A Semi-Automatic Experience-Based Tool for Solving Product Innovation Problem

Mohammad Maqbool Waris[1], Cesar Sanin[1], and Edward Szczerbicki[2], Syed Imran Shafiq[3]

[1] *Department of Mechanical Engineering, University of Newcastle, Callaghan, NSW, Australia*

(MohammadMaqbool.Waris@uon.edu.au, cesar.sanin@newcastle.edu.au)

Address: ES320, Faculty of Engineering and Built Environment, University of Newcastle, Callaghan, NSW 2308, Australia;

[2] *Faculty of Management and Economics, Gdansk University of Technology, Gdansk, Poland*

(edward.szczerbicki@newcastle.edu.au)

[3] *Mechanical Engineering Section, Aligarh Muslim University, Aligarh, India*

(SyedImran.Shafiq@uon.edu.au)

A Semi-Automatic Experience-Based Tool for Solving Product Innovation Problem

In this paper we present the idea of Smart Innovation Engineering (SIE) System and its implementation methodology. The SIE system is semi-automatic system that helps in carrying the process of product innovation. It collects the experiential knowledge from the formal decisional events. This experiential knowledge is collected from the group of similar products having some common functions and features. The SIE system behaves like a group of experts in its domain as it collects, captures and stores the experiential knowledge from similar products as well as reuses this experiential knowledge that ultimately enhances the innovation process of manufactured goods. Moreover, with SIE in hand entrepreneurs and manufacturing organizations will be able to take proper, enhanced decisions and most importantly at appropriate time. This expertise is ever increasing as every decision taken is stored in SIE system in the form of set of experience that can be used in future for similar queries. Implementation of the SIE System using Set of Experience Knowledge Structure (SOE) and Decisional DNA (DDNA) for case study suggests that the SIE system is capable of capturing and reusing the innovation related experiences of the manufactured products. The case study confirmed that the SIE system can be beneficial for entrepreneurs and manufacturing organizations for efficient decision-making in the product innovation process.

Keywords: Product Innovation, Product Design, Smart Innovation Engineering, Set of Experience, Decisional DNA

Introduction and Background

The key features for designing and manufacturing a new product are: required features/functions of the product, technology, resources and materials available, manufacturing processes and other such factors at that time (Waris et al. 2016b). The properly designed and manufactured product initially leaves an impact in the market. But with time, the graph of the manufactured product starts declining. This is due to introduction of new/smart products into the market, technological advancements, development of new materials having enhanced properties/lower costs, improved/cost-effective manufacturing processes and other similar factors. To overcome this, and for the prosperity and survival of the manufacturing unit in this competitive market, the entrepreneurs and manufacturing organizations have to introduce new features in their products leading to innovation. They have to repeat the product innovation process after a particular time otherwise their product may become obsolete.

In fact, the process of product innovation is very difficult and complex as it requires the knowledge about new technological advancements, new materials apart from the complete knowledge of all the similar products having some common/similar functions or features. This knowledge is possessed by a group of experts/innovators. Both knowledge and experience are essential attributes of an innovator that are necessary to find the best possible solution for the required changes leading 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 manufacturing, 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.

Different authors have defined innovation in various ways. In the context of manufactured products it can be defined as the process of making required changes to the already established product by introducing something new that adds value to users and also provide expertise knowledge that can be stored in the organization (O'Sullivan and Dooley 2008). Knowledge and innovation plays an important role in regional growth and it is not a new issue at all. A bottom-up approach to the development of the knowledge economy was thought to be interesting given the high spatial concentration of innovation and knowledge creation activities. Clusters of technologically advanced firms, like Silicon Valley in California, "Route 128" in the Boston area, Baden-Württenberg in the South of Germany, Jutland in Denmark, testified to the presence of some form of increasing returns on the concentration of innovative activity (Capello 2013).

Innovation plays an important role in providing competitive advantage for manufacturing organizations (Gunday et al. 2011). Thus, innovation related activities have become a key imperative for many manufacturing organizations. The drivers of innovation strategies may include market penetration, technology leadership and improving the learning and growth of organizations (Paladino 2007; Vega-Jurado et al. 2008). Strategy for Product innovation implementation includes the use of better components, new materials, advanced technologies and new product functions/features in the development of a product (OECD 2005). Product innovation strategy implementation is also influenced by external factors such as legislation and sustainable development. For example, the external factors like increasing oil and energy prices and the strict norms for reduction in greenhouse gases are driving organizations engaged in car manufacturing to apply innovation strategies to produce more fuel efficient, reliable and controlled emissions automobiles (Gan 2003; Tao et al. 2010). As evident from the development and production of hybrid cars.

Another factor that is considered during product innovation process is ergonomics. Research suggests that ergonomics is related to product characteristics such as safety, efficiency of use, and comfort aimed at maximizing customer satisfaction (Osborne, 1987). Ergonomic properties are recognized as important because firms are competing on ease of use of the product (Nussbaum, 1993). Moreover, the establishment of cross-functional, multi-disciplinary teams was found to be vital to the success of the innovation project (Jayarama 2014). It was reported by Yannou et al. (2008) that innovation is not the outcome of one isolated intelligence, instead, it is the result of a multidisciplinary workgroup led by a process or a methodology.

It was reported by Frishammar (2005) that a strong emphasis on user information leads to incremental rather than radical product innovation. In incremental innovation, forecasting of user need are easier as it is repeated over a short span of time. Level of risk is also lower and have a less complex product development process. As compared to radical innovation, incremental innovation requires relatively low investment thus providing financial advantage. Revenue and profits are also additional positive factors as they show up faster (Smith and Reinertsen 1998).

From the above discussion, it is clear that product innovation is highly complex process that requires vast knowledge about all the similar products possessed by group of experts including experiences of the formal decisional events, knowledge about new materials, technological advancements and various other factors like legislative, ergonomic, financial, etc. We try to address this problem by proposing a system that uses a collective, team-like knowledge developed by past experiences of the innovation related formal decisional events. Through this systematic approach, product innovation process can be performed semi-automatically. We call this system as Smart Innovation Engineering (SIE) System (Waris et al. 2016a, b). Later in this article, we will show how the SIE system can be implemented using Set of Experience Knowledge Structure (SOE) and Decisional DNA (DDNA) for facilitating the product innovation process considering a “Screw Jack” as our case study.

Set of Experience Knowledge Structure and Decisional DNA

The SIE System is based on the Set of Experience Knowledge Structure (SOE) and Decisional DNA (DDNA), which were first presented by Sanin and Szczerbicki (2005a, b, 2008a). It is a Smart Knowledge Management System (SKMS) capable of storing formal decision events explicitly (Sanin and Szczerbicki 2007, 2008b and 2012, Sanchez et al 2013, Sanin et al 2012). Variables (V), functions (F), constraints (C) and rules (R) are the four basic components of the Set of Experience Knowledge Structure (Sanin and Szczerbicki 2005a). SOE comprises a series of 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).This decision support tool smartly captures and stores experiential knowledge and uses such experiences in decision-making when a similar query is presented. SKMS is motivated by Artificial Bio-inspired intelligent techniques that facilitates in solving the real World problems and provide knowledge-based solutions. It has enormous potential to enhance automation of decision making and problem solving for a number of diverse areas, creating unprecedented research opportunities in an extent of fields. SOE and DDNA have been applied successfully in various fields of application like virtual engineering processes, virtual engineering factory, industrial maintenance, semantic enhancement of virtual engineering applications, virtual organization, diagnosis of Alzheimer's disease by decision support medical system, banking activities involving periodic decision making and storing information, digital control system of the geothermal and renewable energy, e-decisional community, and smart interactive TV to name a few. More details can be find in Shafiq et al. (2014). Our research converges on the application of SOE in the development of systematic product innovation.

An SOE (formal decision event) is represented by a unique combination of variables, functions, constraints and rules. Groups of SOE of the same area are called chromosomes that represent a specific area within the organization and store decisional strategies for a particular category. Well organized and grouped sets of chromosome of the organization is collectively known as the Decisional DNA.

Smart Innovation Engineering System

The SIE system is a prominent tool to support the innovation processes in a quick and efficient way. It stores the experiential knowledge of the past decisional events related to product innovation in the form of sets of experience and uses such experiential knowledge in decision making. Manufacturing organizations and entrepreneurs can take improved decisions systematically and at an appropriate time by implementing the SIE system in the process of product innovation. The system gains more and more expertize with time as it stores data, relevant information and knowledge related to formal decision events. Every innovation process is based on some objectives that necessitate product innovation. Well defined and clearly stated innovative objectives triggers the product innovation process. These objectives are directly or indirectly linked to functions or features of the product that are ultimately technically attributed to one or more components of the product.

Bryant et al. (2007) presented a functionality-based methodology that clearly defines the systematic placements of components in the form of hierarchical ontology. In the work by Kurtoglu et al. (2005) a list of more than 100 distinct generically listed component terms are provided. We further extended this functionality-based hierarchy, so as to reach and select the required product fulfilling a particular function. Figure 1 shows this extended functional hierarchy that is used for selecting the Screw Jack model 2 which is selected as a product for our case study illustrating and explaining this approach. Screw Jack model 2 is further represented as a Virtual Engineering Object (VEO). The concept of VEO was presented by Shafiq et al. (2015a, b). VEO represents both the virtual and real world exemplification of manufactured products or components.

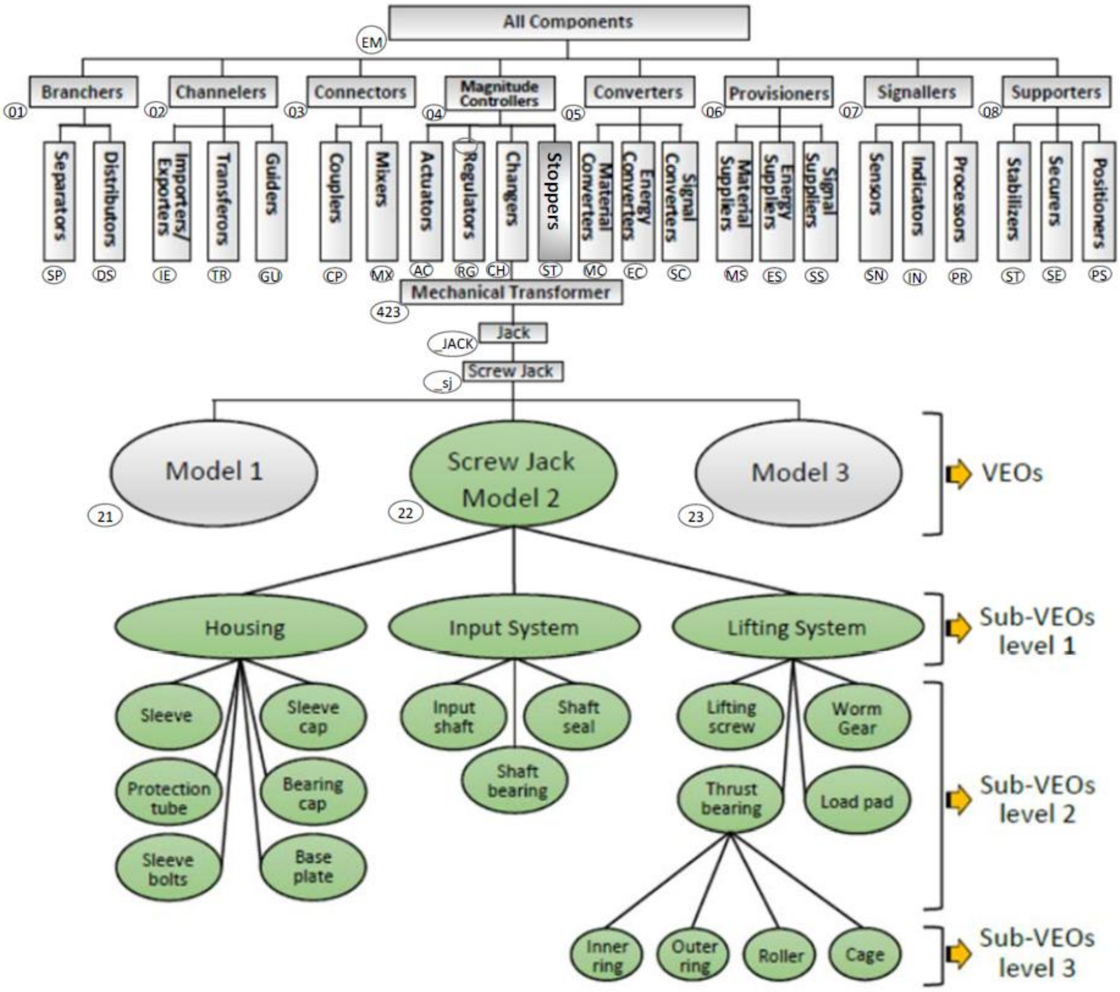

Figure 1. Functionality-based hierarchical structure and representation of a Screw Jack as VEO and sub-VEOs.

The decomposition of the product under consideration is structured as hierarchical nested parts as shown in Figure 1. This product (in this case the ScrewJack Model 2) is represented as a VEO and is further divided into number of sub-VEOs as subsystems representing/performing specific VEO features/functions that are represented as sub-

VEOs level 1 as shown in Figure 1. This decomposition of VEOs continues until we reach the basic component level. The same approach can be applied for selecting any required product on functionality basis.

Architecture of SIE-Decisional DNA

All the relevant information about the product is stored in eight modules that collectively represents SIE-DDNA architecture and is also linked with VEO-DDNA architecture (Figure 2). It is an efficient structure for representing the SOE based experiential knowledge and also has the capability to capture, add, improve, store, share as well as reuse this knowledge in decision making and enhancing the process of product innovation in a similar way as performed by group of experts or innovators. SIE-DDNA architecture contains all the relevant information, knowledge and experience about the product and its features.

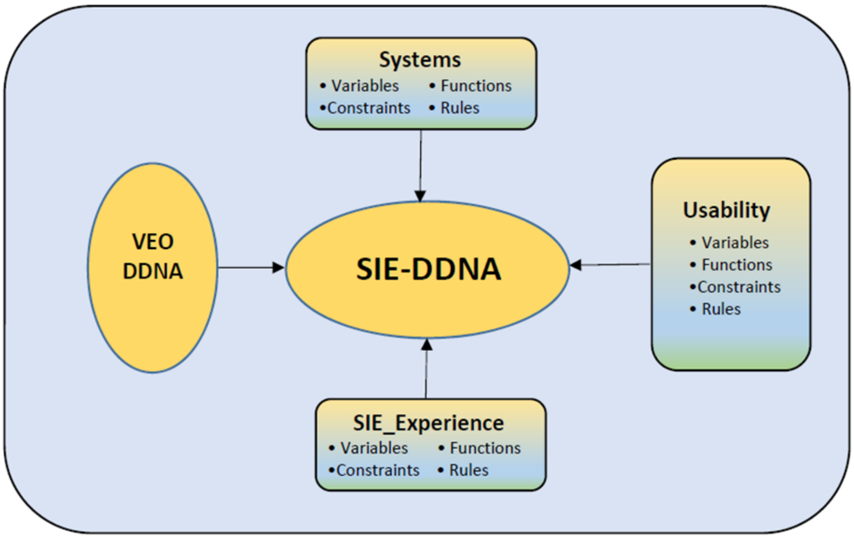

Figure 2. Architecture of a Product Innovation DDNA

There are eight basic modules of a SIE-DDNA structure. Five of these components (Characteristics, Requirements, Functionality, Connections and Present State) are contained in the VEO-DDNA (Shafiq et al. 2015a, b) that is linked to SIE-

DDNA. As these five modules hold the knowledge about the manufacturing scenario of the product, these are required only for the purpose of selecting relevant manufacturing process and better material for required quality. The other three modules (Systems, Usability, and Experience) are crucial components of the SIE system that can be easily realized from the details they contain as explained in the next paragraphs.

System module represents the knowledge about the relationships between various components (VEOs) at the same level or cross levels. This provides complete information about the logical relationships among the components and can be used to understand the genetic structure of the product including hierarchical decomposition and logical relationship of components. One set of variables inside the Systems module contains all the relevant information related to one component. Similarly there is a separate set of variables for each and every component of the product inside the System module. One such set of variables is described below:

C32_VEO_Name stores the commonly known technical name and type of the component number 32 of the product, e.g. 'ThrustBearing_Ball'. The common technical name is 'ThrustBearing', its type 'Ball' is separated and followed by underscore sign. This variable is used for tracing the application of this component in other similar products. *C32_VEO_CODE* stores the Code of the component, e.g. 'EM_08PS629_BRNG_bt31'. This variable is used for finding the position of the component in the functionality-based hierarchical decomposition table of all components. The first two alphabets 'EM' stands for all components (Electromechanical). Followed by underscore '_' is seven letter code '08PS629' which is 3 level functional decomposition of all electromechanical components (see Figure 1). After this an underscore followed by four letter code 'BRNG' is written that represents the general physical component 'Bearing'. Last letters 'bt31' represents the type of the bearing i.e. ‘ThrustBearing Model 31’. It should be clear at this point that this code for ThrustBearing represents it as complete Product (VEO) as a whole and not as a sub-component of ScrewJack. There should be no doubt here regarding this, for example a bolt is a sub-component of hundreds of products but its main identity is bolt which itself is a Virtual Engineering Object (VEO). More on this will be clear when we explain the Usability module. *C32_SupSys* stores the super system of the component inside this particular product (ScrewJack) e.g. super system for ‘ThrustBearing’ is ‘LiftingSystem’. *C32_SubSys* stores the VEO_Code of sub-systems (sub-components) of the component ThrustBearing. For example here VEO_Code for {InnerRing, OuterRing, Roller, and Cage} is stored. *C32_HLevel* stores the hierarchical level of the component inside this particular product e.g. here its value is 2 which indicates that ThrustBearing is at sub-system Level 2 inside the product ScrewJack Model 2. *C32_Qty* stores the number of pieces of this components used here. Similarly these variable are defined for each component of the product.

Apart from this, the System module also contains variables named System1, System2, etc. that stores the names of the main Systems inside the product (if present) that cannot be represented as a component (VEO) e.g. LiftingSystem. All these variables inside the System module can be used for obtaining the genetic structure of the product. This is the complete semantic representation of the product and all of its components. All the knowledge for each component can be obtained as all of them are linked to VEO_DDNA through Name and Code. Apart from this VEO-DDNA is regularly updated with new VEOs, advanced manufacturing processes and materials so that there is always optimal alternatives present for components for the product based on preferences and priorities.

Usability module represents the knowledge about the uses of a particular VEO in other products performing the same/similar function. This is very useful for calculating its performance in other products for calculating its specific/overall performance. Other information like which products have stopped using the given component, its recent applications in other products, and the effect of inclusion of this component on the performance, popularity, sales or price of the other products is also included in this module. *Usability* module is more useful when searching for alternative components (say ThrustBearing) that are used in various other products. It contains variable like veo1, veo2, etc. that basically contains the code of the product where this component is used so as to extract the required knowledge from that VEO.

Experience module represents the knowledge about the past innovation related events. Every formal decision related to the product innovation is stored in this module. This information is stored in these (see Figure 3) variables: *SIE_Obj* [1,2,…,n] which stores the innovation objectives that trigger the product innovation process e.g. Low Maintenance, Easy of Operation, Portability, etc. Based on these objectives, if some changes were done in the product that information is stored in three variables: *Rep_VEO* [1,2,…,m] that contains the list of components/VEOs replaced, *Inc_VEO* [1,2,…,p] that contains the list of VEOs included in the product in place of replaced VEOs, and the *Add_VEO* [1,2,…,q] that contains the list of new VEOs added (to add new function/feature in the product) to complete the innovation process. Apart from these, variable *SIE_PF* is also present in this module that represents the performance factor of this innovation decision and is updated later on based on the performance of the product after innovation process.

Outline view of SIE_Experience

- *SIE_Obj* [1,2,...,n]
- *Rep_VEO* [1,2,...,m]
- *Inc_VEO* [1,2,...,p]
- *Add_VEO* [1,2,...,q]
- *SIE_PF*

Figure 3. Typical variables inside SIE_Experience module.

Implementation of SIE System

Proper implementation of SIE System requires its integration with the Decisional DNA. Main components of SOE are Variables, Functions, Constraints and Rules. Moreover, as discussed in earlier sections the structure of SIE System includes modules like Characteristics, Requirements, Functionality, Connections, Present State, Systems, Usability and Experience. From each module of the SIE system Sets of Experience are created providing more scalable setting, similar to the one used for representing wide range of manufactured products. Sets of experience are generated having specific weightings for the variables of the product. Combination of all the individual Sets of experience are pooled under the SIE system that represents complete knowledge and experience necessary for supporting innovation process of manufactured products. The SIE System is semi-automatic as it presents an established number (say 5) of proposed solutions out of which user selects one solution that completes the product innovation process.

Design of a Test Case Study

The algorithm for the working of SIE system is shown in Figure 4. Associations of the product for our case study (ScrewJack) with VEO_DDNA, System module, Usability module and SIE_Experience module required for facilitating the SIE-based innovation process are presented in Figure 5.

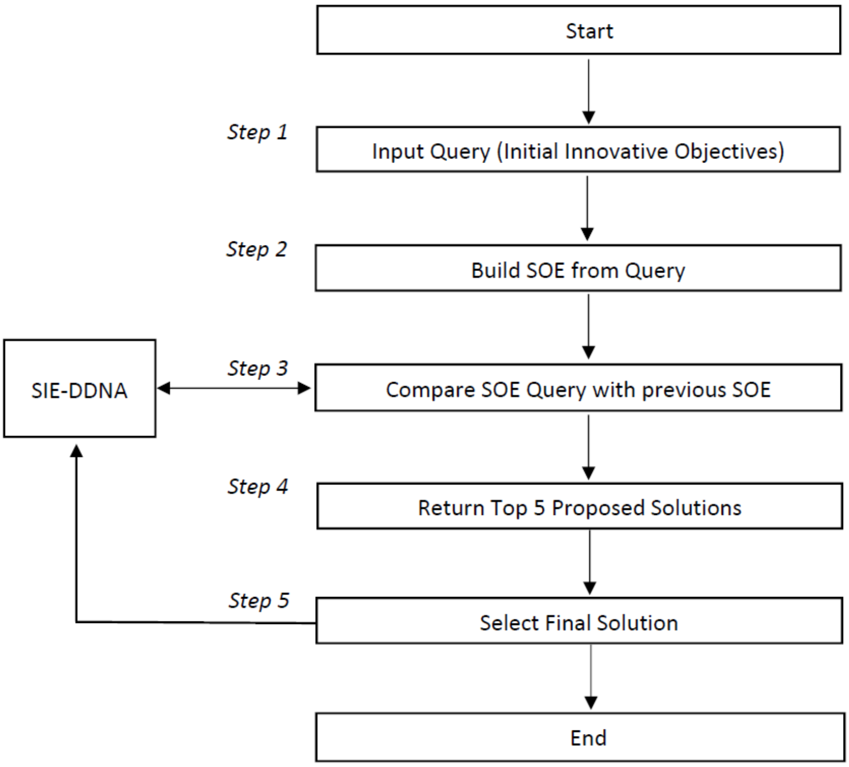

Figure 4. Algorithm of SIE system

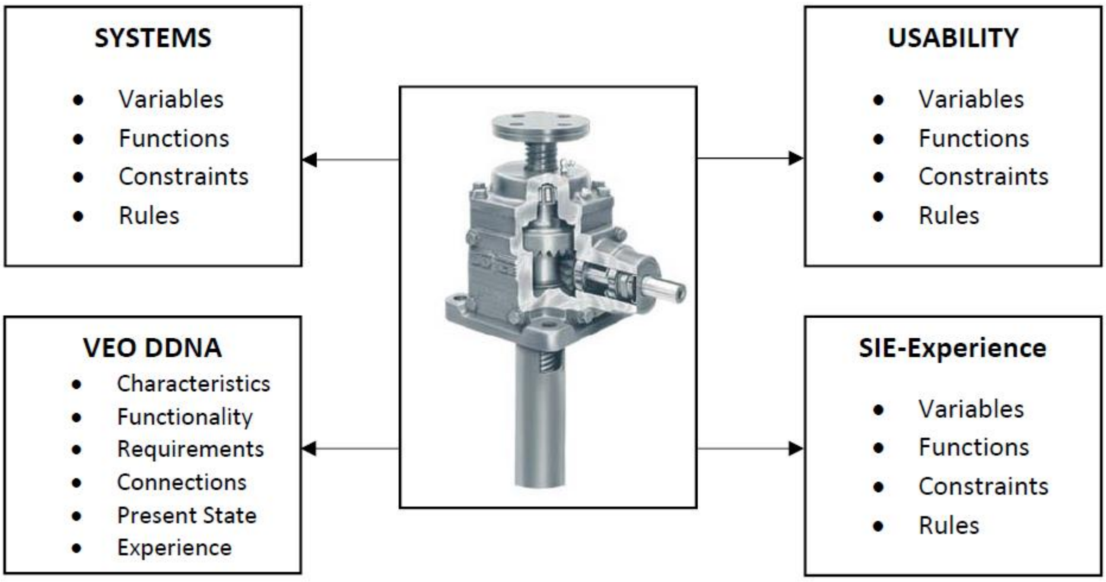

Figure 5. Associations of Screw Jack with SIE-DDNA

The steps in Figure 4 are briefly introduced next.

Step1 Input Query (based on Innovation Objectives): Innovation process is started by feeding the query into the SIE system. This query is basically in the form of list of some Innovation objectives and preferences. Let us consider for the present case study, the Innovation objectives to be Low maintenance, More Stability, and Ease of Operation.

Step2 Build SOE from Query: The above query based on Innovation objectives is converted to a SOE in which the variables, functions, constraints and rules are uniquely combined.

Step3 Compare SOE Query with previous SOE: this SOE query is compared with the similar previous SOE. This comparison is based on comparing Innovation objectives of the *Experience* module and variables from other modules. The input query is then compared with the previous SOE that are ranked according to the common Innovation Objectives and their Performance Factor (*SIE_PF*).

Step4 List of Proposed Solutions (for example top 5): Based on the decisions taken in the previous experiences of similar products and also considering performance factor of those decisions, the SIE system finds out the list of one or more components that may need to be replaced (*Rep_VEO*). The system then looks for the similar components in the VEO-DDNA considering preferences/constraints and assign these components as the probable alternative components (*Inc_VEO*) that may be included in the product in place of those components that need to be replaced. The system will also provide the additional component(s) (*Add_VEO*) that may probably be added to the product in order to include additional function/feature in the product. This additional component is proposed if there was some new innovation objective present in the query that need new component to fulfill it. The SIE system now generates the list of probable solutions in the form of sets of *Inc_VEOs* and *Add_VEO* based on weightages assigned to them and performance factor. The performance factor of these components is calculated on the basis of performance of each component in other similar products. Usability module of each component contain information about the products where it is used. This information is present in the form of variables *veo1*, *veo2*, *veo3*, etc. which stores the code of the component that is used to link it with the VEO_DDNA so that all the information and knowledge about them can be accessed and reused. For example the performance factor of the component 'ThrustBearing' of a particular model is calculated on the basis of its performance in other products where it is used as a component.

Step5 Final Solution: Final solution is selected from the list of proposed solutions by the user based on priorities to complete the process of product innovation. This final solution is then stored in the SIE-DDNA that can be used in future. The changes in the product are also updated in the *System* module that stores information about the genetic structure of the product.

In this way, the product innovation process of the manufactured products can be enhanced by using the semi-automatic Smart Innovation Engineering System. It will help in increasing the life of manufactured products.

Case Study

As stated earlier we select 'ScrewJack Model 2' as a product for our case study. Innovation objectives are 'EaseOfOperation' and 'MoreStability' along with preferences and set of Constraints. The main objective of this case study is to show that the product innovation process can be performed semi-automatically by using SIE System. We also demonstrate that how the experiential knowledge related to the formal decision events of innovation experiences of the similar products can be utilized in decision making. And finally, how the present innovation process is stored in the SIE

System so that it can be used in future when a similar query is presented. The code 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. For illustrative purposes part of CSV file for SIE_Experience is shown in Appendix 1. Similar CSV files were generated for other modules. 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’ (Appendix 1)

    For each column of this row

    Variable.Name(term) // Store each term as Name(Variable)

    Go to next row // second row after ‘Variables’ (Appendix 1)

    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 (see Table 1)
- User select the final solution
- QuerySIE updated and saved as a SOEKS in SIE-DDNA.

Table 1 Top 5 proposed solutions by SIE System

Components to be replaced		Components to be included	
Rep_VEO1	Rep_VEO2	Inc_VEO1	Inc_VEO2
EM_08PS629_SHFT_ds30	EM_08PS629_BRNG_bt33	EM_08PS629_SHFT_ds24	EM_08PS629_BRNG_bt20
EM_08PS629_SHFT_ds30	EM_08PS629_BRNG_bt30	EM_08PS629_SHFT_ds24	EM_08PS629_BRNG_bt35
EM_08PS629_SHFT_ds30	EM_08PS629_BRNG_bt30	EM_08PS629_SHFT_ds36	EM_08PS629_BRNG_bt35
EM_08PS629_SHFT_ds30	EM_08PS629_BRNG_bt30	EM_08PS629_SHFT_ds36	EM_08PS629_BRNG_bt20
EM_08PS629_SHFT_ds30	EM_08PS629_BRNG_bt30	EM_08PS629_SHFT_ds20	EM_08PS629_BRNG_bt35

Conclusion and Future Work

This study demonstrated the effective use of SIE System using Set of Experience Knowledge Structure and Decisional DNA for product innovation process. It is evident from the results of case study that this system is capable of enhancing the process of product innovation by proposing the set of possible solutions. Based on innovation objectives, the SIE system first looks for the component that need to be replaced; for this purpose it uses the innovation related experiential knowledge of the similar products. Then it finds the suitable replacement for that component (Virtual Engineering Object) in the VEO-DDNA according to priorities and constraints and presents the proposed solutions. The user then selects the final solution and this process is stored in the SIE-DDNA system as experiential knowledge that can be used in the future for solving a similar query. The SIE System behaves like a group of experts as it captures, stores, maintains and reuses the experiential knowledge of all the similar products. This expertise is ever increasing as every decision taken is stored in the system. Through this system entrepreneurs and manufacturing organizations are able to take proper and enhanced decisions related to product innovation problems at appropriate time.

Future work includes the extension of the SIE System to cover a wide range of manufactured products and its application for solving problems related to lean innovation and sustainable innovation. At the knowledge engineering level for SIE system we will address the issues related to possible knowledge inconsistence and experiental data replication (Nguyen 2005, Danilowicz and Nguyen 2000). Further, we will place the system in the context of Cyber Physical Systems (CPS) for Industry 4.0.

References

Bryant, C. R., R. B. Stone, J. L. Greer, D. A. McAdams, T. Kurtoglu, and M. I. Campbell. "A Function-Based Component Ontology for Systems Design." *International Conference on Engineering Design*. Paris, France, August 28-31, 2007.

Danilowicz, C., Nguyen N.T. (2000): Consensus-based methods for restoring consistency ofreplicated data. In: Klopotek et al. (eds), Advances in Soft Computing, Proceedings of 9thInternational Conference on Intelligent Information Systems'2000, Physica, 325-336.

Frishammar, J.: Managing information in new product development: A literature review. *International Journal of Innovation and Technology Management* 2(3) (2005): 259-275

Gan, L. "Globalization of the Automobile Industry in China: Dynamics and Barriers in Greening of the Road Transportation." *Energy Policy* 31 (6) (2003): 537–551.

Gunday, G., G. Ulusoy, K. Kilic, and L. Alpkan. "Effects of Innovation Types on Firm Performance." *International Journal of Production Economics* 133 (2) (2011): 662–676.

Jayanth Jayarama, Adegoke Okeb and Daniel Prajogo. "The antecedents and consequences of product and process innovation strategy implementation in Australian manufacturing firms." *International Journal of Production Research* 52(15) (2014): 4424–4439.

Kurtoglu, T., M. I. Campbell, C. R. Bryant, R. B. Stone, and D. A. McAdams. "Deriving a Component Basis for Computational Functional Synthesis." *Proceedings of the International Conference on Engineering Design*, Melbourne, Australia, August 15-18, 2005.

Nguyen N.T. (2005): Processing Inconsistency of Knowledge on Semantic Level. Journalof Universal Computer Science 11(2), 285-302.

Nussbaum, B. "Hot products." *Business Week*. June 7 (1993): 54–7.

OECD. "The Measurement of Scientific and Technological Activities: Guidelines for Collecting and Interpreting Innovation Data" *Oslo Manual*. 3rd ed. Paris: Working Party of National Experts on Scientific and Technology Indicators, OECD (2005): para. 156.

Osborne, D. J. "Ergonomics at work." New York: *John Wiley & Sons, Inc*. (1987).

O'Sullivan, D., L. Dooley. *Applying Innovation*. Sage Publications, (2008).

Paladino, A. “Investigating the Drivers of Innovation and New Product Success: A Comparison of Strategic Orientations.” *Journal of Product Innovation Management* 24 (6) (2007): 534–553.

Roberta Capello. “Knowledge, Innovation, and Regional Performance: Toward Smart Innovation Policies: Introductory Remarks to the Special Issue.” *Growth and Change* Vol. 44 No. 2 (June 2013), pp. 185–194

Sanchez,E., C. Toro, A. Artetxe, M Grana, C Sanin, E Szczerbicki, E. Carrasco, F. Guijarro, Bridging challenges of Clinical Decision Support System with a semantic approach. A case study on breast cancer. Pattern Recognition Letters, 2013, Vol. 34, pp. 1758-1768.

Sanin C, Leonardo Mancilla-Amaya, Zhang H., E Szczerbicki, Decisional DNA: the Concept and its Implementation Platforms, *Cybernetics and Systems: An International Journal* 2012 Vol 43, No 2, pp 67-80.

Sanin, C., and E. Szczerbicki. “A Complete Example of Set of Experience Knowledge Structure in XML.” *In: A. Szuwarzynski. (eds.) Knowledge Management: Selected Issues.* Gdansk University Press, Gdansk, Poland (2005a): 99-112.

Sanin, C., and E. Szczerbicki. “Set of Experience: A Knowledge Structure for Formal Decision Events.” *Foundations of Control and Management Sciences* 3 (2005b): 95-113.

Sanin, C., and E. Szczerbicki. “Towards the Construction of Decisional DNA: A Set of Experience Knowledge Structure Java Class within an Ontology System.” *Cybernetics and Systems* 38(2007): 859-78.

Sanin, C., and E. Szczerbicki. “Decisional DNA and the Smart Knowledge Management System: A Process of Transforming Information into Knowledge.” *In: Gunasekaran, A. (eds.) Techniques and Tool for the Design and Implementation of Enterprise Information Systems*. New York, USA (2008a): 149-75.

Sanin, C., and E. Szczerbicki. “Towards Decisional DNA: Developing a Holistic Set of Experience Knowledge Structure.” *Foundation of Control and Management Science* 9 (2008b): 109-22.

Sanin, C., C. Toro, Z. Haoxi, E. Sanchez, E. SzczerbickiE. Carrasco, W. Peng, and L. Mancilla-Amaya. “Decisional DNA: A Multi-Technology Shareable Knowledge Structure for Decisional Experience.” *Neurocomputing* 88 (2012): 42-53.

Shafiq, S. I., C. Sanin, and E. Szczerbicki. "Set of Experience Knowledge Structure (SOEKS) and Decisional DNA (DDNA): Past, Present and Future." *Cybernetics and Systems* 45(2) (2014): 200-15.

Shafiq, S. I., C. Sanin, E. Szczerbicki, and C. Toro. "Virtual Engineering Objects / Virtual Engineering Processes: A specialized Form of Cyber Physical Systems and Industry 4.0." *Procedia Computer Science* 60 (2015a): 1146-55.

Shafiq, S. I., C. Sanin, C. Toro, and E. Szczerbicki. "Virtual engineering (VEO): Towards Experience-Based Design and Manufacturing for Industry 4.0." *Cybernetics and Systems* 46 (2015b): 35-50.

Smith, P. G. and D. G. Reinertsen. "Developing Products in Half the Time" 2nd edn. *John Wiley and Sons* (1998)

Tao, L., E. Garnsey, D. Probert, and T. Ridgman. "Innovation as Response to Emissions Legislation: Revisiting the Automotive Catalytic Converter at Johnson Matthey." *R&D Management* 40 (2) (2010): 154–168.

Toro, C., E. Sanchez, E. Carrasco, L. Mancilla, C. Sanin, E. Szczerbicki, M. Grana, P. Bonachela, C. Parra, G. Bueno, and F. Guijarro. Using Set of Experience Knowledge Structure to Extend a Rule Set of Clinical Decision Support System for Alzheimer Disease Diagnosis, *Cybernetics and Systems: An International Journal* 43(2) (2012): 81-95.

Vega-Jurado, J., A. Gutiérrez-Gracia, I. Fernández-de-Lucio, and L. Manjarrés-Henríquez. "The Effect of External and Internal Factors on Firms' Product Innovation." *Research Policy* 37 (4) (2008): 616–632.

Waris, M. M., C. Sanin, and E. Szczerbicki. "Smart Innovation Management in Product Life Cycle", in *Information Systems Architecture and Technology: Proceedings of 36th International Conference on Information Systems Architecture and Technology – ISAT 2015*, Wilimowska, Z., Borzemski, L., Grzech, A., Świątek, J. (Eds.), Springer series: Advances in Intellignet Systems and Computing, Vol. 432.

Waris, M. M., C. Sanin, E. Szczerbicki. "Framework for Product Innovation Using SOEKS and Decisional DNA", In Ngoc Thanh Nguyen, Bogdan Trawinski, Hamido Fujita and Tzung-Pei Hong (Eds.): *Intelligent Information and Database Systems. ACIIDS* 2016, Part I, LNAI 9621 (2016a): 1-10

Waris, M. M., C. Sanin, E. Szczerbicki. "Toward Smart Innovation Engineering: Decisional DNA-Based Conceptual Approach." *Cybernetics and Systems*. 47:1-2 (2016b): 149-159

Yannou, B., M. Bigand, T. Gidel, C. Merlo, J.-P. Vaudelin, Collectif, Laconception industrielle de produits : Volume 1, Management des hommes, des projets et des informations. Hermes Science Publications. 2008.

Appendix 1 CSV file component for SIE_Experience

Variables

PrNo	VEO_Code	VEO_Name	SIE_Obj1	SIE_Obj2	Rep_VEO1	Rep_VEO2	Inc_VEO1	Inc_VEO2	Add_VEO1	SIE_PF	Date
1	EM_04CH423_JACK_sj22	ScrewJack_WormGear	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt320			5	30/06/2012
2	EM_04CH423_JACK_sj24	ScrewJack_WormGear	LowMaintenance	MoreStability	EM_08PS629_BRNG_bt33	EM_08PS629_LPAD_bt31	EM_08PS629_BRNG_bt35	EM_08PS629_LPAD_bt51		5	12/06/2012
3	EM_04CH423_JACK_sj33	ScrewJack_WormGear	MoreStability	EaseOfOperation	EM_08PS629_BRNG_bt20		EM_08PS629_BRNG_bt22			3	2/06/2012
4	EM_04CH423_JACK_sj42	ScrewJack_WormGear	MoreStability	EaseOfOperation	EM_08PS629_BRNG_bt35		EM_08PS629_BRNG_bt33			4	13/06/2012
5	EM_08PS629_BRNG_bt30	ThrustBearing_Ball	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds34			7	17/06/2012
6	EM_08PS629_BRNG_bt33	ThrustBearing_Ball	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds36	EM_08PS629_LPAD_cg31	EM_08PS629_SHFT_ds32	EM_08PS629_LPAD_cg35		2	4/06/2012
7	EM_08PS629_BRNG_bt20	ThrustBearing_Ball	EaseOfOperation	LowMaintenance	EM_08PS629_SHFT_ds20		EM_08PS629_SHFT_ds30			8	8/06/2012
8	EM_08PS629_BRNG_bt35	ThrustBearing_Ball	EaseOfOperation	LowMaintenance	EM_08PS629_SHFT_ds30	EM_08PS629_BCAP_jd52	EM_08PS629_SHFT_ds23	EM_08PS629_BCAP_jd50		9	14/06/2012
9	EM_08PS629_SHFT_ds30	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds12		EM_08PS629_SHFT_ds14			4	6/06/2012
10	EM_08PS629_SHFT_ds36	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds30	EM_08PS629_BCAP_hk01	EM_08PS629_SHFT_ds23	EM_08PS629_BCAP_hk32		2	3/06/2012
11	EM_08PS629_SHFT_ds20	Shaft	EaseOfOperation	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds32			4	11/06/2012
12	EM_08PS629_SHFT_ds30	Shaft	EaseOfOperation	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds32			6	9/06/2012
13	EM_08PS629_SHFT_ds12	Shaft	LowMaintenance	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds37			8	5/06/2012
14	EM_08PS629_SHFT_ds30	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt33			6	26/06/2012
15	EM_08PS629_SHFT_ds30	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt320			3	28/06/2012
16	EM_08PS629_SHFT_ds30	Shaft	EaseOfOperation	MoreStability	EM_08PS629_BASE_pd41		EM_08PS629_BASE_pd42			6	1/06/2012
17	EM_08PS629_SHFT_ds30	Shaft	EaseOfOperation	MoreStability	EM_08PS629_BASE_pd43		EM_08PS629_BASE_pd41			4	7/06/2012
18	EM_08PS629_BRNG_bt30	ThrustBearing_Ball	EaseOfOperation	LowMaintenance	EM_08PS629_BASE_pd22		EM_08PS629_BASE_pd25			4	22/06/2012
19	EM_08PS629_BRNG_bt30	ThrustBearing_Ball	EaseOfOperation	LowMaintenance	EM_08PS629_BASE_pd13		EM_08PS629_BASE_pd23			6	15/06/2012
20	EM_08PS629_BASE_pd41	BasePlate	EaseOfOperation	MoreStability	EM_08PS629_BASE_pd41		EM_08PS629_BASE_pd45			8	20/06/2012
21	EM_08PS629_BASE_pd43	BasePlate	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt320			7	30/06/2012
22	EM_08PS629_BASE_pd22	BasePlate	LowMaintenance	MoreStability	EM_08PS629_BRNG_bt33	EM_08PS629_LPAD_bt31	EM_08PS629_BRNG_bt35	EM_08PS629_LPAD_bt51		5	12/06/2012
23	EM_08PS629_BASE_pd13	BasePlate	MoreStability	EaseOfOperation	EM_08PS629_BRNG_bt20		EM_08PS629_BRNG_bt22			8	2/06/2012
24	EM_08PS629_BASE_pd41	BasePlate	MoreStability	EaseOfOperation	EM_08PS629_BRNG_bt35		EM_08PS629_BRNG_bt33			6	13/06/2012
25	EM_08PS629_LPAD_bt31	LoadPad	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds34			4	17/06/2012
26	EM_08PS629_LPAD_cg31	LoadPad	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds36	EM_08PS629_LPAD_cg31	EM_08PS629_SHFT_ds32	EM_08PS629_LPAD_cg35		9	4/06/2012
27	EM_08PS629_BCAP_jd52	BearingCap	EaseOfOperation	LowMaintenance	EM_08PS629_SHFT_ds20		EM_08PS629_SHFT_ds30			6	8/06/2012
28	EM_08PS629_BCAP_hk01	BearingCap	EaseOfOperation	LowMaintenance	EM_08PS629_SHFT_ds30	EM_08PS629_BCAP_jd52	EM_08PS629_SHFT_ds23	EM_08PS629_BCAP_jd50		4	14/06/2012
29	EM_08PS629_BRNG_bt320	ThrustBearing_Ball	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds12		EM_08PS629_SHFT_ds14			6	6/06/2012
30	EM_08PS629_BRNG_bt35	ThrustBearing_Ball	LowMaintenance	EaseOfOperation	EM_08PS629_SHFT_ds30	EM_08PS629_BCAP_hk01	EM_08PS629_SHFT_ds23	EM_08PS629_BCAP_hk32		7	3/06/2012
31	EM_08PS629_BRNG_bt22	ThrustBearing_Ball	EaseOfOperation	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds32			9	11/06/2012
32	EM_08PS629_BRNG_bt33	ThrustBearing_Ball	EaseOfOperation	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds32			5	9/06/2012
33	EM_08PS629_SHFT_ds34	Shaft	LowMaintenance	MoreStability	EM_08PS629_SHFT_ds30		EM_08PS629_SHFT_ds37			8	5/06/2012
34	EM_08PS629_SHFT_ds32	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt33			4	26/06/2012
35	EM_08PS629_SHFT_ds30	Shaft	LowMaintenance	EaseOfOperation	EM_08PS629_BRNG_bt30		EM_08PS629_BRNG_bt320			7	28/06/2012
36	EM_08PS629_SHFT_ds23	Shaft	EaseOfOperation	MoreStability	EM_08PS629_BASE_pd41		EM_08PS629_BASE_pd42			5	1/06/2012
37	EM_08PS629_SHFT_ds14	Shaft	EaseOfOperation	MoreStability	EM_08PS629_BASE_pd43		EM_08PS629_BASE_pd41			8	7/06/2012