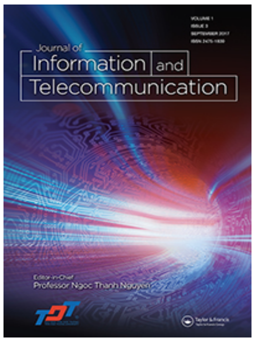

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Smart innovation process enhancement using SOEKS and decisional DNA

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ABSTRACT

Product innovation always requires a foundation based on both knowledge and experience. The production and innovation process of products is very similar to the evolution process of humans. The genetic information of humans is stored in genes, chromosomes and DNA. Similarly, the information about the products can be stored in a system having virtual genes, chromosomes and decisional DNA (DDNA). The present paper proposes a semi-automatic system that facilitates product innovation process using a Smart Knowledge Management System comprising Set of Experience Knowledge Structure and DDNA. This system is called Smart Innovation Engineering System. Through this system, entrepreneurs and organizations will be able to perform the product innovation process technically and quickly, as it stores knowledge in the form of experiences of the past innovative decisions taken. This proposed system is dynamic in nature as it updates itself every time a decision is taken.

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Product innovation; product design; Set of Experience; decisional DNA; Smart Innovation Engineering

1. Introduction

Due to rapid changes in the dynamic environment, organizations involved in manufacturing products cannot grow through cost reduction alone. For the survival and prosperity of the manufacturing unit, entrepreneurs need to find out new ideas that can be implemented in the products leading to innovation. 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 approach in solving innovative problem (Sheu & Lee, 2011): a flash of genius, empiric path and methodical path. Out of these the methodical path is a systematic approach for solving the innovative problem. By systematic analysis an optimal solution can be obtained quickly through this process.

The current study employs a systematic approach for product innovation. Innovation comes from the human minds like entrepreneurs who think and analyse the knowledge smartly (Waris, Sanin, & Szczerbicki, 2016). Both knowledge and experience are essential attributes of an innovator that are necessary to find the optimal solution for the necessary

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changes. These changes are based on the innovative objectives that initiate the product innovation problem for finding the necessary changes to be implemented in the established product. But due to the enormous amount of ever increasing knowledge and rapid changes in the dynamic environment, the innovation process is difficult to practice. Innovators not only need to take proper decisions, they have to do it quickly and systematically so that the changes in the product may be implemented on time. Humans have the ability to store knowledge in their mind from the experiences they face during their life. This experience-based knowledge helps them in taking proper decisions for a relevant task by analysing the knowledge smartly.

Erden, Krogh, and Nonaka (2008) pointed out that innovation is a collective work of a group of people or a team which draws the attention to 'group tacit knowledge' and not an outcome of a single person. So, if the whole group is not available during the innovation process, it will be very difficult to find an optimal solution on time. If the Smart Knowledge Management System (SKMS) can be formulated for representing and analysing data that is able to store experiences based on the decisions taken in the past, such a system will provide quick optimal solutions to a particular innovative problem. This system will act as a complete group of people required for finding solutions for query as it is using all the experiences from the past apart from other essential knowledge about the product. Moreover, the decision taken by this system will be quick due to fast computational ability of computers as compared to humans that also take more time for mutual coordination. Such a Knowledge Management system will help any innovative enterprise to survive in the dynamic environment.

Decision-makers look back on the lessons learnt from the previous similar situations as a base for making current decisions (Sanin & Szczerbicki, 2005a). However, the decision-making process has some shortcomings like high response time, repetitions of decisions already made and inability to keep pace with the dynamic environment. This is due to inefficient knowledge administration and failure to capitalize the experiences within the organization. A knowledge-based tool, known as the Set of Experience Knowledge Structure (SOEKS) comprising decisional DNA (DDNA), was presented by Sanin and Szczerbicki (2005b, 2008a). Waris, Sanin, and Szczerbicki (2017) proposed a semi-automatic system comprising this tool that facilitates product innovation process. This system is called Smart Innovation Engineering (SIE) System. Implementation of this system in the process of product innovation will facilitate entrepreneurs and organizations to take proper decisions at appropriate time as this system stores information, knowledge as well as experiences of the formal decision events. In this way, the system grows and matures with time gaining more and more expertise in its domain.

2. Background

2.1. Product innovation

The most important questions encountered during innovation problem-solving are: (i) when to innovate, and (ii) what to innovate? Most of the time, organizations fail to predict the proper time for analysing and applying innovation. They start analysing at a time when they should have been applying innovation. There must be some point, a particular time, at which the organization need to start analysing the innovative objective.

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Once this point is recognized, the innovation process can be started for finding out the 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 will account for the complete innovation process, that is, from analysis, innovative solution, design, manufacturing, and finally availability of the innovative product in the market. The alarming time for starting to analysing the innovation process is shown as a red circle in Figure 1, called the critical zone. This is the point at which the sales are still increasing but the rate of increase in sales starts decreasing.

Product innovation using SIE System will make the innovation process systematic, smart and fast. After properly selecting the point of analysing innovative objective and obtaining the optimal solution from the proposed system, the selected changes are designed and the product is manufactured accordingly. The product is then launched into the market at the point of applying innovation, that is, the time preferably at the end of maturity phase or at the beginning of decline phase and its sales start increasing again. The whole process can be repeated few times until the effect of innovative changes does not result in appreciable sales of the product or the product becomes obsolete (Okpara, 2007).

2.2. SOEKS and DDNA

The SOEKS is a smart knowledge structure capable of storing explicitly formal decision events, (see Sanin & Szczerbicki, 2007, 2008b; 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.

The SOEKS has four basic components: variables (V), functions (F), constraints (C) and rules (R) (Sanin & Szczerbicki, 2005a) as seen in Figure 2. It comprises a series of

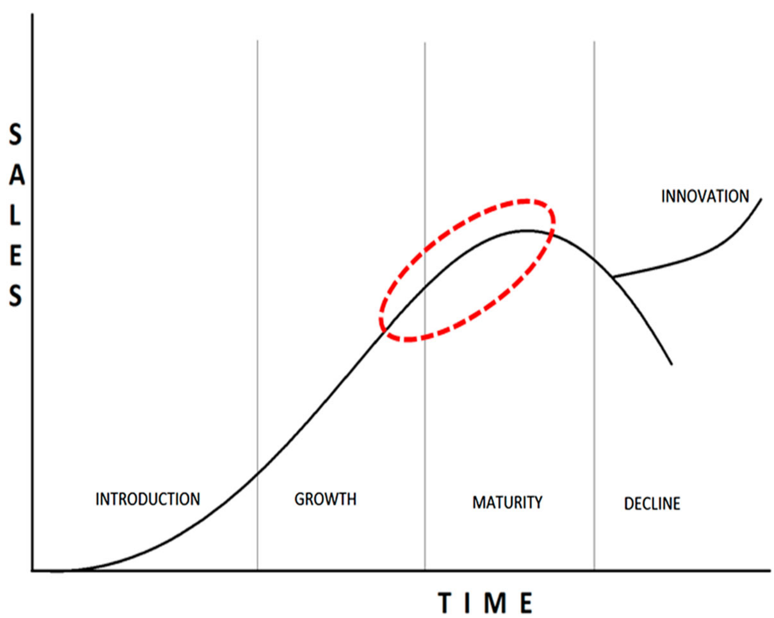

Figure 1. The product life cycle with the introduction of innovation at later phases.

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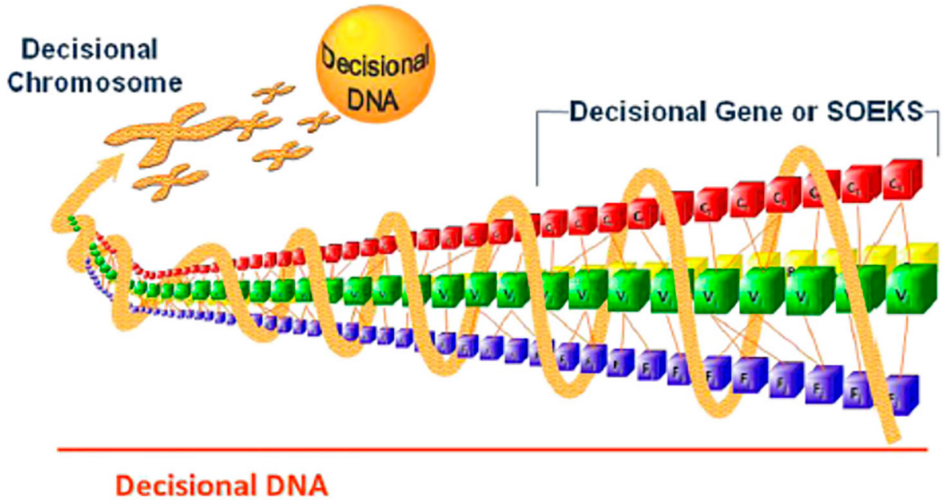

Figure 2. SOE and DDNA (Sanin et al., 2012).

mathematical concepts (logical element), together with a set of rules (ruled based element), and it is built upon a specific event of decision-making (frame element).

Applications of SOEKS and DDNA have been successfully applied in various fields such as 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 support medical systems for Alzheimer's diagnosis to name a few. For details see Shafiq, Sanin, and Szczerbicki (2014). Our research converges on the application of SOEKS in the development of systematic product innovation.

Variables are considered as the root of the structure as they are required to de-fine other components. Functions are the relationship between a dependent variable and a set of input variables. Functions are used by the SOEKS 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 SOEKS. Groups of SOEKS 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 the DDNA of the organization.

3. Product innovation using SOEKS and DDNA

3.1. Genetic structure of a product

First the artefact, or the product, is structured in terms of a hierarchy of nested parts (Murmann & Frenken, 2006) as shown in Figure 3. The product is divided into a number

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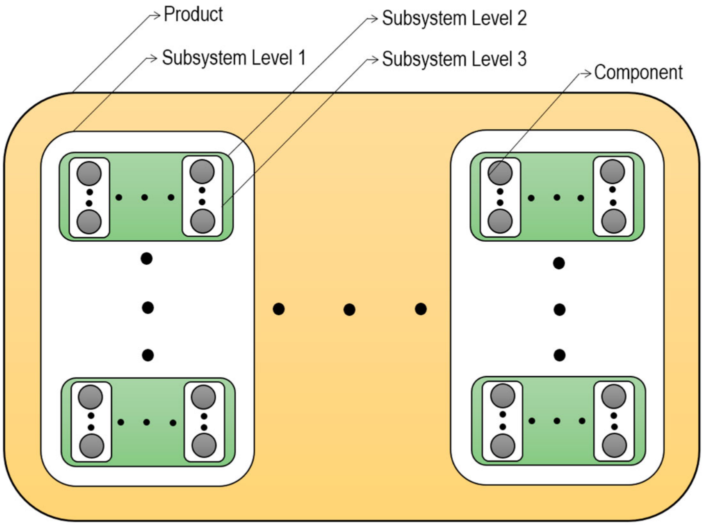

Figure 3. Structure of a product representing its subsystems and components.

of systems performing some specific function of that product, which can be represented as subsystem level 1. Similarly, subsystem level 1 can be subdivided into further subsystems, represented as subsystem level 2 which are subassemblies associated with some sub-function that collectively perform the function at subsystem level 1. This nesting continues until the subsystem level reaches the component level. The four-level hierarchy is shown in Figure 3. The level of subsystems is different for any particular system performing a particular function of the product and can go up to level 10 or more (Chen, Feng, & Chen, 2005) to reach the component level. Moreover the level of each subsystem in the same product does not need to be the same, as it depends upon the complexity of the system. Consider the automobile car as a product, it can be divided into subsystems level 1 like car body, engine, fuel system, suspension system, braking system, electrical system and so on. At subsystem level 2, it can be a piston and so on until it reaches the component level which can be a simple pressure ring under the engine system or a self-locking nut in car body system.

There are inter-relationships among the systems, subsystems and components (Chen & Feng, 2009). These relationships can be at the same level in the same system like piston and cylinder in the engine system, or it can be between subsystems at the same or different level under different systems like relationship between carburettor in fuel injection system and spark plug in engine system.

3.2. Innovation process

Organizations involved in manufacturing products need to find out new ideas and innovate continuously to survive and prosper. They cannot grow only through cost reduction and improved engineering processes. The reasons are competition at international level, rising costs of material and energy, frequent changes in lifestyles, new technologies and automation. Innovation is defined as the process of making changes to something established by introducing something new that add value to users and contributes to the knowledge store of the organization (O'Sullivan & Dooley, 2008). Schumpeter (1934)

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describes innovation as the use of an invention to create a new product or service resulting in the creation of new demand. He termed it as creative destruction as the introduction of a new product into the market destroys the demand of existing products and creates demand for new ones, and so on. There is a clear difference between an 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.

Manufacturers must respond quickly and effectively today to ever-growing demands from users for better products at lower costs. To survive, companies around the world must continuously pursue product innovation (Chen & Feng, 2009). Most manufacturing organizations put their customers' satisfaction on top priority to improve their competitiveness (Ai, Wang, & Liu, 2013). A systematic and proper approach in product innovation can increase the life of the product. Based on innovative objectives, organizations can find out 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. These features and functions are attributed to some systems of the product.

Innovative changes in the product can be performed by modifying one or more systems of the product. These modifications or changes can be at system, subsystem or component level. Accordingly, the required changes can be incorporated into the product to complete the innovation process. Product innovation is a continuous process; no organization, however big or successful, can continue to grow on the past achievements. Okpara (2007) says that enterprises that rely exclusively on innovation will prosper until their products and services become obsolete and non-competitive.

3.3. DDNA of product innovation

Organisms are created by nature through complex physical and chemical actions. Similarly products are also produced by manufacturers through physical and chemical actions (Yong, Peien, & Zhongqin, 2005). Therefore, the essences of their origins are similar. DNA carries out the genetic information of the living organisms. It comprises four basic elements called nucleotides: adenine (A), thymine (T), guanine (G) and cytosine (C). Their combination represents a unique characteristic of this structure. A gene is a portion of a DNA molecule that guides the operation of one particular component of an organism. Chromosome is a set of genes and multiple chromosomes represent the genetic code of the individual (Miller & Levin, 2002). Similarly, the knowledge structure proposed by Sanin and Szczerbicki (2005a) can be used for storing and reusing the formal decisional events.

The unique combination of variables (V), functions (F), constraints (C) and rules (R) represents a formal decisional event or experience. This Set of Experience (SOE) is considered as a part of long strand of DNA, that is, a gene or what we call here decisional gene of the product. A group of sets of experience of the same category is called as decisional chromosome. These chromosomes provide a schematic view of the knowledge. Finally, the DDNA consists of stored experienced decision events, that is, experiential knowledge.

For example, a single decision associated with the fuel injection system of the car represents a SOE, or decisional gene, of fuel injection system. Subsequently, many of these decisions, or sets of experience, associated with fuel injection will comprise a decisional

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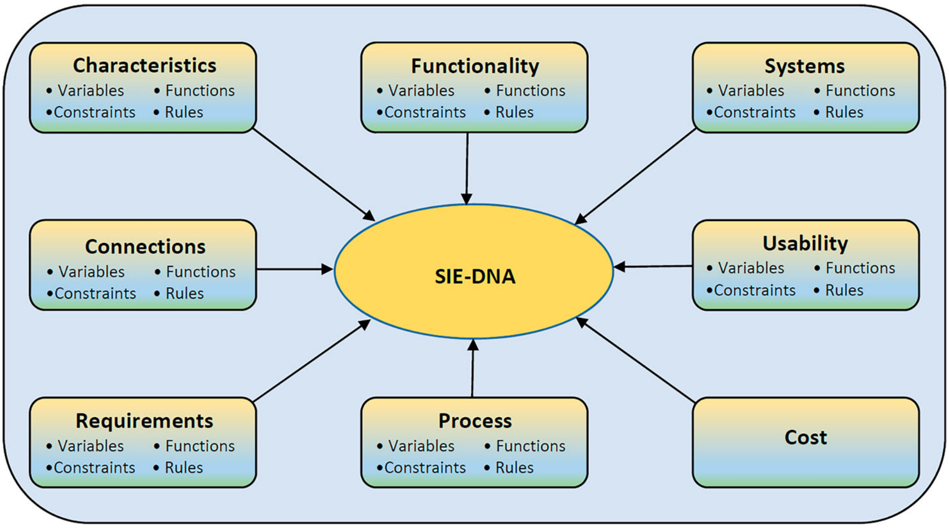

Figure 4. Architecture of a product innovation DDNA.

chromosome of fuel injection system. Similarly many such types of chromosomes, such as suspension chromosome, engine chromosome, car body chromosome, exhaust emission chromosome and so on, will comprise a DDNA of the car. These chromosomes are never complete, as they keep growing with decisions added from time to time. In this way the DDNA continues to gain experiential knowledge which helps it to take decisions based on innovative objectives. This knowledge representation is dynamic in nature and behaves as an expert of the product from every perspective.

The architecture of product innovation DDNA is shown in Figure 4. It is the knowledge representation of a product which is capable of capturing, storing, adding, improving, sharing as well as reusing knowledge in decision-making in a way similar to an innovator or entrepreneur. The product innovation DDNA contains knowledge and experience of each important feature of a product. This information is stored in eight different modules of a product: Characteristics, Functionality, Requirements, Connections, Process, Systems, Usability and Cost. The first five modules come under the DDNA of virtual engineering objects/virtual engineering process (VEO/VEP) that has been studied by Shafiq, Sanin, Szczerbicki, and Toro (2015), and Shafiq, Sanin, Toro, and Szczerbicki (2015). The information and experiential knowledge from VEO/VEP can be easily shared and used for innovation process.

3.3.1. Characteristics

Characteristics module represents the knowledge about dimensions, weight, appearance, etc. of the system, subsystems and components of the product as well as the possible concurrency attributes like versatility or ease of operation.

3.3.2. Functionality

This module represents the knowledge about the basic working, input/output of the object (object collectively represents system, subsystem or a component of the product) and its operational principles. It also contains the operational knowledge of an object such as time consumed and outcome of the process that is performed.

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3.3.3. Connections

It represents the knowledge about the relations between the VEOs in conjunction with the manufacturing scenario.

3.3.4. Requirements

This module represents the knowledge about the necessities of the VEO required for its precise working. It includes the type and amount of power required, space requirements and the extent of user expertise necessary for operating a VEO.

3.3.5. Process

Process module represents the knowledge about the manufacturing process/process planning of the artefact 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 studied by Shafiq, Sanin, Toro, et al. (2015). Three more modules are introduced here.

3.3.6. Systems

This module represents not only the knowledge about the relationships between various systems, subsystems and components like their hierarchy and dependability so as to represent a complete product but also stores the past history of every system, subsystem and component that were used for the same function. It also stores the possible alternative systems, subsystems or components that have the potential of replacing the current one. This module is continuously updated with the alternative systems used in advanced products as well as the new technological systems, inventions and advanced materials. This is the most important module for innovation process.

3.3.7. Usability

Usability module represents the knowledge about the use of a particular system, subsystem or component of the product in other products. This will help in assessing its performance in other products. Information such as which products have stopped using this system or component and in which products it has been introduced recently and its effect on the performance, popularity, sales or price of the product.

3.3.8. Cost

It represents the knowledge about the total cost of all the systems, subsystems and components. It will help in comparing and selecting a system, subsystem, optimum manufacturing process, component material, etc. on cost basis.

The query based on innovative objectives is fed into the SIE System. This query is converted to a SOEKS containing a unique combination of variables, functions, constraints and rules as described above. The system will look for the most similar SOEKS for comparison and based on the similar experiences will provide proposed solutions. For example, the innovative objectives suggest possible changes in five functions or sub-functions. The system will relate these functions and sub-functions with some systems and subsystems of the product. Comparing the experiences from the past having some common

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innovative objectives, the SIE System will provide the set number of possible solutions. At this point it may be noted that generally innovative changes are incremental and not modular, that is, changes are done only in few parts of the product not in all the systems and subsystem stated in innovative objectives. So the system will compare the present query with the past queries having some common objectives. Based on the solutions of the past SOEKS, proposed solutions are obtained suggesting possible changes in some subsystems or components of the product.

The SIE System will then compare the alternatives available in the systems and usability modules. Based on the weights assigned to the attributes, list of solutions are presented by the SIE System. The best solution is chosen and stored in the DDNA of the product innovation as a SOEKS that can be used for solving innovative problem in future. In this way, the SIE System also gains some experiential knowledge and with time it will behave as an expert innovator/entrepreneur having knowledge equivalent to a group of experts, capable of taking quick and smart decisions.

4. Working of SIE system

4.1. Implementation of SIE system

As we have discussed earlier that the structure of the SIE System includes eight modules (Characteristics, Requirements, Functionality, Connections, Process, Systems, Usability and Cost). Sets of experience are created for each module individually that allows the experienced-based knowledge to be stored more systematically for a wide range of similar manufactured products. SOE is a unique combination of Variables, Functions, Constraints and Rules. Proper implementation of SIE System requires its integration with the DDNA. Sets of experience are generated for each individual module having specific weightages for the variables of the product. Combination of all the individual sets of experience are combined under the SIE system that represents complete knowledge and experience necessary for supporting innovation process of manufactured products.

As the DDNA is constructed in JAVA and has been successfully applied in various other fields of application, the code for SIE system was written in Java programming using Windows 7 operating system. The complete information about manufactured product is stored in each module in Comma Separated Values (CSV) files. This information is in the form of sets of Variable, Functions, Constraints and Rules. Separate CSV files were generated for all modules viz. Characteristics, Functions, Systems, etc. A parser was written in Java programming language to read these files. This parser reads Variables, Functions, Constraints and Rules from CSV files. The CSV files contain data in standard format so that the parser collects information as required.

First the parser looks for the term 'Variables' and goes to the next line. The first line after the term 'Variables' contains the name of the Variables. It stores values written in each cell of the first line as the 'Name' of the Variables. Each line after this contains the Value of the corresponding Variables. The parser assigns the values to the respective Variables. This group of Variables is stored in the system as one 'Set of Variables'. Similarly, the parser reads the second set of values from the CSV file and assigns them to the respective Variables that is stored as the second 'Set of Variables'. The same process continues until the parser finds the term 'Functions', 'Constraints' or 'Rules'. In the same way, the parser reads 'Set

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of Functions', 'Set of Constraints' and 'Set of Rules' from the CSV file. One 'Set of Variables' plus 'Set of Functions', 'Set of Constraints' and 'Set of Rules' are combined together to form one SOE. Each line containing the values of Variables results in corresponding SOE.

Same procedure is repeated for other CSV files representing data for different modules of SIE System. Each file represents a category of the SIE System. Collection of SOE of the same category forms a Chromosome of the SIE System and collection of different Chromosomes (for each Module) forms what we call as DDNA of the SIE System.

The Pseudocode of the Java program is presented below explaining the working of the SIE System:

- For each CSV file
  - Read file
  - If term = 'Variables'

        Go to next row   // first row after 'Variables'
        For each column of this row
            Variable.Name(term) // Store each term as Name(Variable)
        Go to next row   // second row after 'Variables'
        For each column of this row
            Variable.CValue(term) // Store each term as CValue(Variable)
        VariableSet = Sum of these Variables
        Repeat the process for all rows

  - Repeat the process for FunctionSet, ConstraintSet and RuleSet
  - For each VariableSet

        SOEKS = VariableSet + FunctionSet + ConstraintSet + RuleSet

- Input Query_SIE   // Query includes VEO_Code, SIE_Obj[] and Constraints

  VEO_Code = EM_04CH423_JACK_sj22
  SIE_Obj1 = 'EaseOfOperation'
  SIE_Obj2 = 'MoreStability'
  ConstraintSet = ***   // Limiting the boundaries for feasible solution
- QuerySIE = new SOEKS   // convert Query into SOEKS
- For each SOEKS   // generated from CSV files
  - Find similarity of QuerySIE with SOEKS

        // similarity is calculated on the basis of Euclidian distance with its value
        // ranging from 0 to 1 (0 being the closest)

- Return SOEKS with minimum similarity
- Get VEO_Code for Rep_VEO1 && Rep_VEO2
- Rep_VEO1.getVEO_Code (=EM_08PS629_SHFT_ds14)
- For VEO_Code = EM_08PS629_SHFT_ds14
  - get VEO_Name (= Shaft)
- For VEO_Name = 'Shaft' && ConstraintSet = QuerySIE.ConstraintSet
  - Find most suitable VEO from VEO_DDNA
- Repeat the process for Rep_VEO2
- Output the top five proposed solutions
- User select the final solution
- QuerySIE updated and saved as a SOEKS in SIE-DDNA.

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4.2. Graphical user interphase (GUI) for SIE system

GUI for the SIE System is shown in Figure 5. This GUI will allow the user to interact with SIE System in a user-friendly language. The user can select the set of values from the drop-down menu and the also be able to define the required Constraints and preferences in the form of set of variables with selected values. This set of information (Query) is then converted into SOE and compared with the similar Sets of Experience that were generated by the SIE System from CSV files as explained earlier in Section 4.1 above. The SIE System then compares the results of the most similar SOE and stores the changes that were made in those Products. These SOE actually represents the experiential knowledge of the successful changes made in product innovation processes of the group of similar products or products with similar features or objectives. Each past decision (SOE) has its Performance Factor (Waris et al., 2016, 2017) that represents the success of the decision taken in that Product Innovation process. The SIE System looks for the best available option for a change that fits in the current Product (based on the constraints/preference set by the user).

The SIE System provide a list of proposed solutions (say 5, 10 or 20) that is displaced in the GUI. At this time, the user/entrepreneur/innovator has the privilege to select the best possible solution from that list. This selection of solution will complete the Product Innovation process and stored in the SIE System as SOE. In this way, the SIE System is a semi-automatic

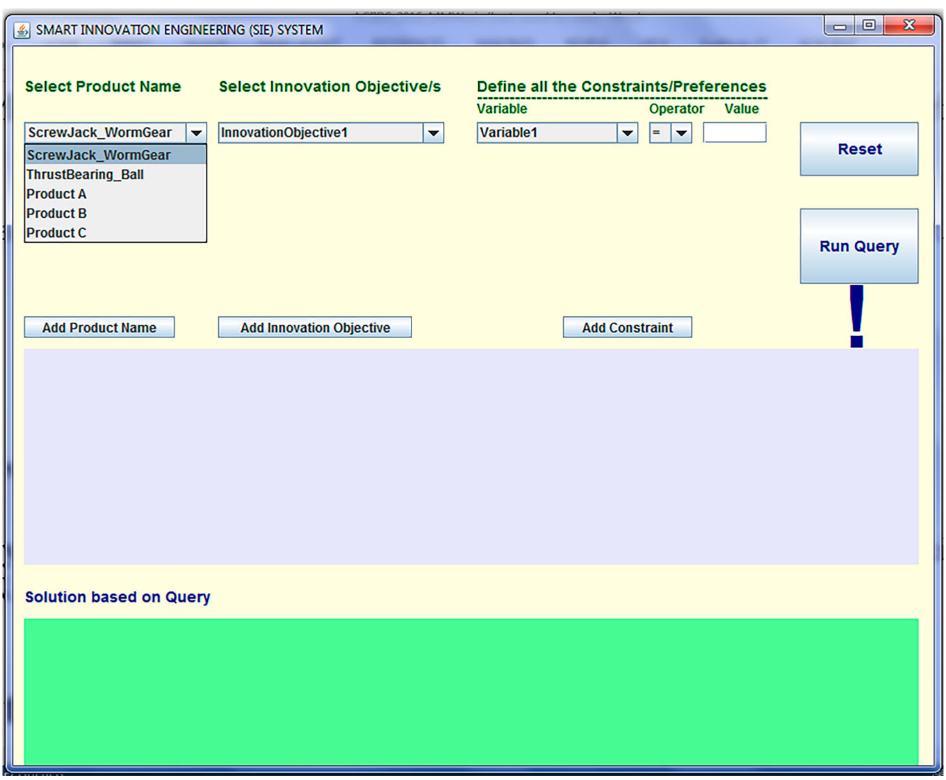

Figure 5. GUI for SIE system.

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system that facilitates the process of Product Innovation. This nature of this system helps in avoiding any absurd/irrelevant result. The SIE System gains experience with each decision taken that increases its expertise and behaves as an expert in its domain.

5. Conclusion

This paper applies SKMS, comprising SOEKS and DDNA, to solve the product innovation problem. The system is capable of storing knowledge as well as experiences of the past decisional events. This semi-automatic system is called SIE System that can be used for enhancing the Product Innovation process. The SIE System will allow the entrepreneurs and organizations to perform the innovation process quickly and technically sound. It stores the past decisional events or sets of experiences which help it in innovation process. The sets of experiences of the same category are grouped as a particular chromosome related to some function or system of the product and many such chromosomes represent a DDNA of the product. The SIE System is dynamic in nature as it updates itself every time a decision is taken. With time it will behave as an expert innovator/entrepreneur capable of taking quick and smart decisions.

Disclosure statement

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Cesar Sanin has been working in the field of knowledge engineering and intelligent technologies for the past 12 years. He obtained degrees in Systems Engineering and Administrative Engineering (in Colombia) and in IT (in Australia). Afterwards, he pursued a Ph.D. degree at the School of Engineering of The University of Newcastle, and received his title in the field of Knowledge Engineering and Intelligent Technologies (2007). Currently, he continues his work at The University of Newcastle as a co-director of the Knowledge Engineering Research Team—KERT. His research focuses on the areas of knowledge engineering, decision support systems and intelligent systems for engineering and business.

Edward Szczerbicki has had very extensive experience in the area of intelligent systems development over an uninterrupted 30-year period, 25 years of which he spent in the top systems research centres in the USA, UK, Germany, and Australia. In this area he contributed to the understanding of information and knowledge engineering in systems operating in environments characterized by informational uncertainties and dynamics. He has published 300+ refereed papers, which attracted over 1200 citations over the last ten years. His academic experience includes ongoing positions with Gdansk University of Technology, Gdansk, Poland; Strathclyde University, Glasgow, Scotland; The

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