it updates itself every time a new decision is taken. With time it can behave as an expert innovator/entrepreneur capable of taking quick and smart decisions. The concept is illustrated with the example of a Screw Jack studied as the case that helps to understand the architecture and the working of the proposed system. In the next research step we refine the components of the introduced architecture and translate it into software representation on a Java platform.

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