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Establishing Intelligent Enterprise through Community of Practice for Product Innovation

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Abstract. This paper presents the idea of implementing the virtual Community of Practice for Product Innovation processes towards the establishment of intelligent enterprise. Since the fourth industrial revolution is passing through the developing phase, implementation of Cyber-Physical Production Systems require more realistic approach. Knowledge Management and Engineering plays an important role in manufacturing industries facing global competition. One of the most promising areas where Knowledge Management is studied and applied is product innovation. This paper explains the efficient and systematic methodology for Knowledge Management through Community of Practice for product innovation. Manufacturing industries can connect with similar industries at global level, sharing and using technical and experiential knowledge in decision making thus converting them into intelligent enterprises.

Keywords: Smart Innovation Engineering, Product Innovation, Set of Experience, Community of Practice, Industry 4.0.

1. Introduction

This paper is an extended version of our paper presented at ACIIDS conference titled " Community of Practice for Product Innovation: Towards the Establishment of Industry 4.0" [1]. The new extended additions to the conference paper include: detailed case study procedure through user-friendly Graphical User Interface, results in graphical and tabular for screw jack as a case study with input query based on innovation objectives, and potential benefits of SIE system as a Community of Practice for product innovation among intelligent enterprises.

Intelligent enterprises of the future need to focus on knowledge-based systems and use them to update the manufacturing units that produce smart products. These products contain comprehensive knowledge related to manufacturing and design/innovation attached to them. Product Innovation (PI) process collects, stores, and reuses knowledge at different stages in a series of knowledge related activities. Knowledge Management (KM) has become the only sustainable competitive advantage for manufacturing enterprises in the present competitive and turbulent environment [2], and PI is a continuous learning process rather that a sporadic event. These enterprises are also facing continuous market changes and need to develop customized products considering short product life cycles [3]. Proper KM therefore plays an important role in PI. The fourth industrial revolution, originally initiated in Germany as Industry 4.0, has attracted much attention in recent times. It is closely related with Cyber-Physical Production System (CPPS), Internet of Things (IoT), Information and Communication Technology (ICT) and Enterprise Integration (EI). Knowledge Engineering

(KE) and KM are important role players in CPPS. The concept of Smart Innovation Engineering (SIE) system proposed by Waris et al is a semi-automatic tool for facilitating PI process [4, 5]. The SIE system uses a collective, team-like knowledge developed by technical knowledge of the products, latest technical advancements and past experiences of the innovation-related formal decisional events. The goal of this paper is to show how SIE system finds application in forming the virtual Community of Practice (CoP) formed by global group of manufacturing organizations in dealing with the issues of PI process and that will indeed be a substantial step towards the establishment of intelligent enterprises of Industry 4.0.

In the context of manufactured products, product innovation is defined as the process of making required changes to the already established product by introducing something new that adds value to users, and also providing expert knowledge that can be stored in the enterprise [6]. Key tasks for product innovation process adding new functions/features to the products, analyzing and finding better components, new materials, and advanced technologies. Moreover, the establishment of cross-functional, multidisciplinary teams was found to be vital to the success of innovation projects [7] within an enterprise. The SIE system can initially be used in a manufacturing enterprise which enhances the enterprise intelligence. However, it can certainly be extended for connecting a network of intelligent enterprises around the globe.

2. Background

This section presents the brief discussion about the concepts of KM, Industry 4.0 and CoP that helps in understanding their integration towards the establishment of Industry 4.0.

2.1. Knowledge Management

Due to the fact that manufacturing enterprises need to practice innovation process frequently and knowledge plays a critical role in it, they need to manage knowledge effectively within and across their organizational borders [2]. The main aim of KM is identify, store and using knowledge for the benefit of organization. The practitioners of KM need to involve in proper knowledge processing so as to make it accessible to enterprises. This will allow the people to share useful information, thus, helping them to improve the performance of their enterprise. [8]. Enterprises can manage their knowledge in different scenarios by using various technologies of KM [9]. Similar to other technologies, KM technologies also have some limitations. Many of them are limited to be used for the particular class of products, and their representation is not in a standard form.

One of the most important attribute of knowledge is its representation in such a way that it can be understood and shared by its users [10]. If not represented properly, knowledge becomes inconsistent, unstable, and unreliable in nature. On the other hand, its proper representation leads to the creation of artificial knowledge in an explicit manner that contributes to emphasize Artificial Intelligence (AI) [11]. This initial idea of KM, based on mechanistic point of view, is used for the development of AI. Earlier, KE was not considered as a branch of engineering. To solve complex problems, human experts need to feed and integrate knowledge into computer systems [12].

Interaction among the members of Communities of Practice (CoPs) on an ongoing basis deepen their knowledge and increases their expertise in concerned area. Use of technology is essentially very important in large CoPs [13], possibly with the support of KMS applications. Moreover, human-oriented CoPs have some drawbacks such as trust, lack of openness, power conflicts among members, and emotional effects that are critical aspects and may result in its failure. Organization's knowledge strategy is one of the main element that can be effectively used for managing knowledge as a resource and results in competitive advantage of organization [14]. The knowledge strategy is strictly associated with the competitive strategy of enterprises defines aims and tools of CoPs [15].

2.2. Industry 4.0

With the aim to strengthen the manufacturing industries, representatives from various backgrounds in Germany promoted the concept of Industry 4.0 in 2011 [16]. The aim of Industry 4.0 is to collectively use autonomous systems like CPS, ICT and AI industries in order to make them more intelligent, self-organizing, and dynamic [17]. This will lead to advanced industries equipped with smart products and intelligent machines. The expected results include self-optimized and highly automated equipment, production of customized and complex products involving higher standards of manufacturing [17]. Thus, important goals of Industry 4.0 includes smart manufacturing and developing smart factories [18].

Product customization also plays an important role nowadays. Customization resulting from the preferences and demands of users tends to be one more variable in the manufacturing process, and smart industries need to practice innovation continuously in order to the manufacture products based on user preferences [19]. In fact, use of experience-based knowledge is one of the main characteristics of Industry 4.0 to support the integration and virtualization of product design/innovation and production process using KBS to manufacture smart products. This will allow the manufacturing organizations to launch the innovated products with the objectives to meet the growing needs of the users and fulfilling their expectations. The use of SIE system in manufacturing enterprises seems to be promising in this scenario. It will also help in handling the continuous flow of new projects in the enterprise involving product innovation resulting from shorter lifecycle of products. Therefore implementation of SIE system in enterprises is a concept that will transform them into intelligent enterprises having a well-defined network of intelligent machines, smart products, systems and processes creating real world virtualization into a huge knowledge engineering system. Potential benefits of Industry 4.0 are flexibility, reduced lead times, reduced costs, and customization of products.

2.3. Community of Practice

In simple words, Community of Practice is defined as a continuous interaction of its members to share their knowledge, expertise and experiences at a common platform and use it to enhance their expertise in order to solve the problems systematically [20, 21]. Considering the substantial role of technology in the present world, more focus is obvious on a specific type of CoP, i.e. virtual CoP [22]. Use of information and communication technology allows them to interact and communicate digitally. Such a CoP in which members interact with each other without any physical presence, is called virtual CoP [20, 22].

There are three fundamental elements or characteristics that distinguishes a community in general from CoP [21]. These fundamental characteristics are domain, community, and practice [20] that are briefly described below.

2.3.1. Domain

Domain is the predefined and specific area of knowledge that defines nature of experiences and issues addressed by the members of CoP. It provides a common platform for sharing the experience-based knowledge among the members of CoP and is very useful in differentiating members from non-members [23]. The domain sets the limits to the area of knowledge explored and developed by its members in order to define their identity [24].

2.3.2. Community

Community is a knowledge structure that effectively establishes a conductive learning environment through systematic interaction and building relationships among members of CoP [20]. In addition to knowledge sharing and practice, the important function of CoP is to build relationships among members on important issues within their well-defined domain. To build a CoP, members must interact continuously, members who interact occasionally to discuss a particular task or topic do not constitute a CoP [20].

2.3.3. Practice

Practice is collection of resources shared by the members of the CoP that include experience-based knowledge, systematic solutions and techniques to the problems [20]. Members of a CoP are collect, store and develop these sharable resources. In other words, the practice is the knowledge within a specific domain owned, developed, and shared among the members of a specific CoP [21]. Thus, practice is a systematic way of acquiring knowledge by a well-defined group of members [25-27].

From the above discussion on essential characteristics, it is clear that CoP focuses on a specific domain, and its members interact around a common platform of knowledge to own, store, develop their practice in finding the best possible solutions to problems based on real experiences.

Knowledge is a valuable asset for the growth of any organization and its sustenance in a highly competitive environment [28]. In the present increasingly dynamic environments and sheer competition among similar enterprises, proper knowledge management has become an essential requirement for survival for enterprises, especially as the world is moving towards the Industry 4.0. In most cases, an enterprise does not possess all the knowledge required for its functioning within its boundaries. It is often required to look outside to compensate for the lacking knowledge [29-31]. Creating links with external knowledge resources is one of the best way to acquire knowledge and look for new ways in addressing the problems faced, such as CoPs or networks of practice [31-33]. Creating CoPs helps its member enterprises in maintaining competitive advantage. Thus, CoP could be systematically used for preserving experience-based knowledge because it allows the retention of knowledge and technical skills about technology and plays an important role to avoid its loss over time.

The current practice shows that CoPs are considered key components of systematic and deliberate KM strategies in modern enterprises [34]. So, the primary function of CoP is to promote knowledge sharing in order to improve the overall performance of the enterprises [35]. The performance can be improved at the individual, group, and organizational level by enhancing employees' working experience, reducing the learning curve, accumulating professional talents for the enterprises, and avoiding overlapping investment on research and development of new products and services [36, 37].

3. Smart Innovation Engineering System

The importance of the aforementioned aspects creates the necessity for systems that collectively work together for intelligent enterprises of Industry 4.0. One such system is SIE system developed by Waris [4, 5, 38]. The SIE system facilitates the product innovation processes and is a prominent tool to perform it quickly and efficiently. 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 [39]. It is a Smart Knowledge Management System (SKMS) used for explicitly storing past decisional events [39, 40]. The architecture of SIE system is surrounded by three main modules, these are: Systems, Usability, and SIE_Experience [5, 38].

To avoid any error, the query based on innovation objectives is entered into the SIE System through a user-friendly Graphical User Interphase (GUI) as shown in Figure 1. This user-friendly GUI allows the user (entrepreneur/innovator or any other authorized person of an enterprise) to interact with SIE System [38]. The user first selects the product undergoing innovation process from the 'Select Product Name' drop-down menu list. In this case study, the product is worm gear type screw jack. The user then adds the selected product to the query by clicking the 'Add Product Name' button, then selects the innovation objective required for innovation of worm gear type screw jack from the 'Select Innovation Objectives' drop-down menu list. After the user selects the first innovation objective and clicks the 'Add Innovation Objective' button, the selected innovation objective (low maintenance) is added to the query and displayed in the text-field as shown in Figure 1. Similarly, user can define more innovation objectives (more stability, in this case study) and add to the query [38].

The user then defines the variables by selecting the variable from the 'Select Variable' drop-down menu list (under 'Define other Variables' label), type/assign the value of the variable in the text box next to 'Enter Value' label and clicks on the 'Add Variable' button to add the variable with the corresponding value to the query. In this way, user defines multiple variables with their values and adds them to the query and is also able to see the complete query in the text-field before execution to avoid any error [38]. If any error occurs during defining the query, it can be redefined correctly by pressing the "Refresh" button.

The SIE system converts the query based on innovation objectives into SOE and compares it with the similar Sets of Experience. SIE system converts the information saved in Comma Separated Values (CSV) files into sets of experience for each module containing complete information about the product [38]. The CSV files contain data in standard format enabling the parser to collect information without any error and as per requirement. The SIE System provides a list of proposed solutions (say five) that is displaced in the GUI letting the user know what changes were made in the past for product innovation in similar cases. The user then searches for the best replacement for the component from the current SIE related DDNA (SIE-DDNA) repository. This allows the user (innovator or entrepreneur) to select the best possible solution out of the proposed list. Further enhancement to the proposed solutions can also be done if required. The changes made to the product are saved, in a standard format, in the CSV file. This selected final solution (new version of the product with changes) is stored in the SIE System as a new SOE that can be used further when a similar query is presented in future [38, 41]. In this way, the SIE System is a semi-automatic system that facilitates the process of Product Innovation. The SIE System gains experience with each decision taken that increases its expertise and behaves as an expert working over long time in its domain [42](Waris, Sanin, and Szczerbicki 2018).

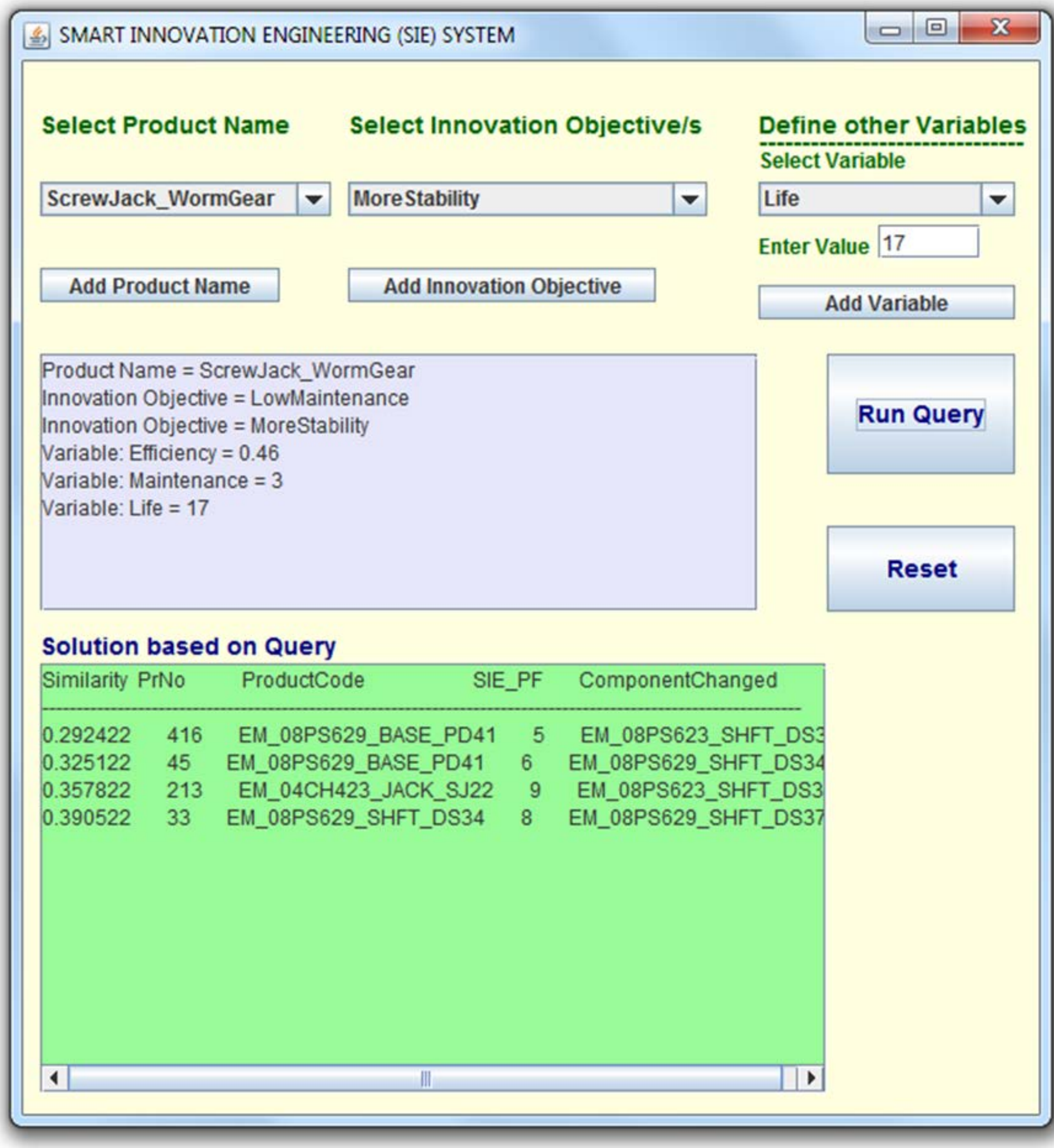

Fig. 1. User-friendly GUI for Smart Innovation Engineering System.

SIE system has the potential to play an important role towards the establishment of smart industries of upcoming Industry 4.0. These industries, manufacturing similar products, can share information among themselves. It is an expert system that can facilitate CPPS and it can be used by large enterprises or groups of small-medium enterprises (SMEs).

For testing the working of SIE system, the sample query is obtained from a repository of 486 SOEs from all modules involved in SIE system. The user first selects the product undergoing innovation process from the 'Select Product Name' drop-down menu list, then selects innovation objectives from the 'Select Innovation Objectives' drop-down menu list. The user then defines variables and their values by selecting them from the 'Select Variable' drop-down menu list. Once the query is built, the user then executes the query by clicking the button ‘Run Query’. The top 5 best matches are returned and displayed in the text-field below the label ‘Solution based on query’ as shown in Figure 1.

The similarity of the input query computed for each of the 486 SOE within the SIE-DDNA is shown in Figure 2. The value of similarity varies from zero to one, with zero being identical and one meaning no similarity at all. Once the similarity for each SOE is calculated, the top similar SOEs are sorted and stored.

The five most similar SOEs for all of the queries along with their similarities, performance factor, and total time taken for execution are displaced in Table 1. Consider Query 2, the similarity is calculated when the Product is ‘Screw Jack’, the innovation objectives are ‘Ease of operation’ and ‘Low Maintenance’ with variables: Efficiency = 0.47, Lubrication = SELF, Life = 16 and SIE_PF = 6. After execution, SIE system returns the five most similar SOEs. These are products with their product numbers (PrNo) 107, 266, 56, 479 and 457, with similarities 0.389286, 0.389562, 0.391558, 0.392331 and 0.392331 respectively, and execution time equal to 0.017533 seconds. The execution time can be considered as excellent for this kind of querying process.

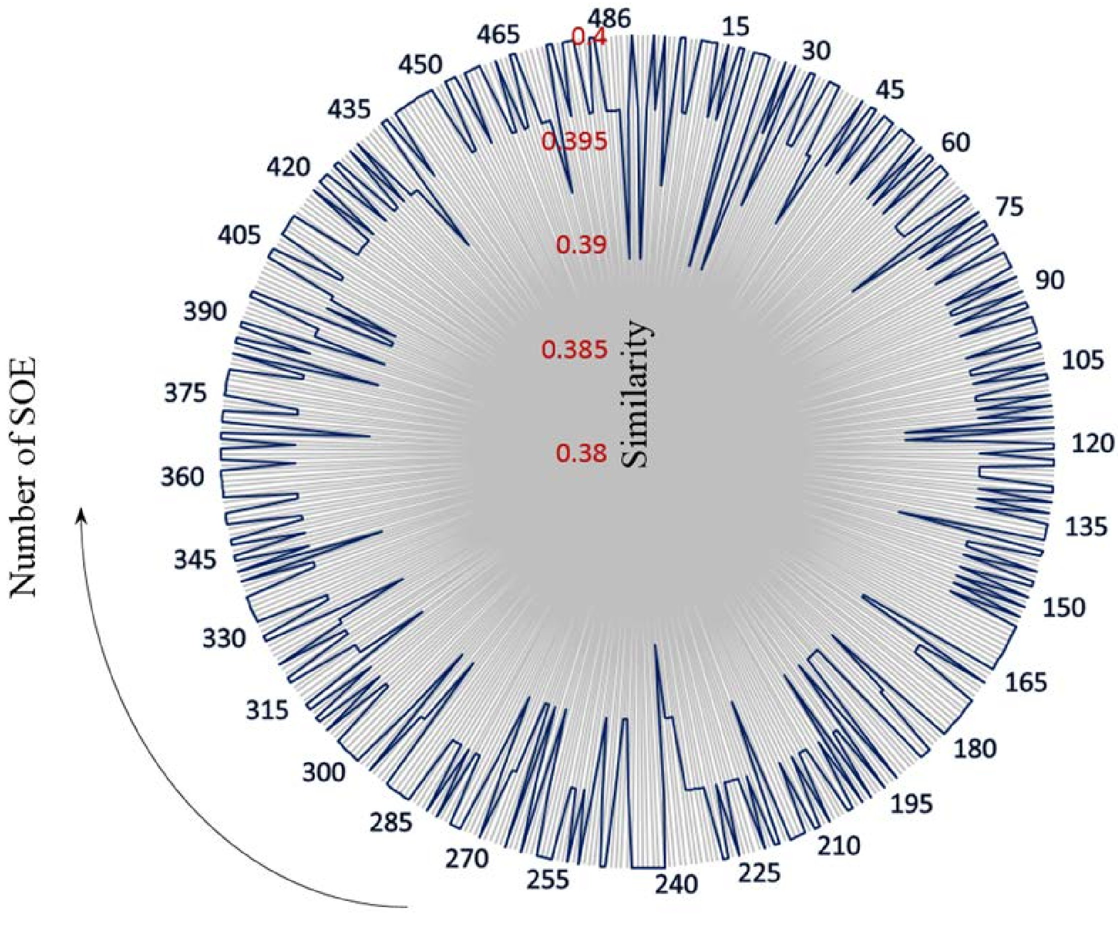

Fig. 2. Similarity between input query and each previous SOE stored in SIE-DDNA.

Table 1
Output solution to random queries based on innovation objectives for case study

Query No.	Input				Output			
	Product	Innovation Objectives	Variables	Value of Variables	Top 5 SOE	Similarity (Top 5 SOE)	SIE _PF	Time taken
1	ScrewJack	EaseOfOperation MoreStability	Efficiency	0.45	39	0.389286	5	0.015395
			Lubrication	YES	263	0.389286	5	
			Life	14	319	0.389562	6	
			SIE_PF	8	4	0.390854	9	
					109	0.392857	9	
2	ScrewJack	EaseOfOperation MoreStability	Efficiency	0.47	107	0.389286	9	0.017533
			Lubrication	SELF	266	0.389562	7	
			Life	16	56	0.391558	7	
			SIE_PF	6	479	0.392331	7	
					457	0.392331	9	
3	ScrewJack	EaseOfOperation MoreStability	Efficiency	0.45	4	0.389286	9	0.014968
			Lubrication	YES	425	0.389286	4	
			Life	17	263	0.392857	5	
			SIE_PF	5	319	0.392857	6	
					109	0.392857	9	
4	ScrewJack	EaseOfOperation MoreStability	Efficiency	0.47	266	0.389542	7	0.015823
			Lubrication	NO	56	0.389542	7	
			Life	19	155	0.392857	5	
			SIE_PF	7	196	0.393120	3	
					43	0.393120	8	

4. SIE System as a Community of Practice for Intelligent Enterprises

In this section, we will try to explain how the SIE system itself can be used as a CoP for PI by the means of virtual connection of manufacturing enterprises at a common platform (i.e. SIE system). The cognitive role of a CoP is focused on the knowledge transfer process. Some central elements must be considered here, for instance, what kind of knowledge is to be exchanged, the nature of the shared knowledge, what procedures and tools are to be used, and for what purpose. The value of CoPs for a given enterprise becomes more significant in a long-term perspective. 'Tech Club' communities in DaimlerChrysler help to solve problems on a daily basis, which results in benefits in a short-term perspective, but simultaneously they help to develop the expertise of members, which results in benefits in a long-term perspective.

Similarly, SIE system is used to facilitate PI process frequently to meet the demands for customized products and short product life cycles. But, at the same time, it is gathering knowledge by storing all experiences of decisional events that can be used for decision making support when a similar query is presented in future, thus presenting long-term benefits. As already mentioned, that SIE system behaves like a group of experts and the experience-based knowledge is stored in different modules ('chromosomes'-containing experiences of certain category) in the form of particular SOEs. And these 'chromosomes' are grouped together to form what is called as a Decisional DNA (DDNA) of the manufacturing enterprises. Connecting DDNAs of various enterprises through the SIE system will bring the experience-based knowledge of various groups of experts at the common platform. This will help these smart factories in PI process as they can perform innovation process systematically and quickly due to fast computational capabilities of SIE system.

For the successful transformation of current manufacturing enterprises into intelligent organizations of Industry 4.0, the knowledge possessed by various actors needs to be sought, elaborated, and mixed to boost innovation and flexibility [13]. This task can be accomplished by using a smart knowledge and information management system as a CoP, where experience-based knowledge can be stored, shared and reused among the groups of enterprises. For this purpose, SIE systems can be implemented in each single enterprise, and then interconnected with each other to form an intelligent group of organizations. We call it a Community of Practice for Product Innovation. The proposed architecture of the CoP for PI is shown in Figure 3.

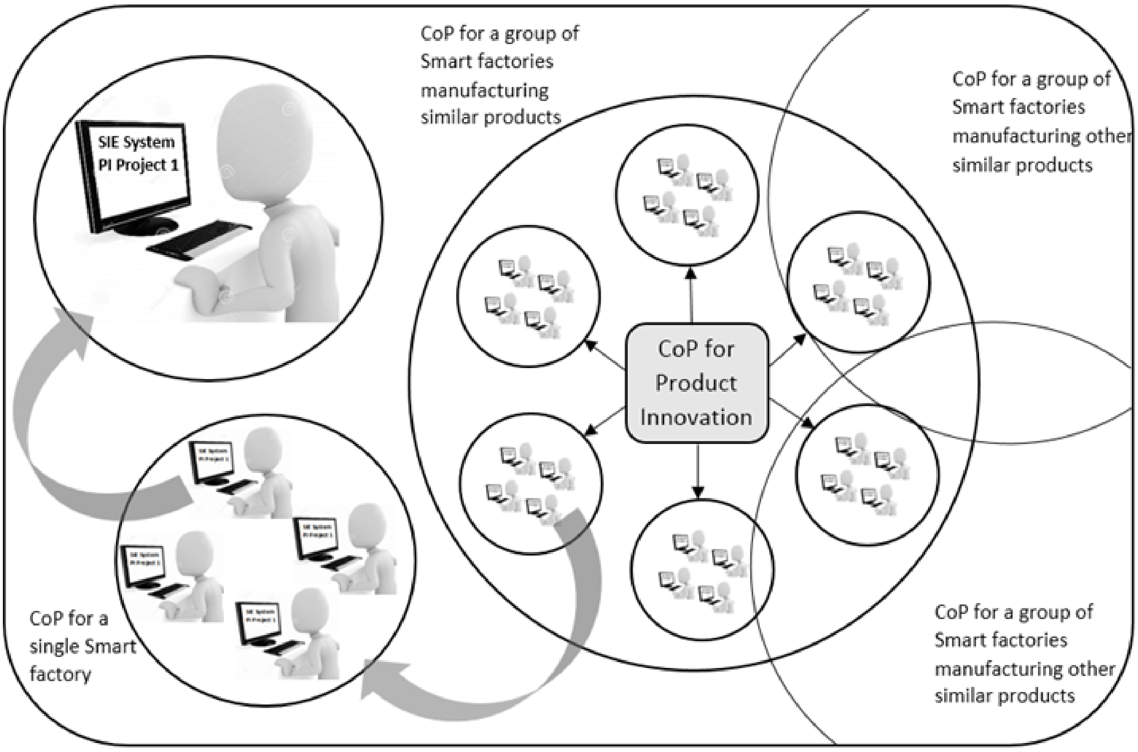

Fig. 2. Layout of Community of Practice for a group of smart factories.

According to Ji Hao, the innovation sources of enterprises include mainly three aspects under the mode of communities of practice: Internal CoP of the enterprises, CoP outside the enterprise, and the interaction among diverse CoPs [43]. We used the above aspects in defining the proposed CoP for PI (see Figure 2). At the root level, the CoP for PI starts by implementing the SIE system in different PI projects inside the same enterprise. This will bring experience-based knowledge of all PI projects onto a single platform, thus building a cognitive connection between these projects. This will allow them to share and reuse the knowledge from the different units thus increasing the overall expertise of the enterprise. Similarly, different enterprises manufacturing the same or similar products co-ordinate to form an integrated CoP for PI. These enterprises now share and reuse experiences among themselves, thus expanding their expertise at a broader hierarchy level. One of the main advantages of such system is that the expert/innovator can take quick and systematic decisions that are based on real experiences. There is no need for scheduling the group of experts' meeting or any other formal time consuming procedure. Here, it should be made clear that the SIE system and the CoP for PI are basically the same. In fact, CoP for PI is an interconnected extension of various production units inside and outside the enterprises.

Further extension of CoP with cross-border integration of industries in different fields will lead to the establishment of highly expert CoP at a global level. Any member of a group of intelligent enterprises will communicate with all other members, including those from different fields. User preferences in other products, demographic, and economic factors will be used to create new ideas leading to enhanced innovation.

These CoPs are very beneficial for high-tech start-ups as they can manufacture products confidently with a high probability of being successful. At the same time, CoP for PI is also beneficial for already successful enterprises as they can regularly update their knowledge system, can create new ideas, and modify regular practice. For example, a manufacturing enterprise that plans to establish another unit in another country, can use this system to modify a given product according to the user preferences, demographic factors, economic conditions, resources and technologies available in that country, government norms, economic factors, and other such conditions.

The role of government is also very crucial in forming such CoPs. It should be committed to create and provide favorable environment for proper and legal communication among its members at global level. Making and implementing effective industrial policies and providing incentives for new members will be fruitful both for industries and nations.

The importance and contribution of SIE systems as a CoP for PI can be aligned with the potential benefits that it offers towards the establishment of future intelligent enterprises as required by Industry 4.0. CoP for PI will:

- identify, create, store, share, and reuse knowledge,
- reduce the dependence on experts and the common problem of experts unavailability,
- permit faster problem solving and response time to needs and inquiries,
- enable accelerated learning and spawn new innovative ideas for products,
- constitute an appropriate medium of virtual communication among experts of different enterprises engaged in sharing knowledge, developing expertise, and solving problems,
- create a structured and expert repository enabling further enhanced learning and documenting knowledge,
- allow manufacturing organizations to choose from the list of proposed solutions based on user preferences, thus permitting flexibility in the product innovation process,
- SIE based innovation process is much quicker as compared to the time taken by human group of experts,
- enable modifications to be made at short notice for customized products.

5. Conclusion

Due to the competitive nature of today's industry and recent development resulting in higher availability and affordability of computer networks, sensors and data acquisition, more and more industrial organizations are forced to move toward implementation of high-tech methodologies. This paper presents the concept of Community of Practice for Product Innovation, its development methodology for implementation towards the establishment of intelligent enterprises of Industry 4.0, and its advantages for manufacturing enterprises and nations as a whole. It explains how the Smart Innovation Engineering (SIE) itself behaves as an expert Community of Practice. Implementing this system in manufacturing enterprises will allow them to take quick and systematic innovation-related decisions. The analysis of its basic perceptions and implementation approaches shows that SIE is an expert system that can facilitate Cyber Physical Systems (CPS), play a vital role towards the establishment of Industry 4.0, and has the potential to be used for lean and sustainable innovation in the future. The SIE system has the capacity to be used by large enterprises, groups of SMEs manufacturing similar products, or by new high-tech start-ups.

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