Extended Product lifecycle management with knowledge management

Research Proposal

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1- Introduction

Anything that is produced and offered to the markets can be a product. Each product has a lifecycle, whether the product is a car or a software program or a service. Product lifecycle has different phases from the time that it is raised as business idea at the first phase to disposal as the last stage. Product lifecycle management is a business approach for management and the use of product, process and resource related data, information and knowledge. With this management, enterprises try to use their company's intellectual capitals. The initial PLM systems had been developed to store and manage Computer Aided Design (CAD) files and giving access to these data in different stage of the product lifecycle for users. Afterward, PLM systems, more developed to cover the management of process and resource data, and later on, managing of product related data, information and knowledge on all phases of product lifecycle. Each enterprise, according to its needs and competencies, implementing and using different capabilities of PLM systems, but still Bill of Material (BoM), Bill of Process (BoP) and Bill of resource (BoR) are forming the core of PLM systems. PLM systems try to manage data by integration with other engineering software programs to import data from them and manage those data for exporting to other software programs or makes them accessible for users. These integrations cause the managing of virtual data and information by the PLM systems, which are generated by different engineers such as designers or manufacturing engineers. CAD files and simulations are two types of virtual data. These data consist of some knowledges that had been generated by different engineers, which can be called virtual knowledge.

Real World Knowledge is another type of knowledge that are exist in the enterprises. This knowledge can be captured from the happenings in the real environment such as failure reports, quality and audit reports, product performance, production data and operator's experiences. Sometimes capturing these knowledges is very easy for example production throughput, but sometimes it is very hard, because they are unwritten and uncodified.

Capturing and managing these real world knowledges, can help manufacturers to reduce their costs by making a better decisions and reusing of virtual models.

Firstly these knowledges can clarify consequences and of previous decisions. They can also clarify some hidden and unconsidered issues about decision cases. The Real World Knowledge covers different types of knowledge, such as production reports, maintenance reports or operator experience.

Secondly, the real world knowledge, can support to determine the level of virtual confidence (Oscarsson et al., 2015). Virtual models as one kind of virtual knowledge which had been explained before, have been designed to reduce costs by simulating the reality. The correctness and accuracy of a virtual model, clarify the level of confidence for that model and its results, for reusing that model to solve another problem. With comparing of the real world knowledge and virtual models expectations, the accuracy of the model can be evaluated, and the reliability of the model can be measured.

There are lots of knowledge management systems have been developed, but most of them are trying to manage the organizational knowledge. The focus of this research is collecting the real world knowledge, in an automotive industry and converting them to the usable and classified format. Afterward, those knowledges should be stored and managed in the extended PLM platform.

2- Literature review

In this section the initial literature review about the research areas will be explained. This review can help to find the state of the art in the research area, and can help to find if there is any previous research and designs about real world knowledge management on the product lifecycle management platform.

This section divided into two main parts. The first part is about product lifecycle, and a brief explanation about the PLM system that will be used in this project. The second section is about knowledge, knowledge types, and addressing the previous researches about knowledge management systems in the manufacturing area, and its relation to the PLM systems.

2.1 Product Lifecycle Management (PLM)

Anything that has been produced and offered to the market can be a product. Products can be tangible such as phones, tables or cars and they can be intangible such as software programs and services. Each product has a lifecycle which starts from the first time that it has been appeared as an idea until the end of its life.

A product life cycle (PLC) can be divided to different phases. Crnkovic divided product life cycle to six phases of business idea, requirements management, development, production, operation and maintenance and disposal (Crnkovic et al., 2003). Stark divided product lifecycle to five different phases, but in two different ways. He divide product life cycle to imagine, define realise, support or service and retire, according to the manufacturing aspect. From user aspect, he divided lifecycle of product to imagine, define, realise, use or operate and dispose or recycle phases(John Stark, 2005). PLC had been divided to five phase of plan, design, build, support and dispose, according to Grieves categorization of PLC phases(Grieves, 2005).

Product lifecycle management (PLM) had been emerged in the mid 1980’s to early 1990’s for managing data and information which are related to the product (CIMdata, 2003). PLM also named as product data management, and it was more focused on managing product computer added design (CAD) information. From those years until now, PLM systems tries to cover more aspects of product lifecycle information such as manufacturing information, resources information, customers information and etc.

Product lifecycle management had been defined in different ways. In the following some of these definitions will be given and finally, a new definition for the PLM will be provided.

The National Institute of Standard and Technology (NIST) defined PLM as a strategic approach to creating and managing a company's product-related intellectual capital (Subrahmanian et al., 2006). CIMdat defined PLM as a business approach to provide solutions for supporting the creation, management, dissemination and use of product information, during lifecycle of product, and integrating people, processes, business systems and information (CIMdata, 2002). Stark defined PLM as a business activity of managing a company’s products during their lifecycle (John Stark, 2005). PLM had been described by Saaksvuori and Immonen as a holistic business concept.

They mentioned that PLM should manage product and its lifecycle and other things such as: documents, BOM's, test specification, quality standards, analysis results, engineering requirements, environmental component information, change orders, product performance information manufacturing procedures, component suppliers, and etc. (Saaksvuori and Immonen, 2005). Grieves described PLM as an integrated, information-driven approach contained of technology, people and process and practice to all phases of a product's life (Grieves, 2005). Siemens Company as a PLM system developer company defined PLM as information management system that can integrate data, processes, business systems and, ultimately, people in an extended enterprise.

These above definitions had been defined PLM according to different point of views. PLM had been defined as a business approach or as an integration of business software or a business activity or an information management system and many other definition. If it has been looked very abstract, it can be defined as strategic business approach or business activity of managing as NIST or Stark had explained it. From other point of view it can be defined on detailed an as computer system, such as Siemens' PLM definition.

A new definition has been provided for PLM for this project. It has been tried to define PLM precisely, and be clear about the information that should be covered by PLM system.

For this project PLM had been defined as a business approach for management and use of product, process and resource related data, information and knowledge as corporate intellectual capitals, over the extended enterprise.

According to this definition, the management aspect of PLM has been highlighted and it covers only management of product data information and knowledge. The PLM system is not engineering application, but it contains and mange input and output data and information from those engineering software programs. Each PLM system needs an IT infrastructure to handle data storage and also can integrate with other engineering software programs. The PLM system should have data management functionalities, such as data transferring, data searching, user defining, authorization defining, and etc.

Kim et al mentioned that majority of manufacturers use PLM for management of PPR (Product, Process, and Resource) data (Kim et al., 2007). "Bill of Material", "Bill of Process" and "Bill of Resource" are three main structure of PLM systems and they can be considered as backbone of product lifecycle management systems. Bill of Martial (BoM) is a product structure that shows different parts and assemblies of a product. Bill of Process (BoP) is a structure that clarifies different processes and their relationships for manufacturing a product and Bill of Resource (BoR) is a factory and resources structures which are needed for producing a product.

The PLM definition and its structure are very important facts when the knowledge management wants to be connected and implemented with the PLM platform.

2.2 Knowledge management

Knowledge can be applied to create new and better solution for decision making (Wiig, 1994). Data information and knowledge are three concepts that related to each other. Data are simply symbols such as numbers, without any context and relationship. When different data have been related to each other, reckonable, understandable and comprehensible, those data become to information. Whenever information has been recognized and understood by a person, and there will be a meaning for it, then it can be called knowledge (Mills and Goossenaerts, 2001).

Knowledge had been divided to two different types of tacit and explicit in many books and articles, but Nickols divided knowledge to three types. He added implicit to those two types of knowledge (Nickols F.W., n.d.). Explicit knowledge is an objective knowledge and can be codified and articulated in some ways (Nonaka, 2007; Wiig, 1994). Tacit knowledge is subjective and cannot be codified and it's in human minds (Grant, 2007; Nonaka, 2007; Polanyi, 2012). Implicit knowledge is the kind of knowledge that has not yet been articulated (Nickols F.W., n.d.). In the manufacturing area, instructions are a sample of explicit knowledge, Operator's experiences are a sample of tacit knowledge and maintenance reports are a sample of implicit knowledge.

Wiig divided knowledge to four conceptual levels (Wiig, 1994):

Goal-setting or idealistic knowledge: This knowledge has been used for identifying of what is possible and for creating goals and values. Some part of this knowledge is explicit, but most of it is tacit. This knowledge can answer "Why" question.

Systematic knowledge: This knowledge has been used to analyze in depth and create new alternatives and methods. This knowledge is to a large extent explicit.

Pragmatic knowledge: this is knowledge for making decisions and perform daily works. It is explicit knowledge and answer to "How" question.

Automatic knowledge: Automatic knowledge is a kind of tacit knowledge that has been used to do tasks automatically, without any analyzing and reasoning.

Nonaka had been designed a model (SECI model) for knowledge conversion between tacit and explicit and Figure 1 shows a model based on Nonaka's model, had been designed by Folkard et al (Folkard et al., 2012; Nonaka, 2007).

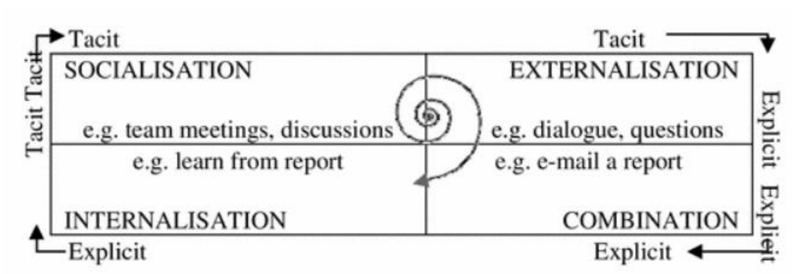

Figure 1. Knowledge conversion model (Folkard et al., 2012)

Many other methods had been explained for converting tacit knowledge to explicit knowledge (Lubit, 2001, 2001; Yu-n et al., 2000).

Some researches had been done about manufacturing knowledge management. Baxter had been defined a knowledge management framework for design related knowledges (Baxter et al., 2009).

Guerra-Zubiaga and Young defined a manufacturing facility information and knowledge model to save and manage the knowledge related to the facilities. Manufacturing knowledges had been divided to process knowledge and resource knowledge in this article, and process knowledge had been divided to seven different types:

- Explicit process knowledge using tables
- Explicit process knowledge using graphs
- Tacit process knowledge using video clips
- Tacit process knowledge using sketch and procedure
- Tacit process knowledge using patterns
- Tacit process knowledge using storytelling
- Implicit process knowledge

Their model can manage some types of real world knowledge but not at the PLM platform. They designed a knowledge management system for managing those captured knowledges (Guerra-Zubiaga and Young, 2008)

PLM systems are initially managing data, but later, they developed to manage product lifecycle information. One step further is managing knowledge, and different approaches had been presented for product lifecycle knowledge management. Using ontology is one type of knowledge management and it had been offered to manage manufacturing knowledge. Mostefia and Bouras present overviews of different ontologies used for product lifecycle management (Mostefai and Bouras, 2006).

In 2006, Young et al. suggested to use heavy weight ontologies instead of lightweight ontologies(Young et al., 2007). They assumed that PLM systems had been used for managing of product related information, and using ontologies can help to manage other types of information and knowledge such as manufacturing, operation and disposal knowledges. Light weight ontologies definition of terms is easily understood, and ontology has been structured with textual definition for terminology. Heavy weight ontologies are more mathematically rigorous. They compared Ontology Web Language-Services (OWL-S) and Process Specification Language (PLS) as two types of ontologies for managing a simple process knowledge, and they showed the advantage of using heavy weight ontologies (PLS). The main advantage that they showed was capability for process sequencing with the PLS approach, and they also explained some weaknesses of using PLS such as not complete supporting of manufacturing resources (Young et al., 2007).

Raza et al. used ontologies as a knowledge based service in addition to the PLM system for managing changes in the manufacturing assembly line. They captured assembly process in the

Ford engine factory as an ontology, and implemented that ontology, with integration with the PLM system. They demonstrated how these system can helps designers, to know constraints of production, when they want to do some changes (Raza et al., 2011).

Chungoora et al explained the Interoperable Manufacturing Knowledge System (IMKS) approach as a heavy weight ontological approach for sharing manufacturing knowledge by integration with the PLM system(Chungoora et al., 2012). According to this approach, some light weight ontologies should be defined for different domains such as manufacturing and design, and those ontologies should be connected to a core concept ontology. In this approach a possibility for knowledge feedback from manufacturing stage to design stage, had been considered, but it is very simple and immature. This approach also used PLM system as a wallet for the design models and drawings, and the ontology can be replaced as the PLM data Model. They also mentioned that the IMKS approach can be utilise as a method to deliver PLM system development, instead of current PLM data and information models (Chungoora et al., 2012).

Matsokis and Kiritsis also developed an ontology-based approach for product lifecycle management, and explained how PLM data model can transforms to ontology based model. They used Web Ontology Language-Description Logic (OWL-DL) for developing their model (Matsokis and Kiritsis, 2010).

There is a case study article from Nila et al. about deployment of knowledge management in a PLM platform(Nila et al., 2013). At this article they explained that they started an implementation of knowledge management integration with a PLM system, but the initial and abstract model had been offered for the PLM interface with KM Integration and agile development. They adopted this model from Segoneds method (Segonds, 2011). They explained that they started the knowledge extraction with some interviews and analyzed the existing methodologies for knowledge management in their case study. They explained that this project is not finished and they only explained briefly about what happened until the publication date.

Urwin and young also published an article in 2014, and explained how they made machining knowledge accessible trough the PLM system. In their case study, machining knowledge had been accessible with a search web page which connected to the PLM system(Urwin and Young, 2014). The described methodology is very limited and specific.

According to above articles and literatures, PLM systems are systems for managing product related data and information at the enterprises. Many researches happened to manage knowledge at the manufacturing area, and some knowledge management system and different ontologies approaches had been developed for them. Those researches are about managing manufacturing basics knowledge and they are not completely used PLM platform as a product lifecycle management system for making those knowledge accessible and usable for all users. Most of them suggested to use knowledge management systems instead of product lifecycle data and information system. At the next chapter, the research methodology for achieving the research objectives will be explained.

3- Aim

The aim of this project is extending PLM system with a knowledge management system for managing real world knowledge, in the manufacturing environment. Real world knowledge can support decision makers to evaluate previous decisions and also clarify different aspects of decisions. It helps to prevent mistakes from early stage of the product development process, and helps to shorten that product development process time. By comparison of the real world knowledge with predictions of virtual models, the correctness and accuracy of those models can be specified (Virtual confidence). The PLM system is a good platform to access to the real world knowledge, or even presenting the related knowledge for decision making.

4- Objectives

For achieving the aim of this project some objectives had been defined. Defining these objectives helps to achieve the aim of research, step by step. Since this project is going to be done by cooperation of university and industry, most of objectives should be followed in the industry. The research objectives are:

1. *Knowledge collection and classification:* The first objective of this project is classifying the collected real world knowledge. For fulfilling this objective, initially a knowledge collection

should be done in the factory. This knowledge collection contains different types of knowledge, including tacit, implicit and explicit knowledge. For classification of collected knowledge, some criteria such as the structure of the PLM system, and the relation of different knowledges should be considered. The abstraction level or the concrete level of the final implementation, also has an important affection on the knowledge classification. Beside the knowledge collection, more information about them should be identified to clarify the knowledge provenance information.

2. *Knowledge conversion:* Since knowledge can be existed in different types, only collecting and classifying them is not enough, and they should be converted to the usable and identical knowledge. Tacit and implicit knowledge should convert to the explicit knowledge and sometimes it needs to merge different knowledge with each other to create a new knowledge as a result. This conversion should be in a way that makes them easy to store and manage in the extended PLM.
3. *Knowledge management in the extended PLM:* the last objective of this research is defining of a knowledge management architecture, which is integrated with the PLM system. This knowledge management system should capture and save the real world knowledge, and after that with connection to the PLM system, make those knowledge available and retrievable for users. The architecture should cover the whole knowledge flow, from the initial knowledge generation to knowledge conversion and knowledge management.

This objectives leads the research to its final aim. At the end of this research, different decision makers at the factory can use the real world knowledge, in the early stages of production development, for making decisions. These knowledge also can be used to verify the efficiency of virtual models, for later reuse of them.

5- Expected result

Through the completion of this research, some results are expected to achieve. Since the industrial partner is also expecting some results from the research before the final result, some intermediate results should be delivered to them.

From the fulfilling the first objective, the company knows which kinds of real world knowledge exist in their factories. It helps them to have an overall view of their data and information, and find different gaps of information in their system. Their knowledge flows will be clarified, and they can prevent from some reworks. It is common in the enterprises, to have duplicate information in many documents and data bases, and this knowledge collection specified those information for managing them in a better way.

When the second objective has been followed, then lots of tacit knowledge can be converted to the explicit knowledge. Some of the intellectual capitals are hidden in the human's mind, and they had been gained by experiences. This knowledge will be lost after a person retired or moved to another company, or even move to another section. This knowledge conversion tries to make this knowledge codified and usable. Implicit knowledge, such as reports are another type of knowledge that should be converted to usable knowledge.

The result of last objective can be considered as the result of the whole project. At the end of this project, the company can have an access to their manufacturing knowledge, through the extended PLM system. Users can get the information about any part in the Bill of Material (BoM), or any process in the Bill of Process (BoP), or any resource in the Bill of Resources (BoR). These real world knowledge also can be used in other information systems, for further processing. This real world knowledge can clarify the correctness of the virtual models, and therefore how users can rely on them for future use.

6- Research methodology

Defining the research methodology is one of the main parts of the research. With selecting and defining the research methodology, research has been guided in a specific way. The path to achieve the research aim will be clarified, steps will be identified, and some problems can be predictable. The researcher can make a better plan for the research with selecting an appropriate research methodology.

Before explaining research methodology, this research should be evaluated about its philosophical approach and paradigm. Orlikowski and Baroudi defined three different philosophical research perspectives for information system researches (Orlikowski and Baroudi, 1990). The first paradigm is positivism, and in this type of research, researcher believes that reality exists objectively and it is not depend on the human roles and social factors. Positivists prefer quantitative methods for analyzing data, and they study the science according to its existence, without the researcher or other human roles. This approach is the oldest approach, and had been used in most of natural sciences such as physics.

The second paradigm is interpretivism. In this type of philosophical approach, human and social interaction involved in a research, and qualitative analysis has been used by interpretivist.

The third approach that Orlikowski and Baroudi defined is critical thinking. In the critical thinking approach, researcher creates knowledge and thoughtful of the several forms of social domination, so that people can act to eliminate them.

According to this research objectives, real world knowledge is the main focus of this project, and interpretation of those knowledge depends on the researcher and other peoples those are involved in this research such as operators. The nature of this research is related to the interpretivism philosophical paradigm, and its characteristics are similar to this approach characteristics.

Oates defined some characteristics for interpretivist research approach, and those characteristics should be evaluated for this project(Oates, 2006). In this research, knowledge can be extracted from human mind or document that researcher should investigate on them, and many different knowledge can be extracted from them, which all of them can be truth. For this research, the researcher assumptions, thoughts, methods, and beliefs are affecting research process and results. In this research, it will be tried to relay more on the documents and common thoughts for achieving the research objectives to eliminate researcher's effects on the project.

Another characteristic that Oates explained for interpretivism research philosophy is studying people in their natural social setting and not in the artificial environment such as laboratory. This research is also focusing on real world knowledge, and it has this characteristic in itself.

According to above characteristics of this research, it will be interpretive research, but the final artifact should be design in a way that can be used in different manufacturing areas, with different types of knowledge.

Oates explained a model for research process in his book about researching in the information system fields(Oates, 2006). In her model a research starts with the experience and motivation and at the same time the literature review also should be done simultaneously. Then, before selecting the research strategy, research questions should be specified. After selecting research strategy, data generation methods should be specified and the analyzing procedure of those data should be identified(Oates, 2006).

At previous sections, motivation for studies and literature review had been explained. The research questions are raised as the objectives of the research and at this section, the research strategy, data collection methodology and data analysis methodology for this research project will be explained.

There are many different classification had been explained, for research strategies. Oates divided research strategy to six different types. The strategies are “Survey”, “Design and creation”, “Experiment”, “Case study”, “Action research” and “Ethnography”. Each strategy has its own definition and characteristics, and according to that definition and characteristics, the research strategy should be selected. In some researches, the combination of these strategies have be used. When all strategies had been studied, the design and creation method had been selected for this research. At the design and creation strategy, the result of the research should be an artifact. An artifact can be a model, constructs, methods, instantiation or anything else. Since the aim of this project is a tool for the company, for presenting the real world knowledge, in the manufacturing plant and at the PLM platform, the aim will be artifact and the research strategy should be design and creation.

Vaishnavi and Kuechler defined five process steps for design and creation strategy (Vaishnavi V. and Kuechler W., 2004). Those steps are awareness of problem, suggestion, development, evaluation and conclusion, and they had been used for creation of a design and creation research framework for this project (Figure 2).

In most of design and creation researches, some industries involved in the project to use the results of the research. This research is also going to be done in the Volvo Cars Engine factory, and because of that, during the research performing, both industry needs and scientific aspect of the research should be considered. Figure 2 shows the relation of these three process, during their evolutions.

The first step is awareness of problem. This problem identification coming from a problem or need in the industry. Sometimes the problem or need had been found by the industries themselves, and sometimes the researcher investigates on this and finds the problem. It is also important to specify that the problem is a new problem, or it is a known problem. This problem evaluation can helps to identify the knowledge contribution of this research, and the research area for literature review. Sandberg and Alvesson describes different ways of constructing research questions in their article(Sandberg and Alvesson, 2011). For this research, research objectives had been defined instead of research questions, but this articles can helps to explain how these objectives had been constructed. Sandbeg and Alvesson divided ways of constructing research questions to gap-spotting and problematization. According to their survey, most of research questions had been constructed in the gap-spotting way. In the gap-spotting way, researcher reviewed existing literatures and find spotting gaps in those literatures, for defining research questions. They explained different types of gap-spotting modes such as competing explanation, overlooked area, under-researched, lack of empirical support and extending and complementing existing literature. According to the literature review section, the objectives of this project had been constructed with gap-spotting approach. The previous researches about knowledge collection and knowledge conversion will be used and the manufacturing knowledge management methods will be evaluated and will be used on the extended PLM platform.

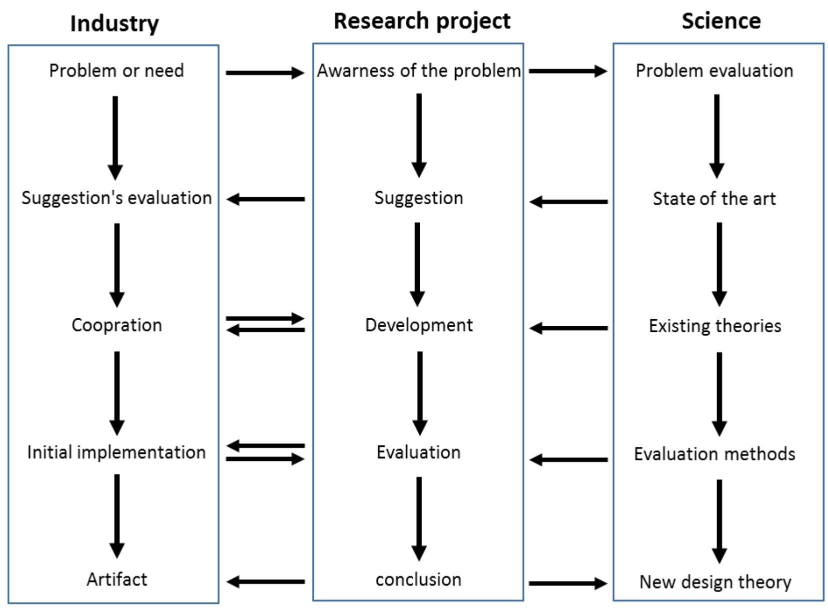

Figure 2. Design and creation research framework

The problem that this research is aiming to solve is managing the real world knowledge at the extended PLM, but it is not easy to identify that it is new problem or known problem. Some part of this problem had been solved by previous researches as mentioned at the literature review section, but the whole problem can be considered as a new problem.

The next step of the research methodology is “State of the art” and for this research latest designs for managing knowledge at the manufacturing area had been explained at the literature review. The literature review shows that there is not any known solution for solving the research problem, but some of those methods can help to solve the problem.

The next step of research is finding suggestions for this knowledge management. Suggestions should offered to the industry for initial evaluation. At this research the procedure that knowledge should be collected has been explained for the industry, and the overall plan for converting and managing of those knowledge had been specified (Research Proposal). When suggestions have been evaluated and accepted by the industry, the development phase of the research will be started. During the artifact development, some existing theories should be used. These theories can be descriptive such as theories about knowledge classification, or prescriptive such as business knowledge management methods. During the development phase the literature review will be continued to support the design development with different theories. The relation of industry and research at the development phase is bilateral. The industry feeds the research with data and information, the knowledge collection should be done at the industry. The research also gives some results to the industry during the development procedure. For example, the results of knowledge collection can helps the factory to know their knowledge sources.

When the knowledge management system has been developed, then it should be evaluated with initial implementation at the industry. This implementation will be done on a small scale prototype, and the results can be used for evaluation with evaluation methods. Oates divided design researches' evaluation to three levels. Three levels of evaluation are "proof of concept", "proof by demonstration" and "real-world evaluation"(Oates, 2006). In this research the evaluation will be by implementation at the real-world, and evaluation criteria's will be performance, usability, accessibility, accuracy and reliability.

The last step of this research project will be conclusion. At the end of this research the industry can have a prototype of real-world knowledge management system, and a new design theory will be added to the knowledge. Gregor divided theories in information systems to five different types (Gregor, 2006). Analysis, explanation, prediction, explanation and prediction, and design an action are five types of theories and each of them has their own structure and features. According to those structure and features, some design and action theories will be generated after this research. Gregor explained that design and action theories are describing how to do something. These theories can represented physically in different ways such as words, tables, screenshots and diagrams. The phenomena of interest in this type of theory can be users, work context, system architecture and etc. Scope of these theories, are systems that support emergent knowledge processes.

It is also possible that another type of theories be generated through the project process, such as analysis and explanation. These types of theories can relate to the knowledge classification and knowledge conversion.

Robinson divided research design into two different types; fixed design and flexible design (Robinson, 2011). At the fixed design research, the research procedure is fixed before starting the data collection. The analysis method has been selected in advance. Briefly, at the fixed design, the researcher knows exactly what looking for. For the fixed design quantitative data collection is used. From those five research strategies that Oates defined, experiment and survey can be placed in the fixed design group.

In the flexible research design, results of early stage of design will be used for designing of next stages. The design will be improved and modified during the research, and most of researches with case study, ethnographic and design and creation strategies are belongs to this group.

Since the design and creation research strategy had been selected for this project, and the knowledge collection and knowledge analysis and conversion are qualitative data collection and analysis, then for this project flexible research design has been selected. Types of knowledge is the basis for knowledge conversion and knowledge management design, and before knowledge collection, detail designing of those steps are not possible.

One of the main issue, when a design and creation strategy has been selected, is knowledge contribution. Researcher should specify knowledge contribution of the research precisely to separate it from a normal design project. Gregor and Hevner designed a framework for knowledge contribution of design since researches (Gregor and Hevner, 2013). According to the framework that has been showed at the Figure 3, the relation of research and knowledge can be divided into four types.

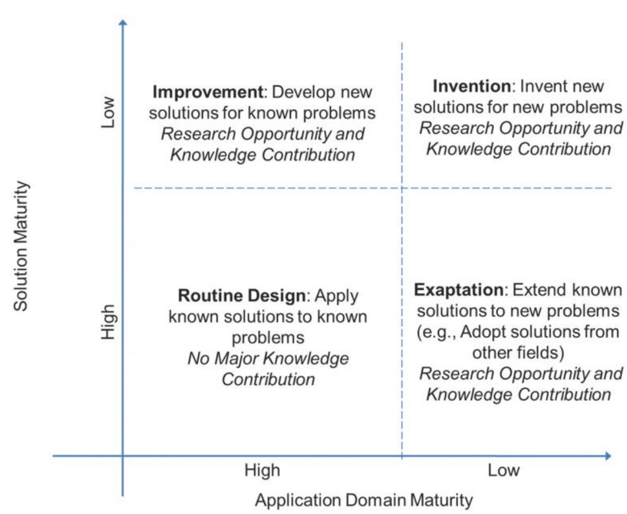

Figure 3. DSR Knowledge contribution framework (Gregor and Hevner, 2013)

If the problem is a new problem and researcher want to create a new solution for that problem, then the knowledge contribution of the research is invention type. If the researcher using a known solution or adopting a solution from another field for a new problem, then the contribution will be in exaptation mode. The third is improvement and it is happened when the new solution has been developed for known problem. Whenever the known solution has been used for the known problem then there is not major knowledge contribution, and it is a normal design project. As mentioned before, the problem of this project is managing of real-world knowledge at the extended PLM system, and this is a new problem. The solution for this problem will be a knowledge management system with possibility of integration with the PLM system. This will be a new solution for the problem and because of that, knowledge contribution of this design research is an invention type.

After the design strategy selection, data collection methodology should be specifies.

Data collection methodology

This project is about knowledge management, and knowledge collection is the base of this project. Since data is one kind of knowledge, in this writing, data collection and knowledge collection has same meaning.

Creswell defined an approach for data collection as showed in Figure 4 (Creswell, 2006). For data collection, this approach will be used in this research. The first step is specifying of the data collection site, and for this research Volvo Cars Engine factory had been selected. The second step is making an agreement with the company for accessing to their data and information. Since this project had been defined with cooperation of VCE before the beginning, then they are involved in this project. However, a meeting had been held, and the company agreed that researcher can use their data and information for the research.

Figure 4. Data collection activities (Creswell, 2006)

The third step is purposefully sampling. This research is focusing on the manufacturing knowledge and sampling will be done with this focusing, but this data collection cannot be done on all of operations at the factory. Because of that, one operation from each type of operation will be selected, as a representative of similar ones (Figure 5). With this sampling, all different types of processes has been covered, and most important common patterns of operations in the factory will be studied. At this stage of data collection, one operation in the factory has been selected and further steps of data collection will be continued for this operation to the end. Afterward, the second operation will be selected and data collection proceed on that operation. Accordingly, the data collection steps after sampling step will be repeated four times, for each type of operation.

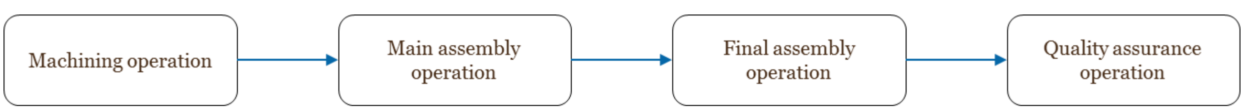

Figure 5. Selected samples for data collection

When the operation has been selected, data, information and knowledge about that operation should be collected at the collecting data activity. Since, many different variety of knowledge are exist about an operation, knowledge searching space has been divided to four areas.

1. *Product, process and resource knowledge area:* At this area, the operation will be evaluated according to the PPR knowledge. All PPR, and all PPR related data, information and knowledge, about the selected station will be specified. It is expected that most of data collection will be happened in this area.
2. *Relation with supplier and customer:* At this area, the relation of desired station with its supplier and customer will be checked. Supplier and customer can be previous and next stations for machining operation or suppling of components in an assembly station. The material handling, logistic and transportation knowledge is a kind of knowledge in this area.
3. *Operation role in the production line:* At this area, the role of the operation in the production line will be considered for knowledge collection. Information about the station positioning, line balancing and discrete event simulation knowledge are some kind of knowledge from this area.
4. *Station role in the product and process development:* There are some data, information and knowledge about the operation, which has been generated and has been used when that operation wanted to be designed, installed and started up, for a product and process development. Some of them are despaired, after the starting of new production system. These data, information and knowledge are placed in this area.

Some knowledges are belonged to two or more knowledge areas, however this knowledge area classification gives a structure for knowledge collection.

For knowledge collection, different data collection methods had been defined, and for this project according to the needs, some or all of these methods can be used. Data collection methods are documents, interviews, questionnaires, observations and test and scale. Figure 6 shows how these data collection methods will be used in at different steps. Before starting knowledge collection, a primary interview should be done with operation’s responsible to get an overview about that operation to know what is happed in that operation. Knowledge collection will be started with documents as a first step, because it take less time to have access to them, and they consist of lots of information and knowledge.

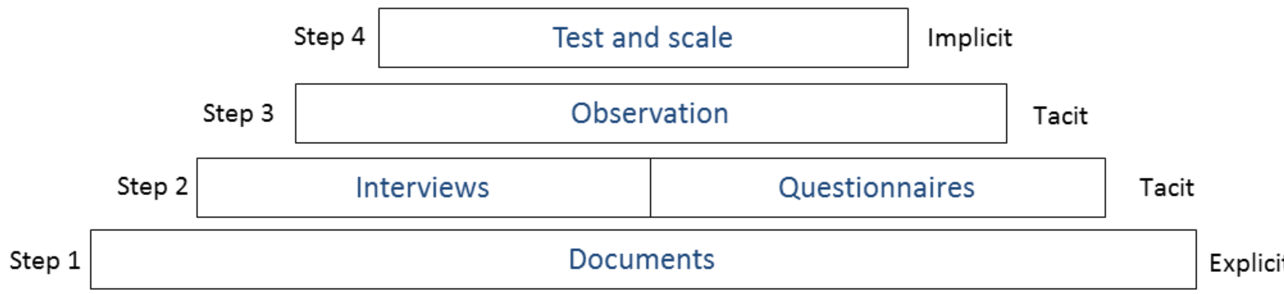

Figure 6. Knowledge collection steps and dominant knowledge type

Interviews and questionnaires are the next step for collecting knowledge. These step is for collecting tacit knowledges such as operator's experiences. The collected documents can be used as a basis for interviews and questionnaires, but also it will be tried to collecting hidden knowledge in human minds by interviews and questionnaires.

Two other steps, observation and test and scale, will be used if they needed for clarifying some knowledge or converting of tacit to explicit knowledge.

Since, knowledge areas have lots of common knowledges and they are connected to each other, the knowledge collection procedure will be stepwise. It means that initial, the first step (Documents) will be implemented on all four knowledge areas, and then, interviews and questionnaires will be done about those areas. This procedure continues for all steps, until knowledge of that operation became completed. Afterward, the whole data and knowledge collection should be proceed for other types of operations, such as main assembly and final assembly.

Since, the first step is the basis for other steps, it should be planned in more detail, and other steps can be planned later according to the results of the first steps. Because of that, at the flowing, knowledge collation with documents will be explained in more details.

Documents can be exist in many different types and formats, such as standards, guides, electric sources, minutes of meetings, photos, drawings, and etc. In this project most of them will be explicit knowledge such as drawings, computer files, 3D mode, but they can be tacit and implicit also.

Before starting document collection, analysis that are going to be done on those documents should be generally specified, to makes the data collection more purposeful, and to get all needed information about that document. Oates defined two approaches for analyzing documents and in this project one or both of those approaches will be used, according to the type of document(Oates, 2006).

1. *Documents as vessel:* In this approach, document's content and theme will be analyzed. For example, analyzing of abundance of machine number 10 in maintenance reports is a kind of this approach for document analysis. Two types of document analysis have been defined for this approach: content analysis and theme analysis.
    1.1. Content analysis: Content analysis is one of the qualitative data analysis techniques, that making valid and replicable inferences from text (or other meaningful matter) to the contexts of their use. For example, with this method the failure reports of a station can be analyzed and the number of specific failures can be counted. Krippendorf explained this methodology in his book, that can be used for this project (Krippendorf, 2003). Some computer software programs such as R-Text mining, Rapid Miner and iKnow will be used for content analysis if needed.
    1.2. Theme analysis: Theme analysis is a method for analyzing documents, with a defined pattern based on a theme. Thematic analysis is more advanced analysis compare to the content analysis that is simply counting phrases or words in a text and it moves on to identifying implicit and explicit ideas within the data (Braun and Clarke, 2006; Corbin and Strauss, 2007). For theme analysis the Deddose software program can be used.
2. *Document as object:* In this approach documents are considered as an objects in their own rights For example, the usage of Technical specification documents by different disciplines can be analyzed in this approach. . In this project, features and relation of documents will be analyzed with this approach.
    2.1. Documents' features and provenance data: Ram and Liu defined a generic model that represent data provenances and they named it W7. In that model seven questions should be answered to clarify the provenance of data. These questions are "What", "When", "Where", "hoW", "Who", "Which", and "Why" (Ram and Liu, 2006). With identifying of

document's features such as title, description, format, produces and use, answering of above seven question will be easier.

With these data analysis approaches, collected documents can be analyzed and different knowledges which are exist in those documents, will be highlighted. With clarifying knowledge sources, the knowledge flow can be specified.

According to the Figure 4, the next data collection activity is recording collected data and knowledges. Because of the confidentiality of information, in the Volvo Cars Corporation, all document and information should be recorded at their information systems for analyzing, but documents and their analysis results can be used outside of the company with some changes and flowing the company's confidentiality rules.

During the data collection procedure, some field issues can be rose, but since in this project, the VCE is a part of this project, these issues can be solved with cooperation of VCE stuffs.

The last activity of data collection is storing collected data for analysis, and as mentioned at recording activity, those data should be stored at the VCE's information systems for later usage.

7- Research quality

Every research should be proofed for its quality, and this research also will be evaluated according to different research quality criteria. Lincoln and Guba defined different types of criteria for positivist and interpretivist research. Their criteria for positivism are validity, objectivity, reliability, internal validity and external validity.

As it had been mentioned before, this research is interpretive research and because of that, its quality should be measured with interpretivism criteria. Those criteria are trustworthiness, confirmability, dependability, credibility and transferability.

According to these criteria, this research will be planned in detail, and the process of the research will be well documented. All aspects of knowledge collection and knowledge conversion, will be considered. As explained before, different types of application areas will be surveyed to cover different kinds of knowledge from all kind of operation in the factory. With the usage and different data collection methods, it will be preventing from mistakes in knowledge collection and they can be used as support for each other.

The real world knowledge management system as the final artifact of this research will be designed in a way which can be used for different kinds of manufacturing factories and makes this research transferable.

8- Project plan

Duration of this research project is five years, with specifying of 80% of researcher's working time on it. Figure 7 shows the project plan for the five years of the research. The project had been started form April 2015, with preparation and planning the project. The literature review for this project is divided to two steps. The first step is more completed literature review for specifying the state of the art and related knowledge in the research area. The second step is reviewing needed literature during the rest of project, those are related to tasks that are going to fulfill.

Since this PhD project is an industrial PhD and it should be done with the industry's collaboration, a model has been used for different stages of this research. Thesis steering model (TSM) is the model that is presented by Heldal et al.,and they had been defined different gates for different stages of PhD research. Some of those gates had been used for this research and they are start gate, vision gate, concept gate development gate and end gate. These gates have been placed in the project plan.

Knowledge collection had been started after vision gate, and it will continued for one year. During this knowledge collection, one conference paper will be published about knowledge collection and knowledge classification as the first objective of this research. The next step is knowledge analysis and research development is consists of second and third objectives. Collected knowledge will be analyzed and knowledge conversion applied for them if they needed, and after that a system will be developed for managing those knowledge on the PLM platform. One journal paper and one conference paper will be published during this stage.

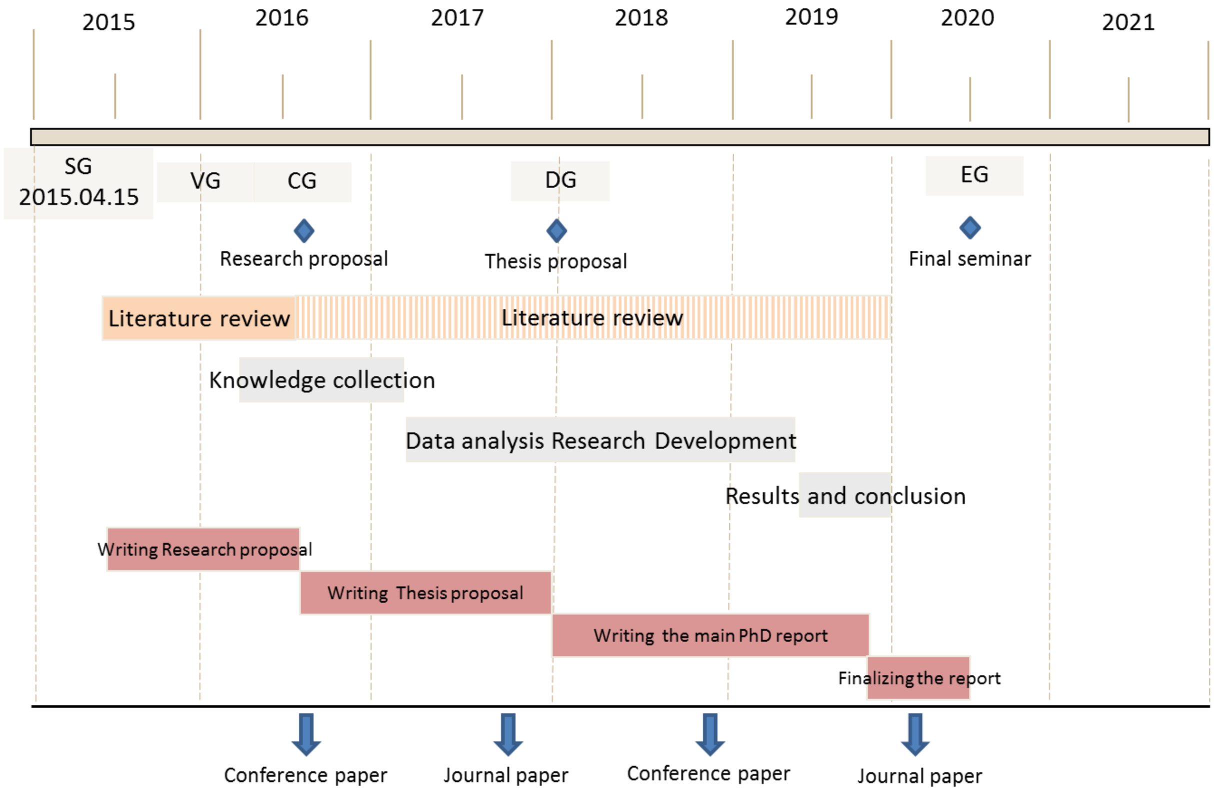

Figure 7.Overall Research Project plan

Afterward, the research will be evaluated and concluded. The evaluation will be done by implementing a prototype at the industry, according to different research evaluation criteria such as functionality, accuracy, usability and fit with organization.

Research proposal, thesis proposal and final PhD thesis report will be prepared according to the plan as they have been showed in Figure 7.

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