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A Conceptual Architecture of Ontology Based KM System for Failure Mode and Effects Analysis

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Abstract: Failure Mode and Effects Analysis (FMEA) is a systematic method for procedure analyses and risk assessment. It is a structured way to identify potential failure modes of a product or process, probability of their occurrence, and their overall effects. The basic purpose of this analysis is to mitigate the risk and the impact associated to a failure by planning and prioritizing actions to make a product or a process robust to failure. Effective manufacturing and improved quality products are the fruits of successful implementation of FMEA. During this activity valuable knowledge is generated which turns into product or process quality and efficiency. If this knowledge can be shared and reused then it would be helpful in early identification of failure points and their troubleshooting, and will also help the quality management to get decision support in time. But integration and reuse of this knowledge is difficult because there are number of challenges e.g., unavailability of unified criteria of FMEA knowledge, lack of semantic organization, natural language text based description of knowledge, most of the times FMEA is started from scratch instead of using existing knowledge that makes it incomplete for larger systems, and above all its success depends on the knowledge which is stored in the brains of perfectionists in the form of experience which may or may not be available anytime anywhere. In this article we are proposing an Information and Communication Technology (ICT) based solution to preserve, reuse, and share the valuable knowledge produced during FMEA. In proposed system existing knowledge available in repositories and experts head will be gathered and stored in a knowledge base using an ontology, and at the time of need this knowledge base will be inferred to make decisions in order to mitigate the probable risks. Ontology based approaches are best suited for the knowledge management systems, in which human experts are required to model and analyze their expertise in order to feed them in a conceptual knowledge base for its preservation and reuse.
Keywords: Knowledge Management (KM), ontology, Failure Mode and Effects Analysis (FMEA).

1 Introduction

Knowledge is often defined as "justified true belief". Facts, information, and skills acquired by practical experience or education are also called knowledge. Knowledge is the information combined with experience, context, interpretation, and reflection. It is a high-value form of information that is ready to apply to decisions and actions [3]. In this era knowledge is the core asset of any organization. It is important for the organizations to know what they know. Nowadays sustainability of an organization depends on what it knows, how efficiently it utilizes what it knows, and how quickly it acquires and utilizes new knowledge [3], and in other words success of any organization relies on the effective management of its knowledge. Organizational knowledge can reside in the minds of experts and experienced employs of organizations, files in cabinets, or in huge volumes of databases on servers. Since ages human beings and organizations have been creating, acquiring, communicating, and re-utilizing their knowledge. Knowledge management can be defined as doing what is needed to get the most out of the knowledge resources [6]. It is also the collection of activities of knowledge gathering, structuring, refinement, and dissemination. Nowadays ICT is helping to make these activities more effective for organizations. Knowledge management systems have been and are being designed and developed to facilitate organizations in managing their knowledge and making it useful in the absence of concerned experts. But knowledge management systems are very difficult to build. It is difficult to find experts who are willing to share their knowledge, and allow experiencing how they solve problems. It is difficult to gather, compile and refine the knowledge across the organization from person to person, documenting the way how decisions are reached, and structuring it to represent on machine.

A project risk is defined as an uncertain and undesired event or condition which affects the objectives of a project in positive or negative way [15].Risk management is an endeavor to identify and manage internal events and external threats that can affect the likelihood of a project's success. It identifies risk events, plans how to minimize the consequences or impact of the risk event, lists all anticipated tasks that can be completed in order to avoid undesired events, and builds contingency plans to handle such events after their occurrence. It is a proactive approach to reduce surprises and negative consequences. It provides better control over the future, makes a project manager ready to take the advantage of appropriate risks; and increases the probability of meeting project objectives within budget and time [8]. Successful project management is based on effective risk planning and management. Risk management helps a project manager to actively handle all expected and unexpected risks on projects. There are various other factors that affect a project's success but inadequate risk management increases the possibility of project failure.

Risk management process is based on four major actions; risk identification, risk assessment, risk response development, and risk response control [1]. In risk identification phase all probable risks are considered which can potentially make a process or product fail to achieve its objectives; brain storming, problem identification, and risk profiling are effective approaches for this phase. In risk assessment phase, the value of risk associated to a product or process is determined by calculating the magnitude and probability of an undesired event. There are different tools for risk assessment, e.g. scenario analysis for event probability and impact, risk assessment matrix, FMEA, probability analysis; and Semi-quantitative scenario analysis. Risk response development phase is responsible for deciding an appropriate response for assessed risk. This response could be mitigation, avoidance, transfer, or retention of the risk. To control risk, response strategies are designed and executed, events are monitored, contingency plans are initiated and new risks are identified; all these tasks are completed in risk response control phase.

FMEA is an effective systematic technique for failure analysis during product life cycle. Its purpose is to identify all potential failure modes related to a system, product or process in advance, so that experts can think about their remedies and can take actions to reduce the probability of their occurrence or severity of their impacts [18]. For the very first time FMEA was used in the 1960's in the aerospace industry during the Apollo missions. In 1974, the US Navy developed MIL-STD-1629 about the use of FMEA. In the late 1970's, the automotive industry started using FMEA and they realized about the advantages of using this tool to reduce risks in order to improve quality of the product [18]. Now this inductive reasoning analysis is in practice in almost every field of engineering and technology and especially it has become a preliminary step of quality engineering, reliability engineering, and safety engineering. FMEA report outlines the findings which have been developed from worksheets. The findings focus on the failure modes which can have significant effects on the system and categorize them as catastrophic, critical, down to minimal, nuisance value, or etc. An FMEA covering the complete system includes its constituent FMEAs by a reviewing and analyzing the interfaces between the subsystems. During the analysis some failure modes are difficult to assess, so FMEA is responsible for the assessment of such failure modes by executing practical tests and generating their results. In time prepared comprehensive FMEA provides technical support in identification of weak points in a system, reduces the cost of modification along the product life cycle [2][4].Organizations spend a lot of effort and high cost to apply FMEA method but still the knowledge they acquire during this analysis is neither reused nor shared. Major reason is that the failure modes are not semantically organized. Their interpretation varies from person to person and from situation to situation. Even there is a possibility that a team prepared an FMEA in one situation, might not be able to apply the same to some other situation. Also reusing of this information becomes imprecise and unproductive because of its larger size and its production again and again [12]. So an IT based solution is needed to store, share, reuse, and infer the knowledge produced by FMEA. Artificial Intelligence (AI) has been supportive in not only storing and manipulating data but also in acquiring, manipulating, and representing knowledge. Knowledge based systems based on the concept of ontologies and expert systems have been popular for addressing knowledge management problems. In this article we will focus on the ontology based knowledge management systems which have been formulated for FMEA. We also propose a conceptual model of an ontology based knowledge management system for FMEA, which we believe is able to solve all above mentioned problems. Ontology is an axiomatic theory, designed for a specific domain composed of objects, and is made explicit by means of a formal specific language [21].

2 Related Work

There are different technologies which have been helpful for applying knowledge, but AI played major role in enabling these systems to work. AI systems are based on the belief that intelligence and knowledge are closely related to each other. Knowledge is associated with the human's capability to manipulate cognitive symbols, whereas human intelligence deals with our ability to learn and communicate our understandings in order to solve problems. Human beings are born with a certain degree of intelligence, by using this they learn and acquire new knowledge. There are some AI systems which are known as knowledge based systems and their purpose is to mimic problem solving capabilities of the experts of a specific domain. These intelligent systems and their associated technologies assist us in every phase of knowledge management [6]. Four AI techniques have been widely used to build knowledge management systems, which are Case Based Reasoning (CBR), rule based expert systems, fuzzy logic, and ontologies. Ontologies are found better than rest of the three, as some disadvantages are associated with rule-based systems (fuzzy or crisp). For example in many situations, a large number of rules are required to represent the domain knowledge, and it could make the inference mechanism quite complex and time consuming, as it adds difficulty in coding, verifying, validating, and maintaining these rules. Moreover they do not have any ability to learn [6]. Whereas the major disadvantage associated with CBR is that all cases are needed to be stored in case library with additional care about their references and attributes, efficient methods are needed to search the cases and identify their search attributes, and they do not provided well presented information to their users [11].
Purpose of ontology development is to provide semantically shared domain knowledge for intelligent inferencing, since ontologies are famous for domains like semantic web, system engineering, bio-medical informatics,software engineering, e-commerce, knowledge engineering, knowl-

edge management, artificial intelligence, natural language processing, etc. Ontologies play a distinct role in information retrieval and information systems, they better serve as system models and help in storing and retrieving knowledge semantically. Ontology engineering is a sub-field of knowledge engineering. Its aim is to make knowledge explicit, which is hidden in software applications, business procedures, and in enterprise repositories [16]. While constructing an ontology for any domain, knowledge acquisition is the major bottleneck, so in the knowledge management systems. But there are some automated knowledge acquisition techniques which can be applied e.g., linguistic techniques to acquire knowledge from unstructured text documents, machine learning techniques to acquire knowledge from structured documents, crawling through web, and requesting experts for required knowledge according to a template [14].

Some work has been found in which ontologies have been helpful in managing knowledge produced by FMEA. Authors in [12] applied ontology based knowledge retrieval approach for distributed knowledge sharing and reuse in the PFMEA domain. Using this strategy the authors were able to construct a complex search patterns, combining many complex roles of PFMEA, and connecting them to a particular instance. This system helped them to establish actions with adequate knowledge retrieval and semantic organization. In [5] the authors realized that traditional way (text based) to represent knowledge produced and used during FMEA, makes it difficult to reuse. That's why they developed an ontology, based on the standard ISO-15926 to improve the representation of knowledge used and produced during FMEA. In [13], authors are trying for lead free soldered, for its accomplishment they need to carry an FMEA to find all critical failures associated to this process and their impact on the quality of lead free soldered joints. They suppose that ontology is suitable to store the knowledge produced during FMEA as it offers the common understanding of the domain of their focus and its procedures; and it is also a computationally processed model to represent knowledge. Authors in [4] believe that FMEA is highly effective method to prevent the failure of a system in early phases of its development but a lot of effort is needed to develop an FMEA and it is difficult to earn the advantages immediately. To get more advantages from FMEA it is needed to shorten its development process by reusing the knowledge gathered in already developed FMEA. Knowledge produced by FMEA is in natural language, that's why systematized components, functions and failure modes are not explicit and are hard to reuse. Most of the times the meanings of such natural language documents, depend on the understanding of the team who prepare these and may not be clearly interpret-able for a different one. Authors found that ontology could help to integrate the related knowledge by providing uniform semantic knowledge of a domain for solving a fore mentioned problems. In [7] authors tried to transform scattered knowledge of extended functional model to FMEA sheets using ontology. Functional model included the knowledge of functional structure and faulty behavior. They developed the ontology by identifying the knowledge models in various forms and mapped the ontology by identifying correspondence relations between the concepts of two ontologies. Authors were also trying to transform this knowledge to FTA. Authors in [20] found that FMEA knowledge structure lacks unified standards because of this it cannot be collected during manufacturing process. Because of this for many organizations FMEA is not an effective and feasible method for improvement in manufacturing process. They proposed a system to extract and convert FMEA existing knowledge to develop a systematic, structured ontology-based FMEA knowledge management system. This system was helpful for intelligent inquiry and reasoning from FMEA knowledge in order to make decisions timely, to handle quality issues in manufacturing process. Similarly [4] [9][19]used ontology to smooth the progress of FMEA proceedings.

They all have done a lot for reusing the knowledge gathered during FMEA using ontologies for different industries but still some very important things are missing from the scene. For the very first time [10] presented an approach to bind FMEA and ontologies together but this model

lacks the facility of inference because according to authors ontology is just a conceptual model without having any rules. Authors in [4] focused on the deficiencies left by [10] by combining knowledge management and quality management systems to reuse the existing FMEA knowledge easily but according to them this work still misses a commonsense ontology to provide the parts of standardized and functional taxonomy. Authors in [13] proposed a method for better FMEA procedure representation using ontologies for lead free soldering but still his work is under research. Moreover no specific ontology is found to address the FMEA knowledge sharing and reuse for automotive domain.
In this article we are proposing a conceptual architecture for ontology based knowledge management system specifically for automotive domain.

3 Proposed Conceptual Architecture

Working of knowledge management systems is based on four major actions; Knowledge gathering, knowledge organization and structuring, knowledge refinement, and knowledge distribution. Figure 1, depicts a conceptual architecture for a knowledge management system and in the following subsections it is described in terms of four major knowledge management actions.

3.1 Knowledge Gathering

Knowledge gathering is the set of activities which are responsible for acquisition of the knowledge to be managed. According to the given model it will be accomplished by gathering existing FMEA reports completed by experts and also by gathering the rationales and heuristics of the knowledge of domain experts.

3.2 Knowledge Organization and Structuring

From information science perspective an ontology is described as formal description of a domain, in terms of instances and relationship between those instances. According to the given model it will describe the basic structure for the instances which will be stored in the knowledge base. Knowledge to be structured and stored will be provided to ontology populator after its extraction from existing FMEA reports and document files composed on the heuristics and rationales of experts. Ontology populator will learn the structure of instances and their relationships from ontology and will populate the knowledge in the knowledge base. To extract knowledge from existing reports some Natural Language Processing techniques will be applied, but depending on the accuracy of the techniques some human intervention would be needed.

3.3 Knowledge Refinement

Once the existence knowledge is gathered the next phase is about its refinement. For refinement of this knowledge some experts will be invited to query the system for specific problems of domain. Purpose of this querying would be to validate the knowledge in the knowledge base that if it is correct or enough to solve all probable problems expected in the domain. These experts will be authorized to update the knowledge base according to their level of expertise. They can add new instances and also can update the existing ones.

3.4 Knowledge Distribution

Once the knowledge base is updated with appropriate and refined knowledge, it is ready to assist its users via browser interface. Inference engine will depict the rationales of experts and will provide intelligent conclusions after inferring through knowledge base. This conceptual architecture is equally useful in multi-user environment, where number of authenticated users can interact with the system via internet.

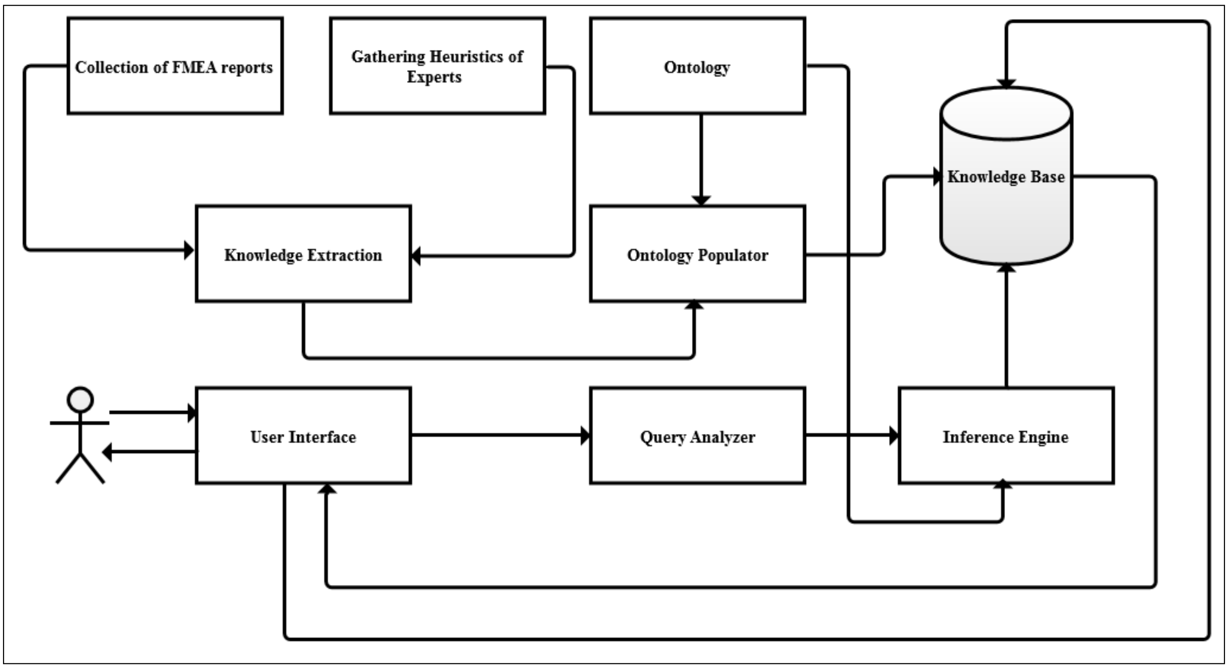

Figure 1: Conceptual Architecture of Ontology Based Knowledge Management System for Failure Mode and Effects Analysis (FMEA)

4 Required Tools and Techniques

Collection of FMEA reports would be in a formal way by requesting the organizations to provide these. Heuristics of experts over FMEA can be gathered by interviewing them about a given scenario and cross validating their views. These views can be stored in machine readable documents. Once the basic knowledge is gathered, GATE (General Architecture for Text Engineering) can be used to extract required knowledge, It is an open source infrastructure to develop and implement software components to process human languages, it helps in keeping data separate from application. We will use Protege to create ontology and its instances. Protege is an open source software tool to develop domain models and knowledge based systems with ontologies. It provides both of the main ways to model ontologies e.g., frame based and OWL. It provides full reasoning support to compute the inferred ontology class hierarchy and for consistency checking. OWL-Lite can be used to get full support of existing Description Logic reasoners for inference engine. Jena can be used to query the ontology and to update its instances.

5 Conclusion

Strategic management of any organization revolves around the risk management. Good risk management focuses on the identification and treatment of the risk in time, to increase the probability of the success and decrease the probability of the failure in achieving overall objectives of an organization. FMEA is a systematic way to identify probable failure modes and their overall effects on a system, if this analysis is timely completed, it helps to reduce the probability of risk occurrence. In this article we proposed a conceptual architecture for ontology based knowledge management system to eliminate the problems regarding poor management of the knowledge produced during FMEA, to timely generate FMEA reports even in the absence of domain experts, and to reuse and share existing FMEA knowledge. Ontologies are like repositories to organize formal knowledge and information represented by common vocabulary of a language to support reasoning, they are becoming the core component for many applications e.g., knowledge portals, knowledge management and integration systems, and e-commerce applications. Ontologies are helpful in exchange of knowledge, reusing existing knowledge, for reasoning and inferring on existing knowledge [17]. As ontologies use common understanding of concepts of a domain this is why FMEA knowledge stored in ontology will be general, comprehensive, machine readable and explicit. In future we will materialize this conceptual model for automotive domain.

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