The Requirement Analysis and Knowledge Management Methodologies in a Product Service System

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Abstract. Manufacturing enterprises are making more efforts in providing high value added services in addition to their traditional product business. A service-centric product service system (PSS) is present in this paper which is used as a decision support tool and offers a means of supporting decision-making for maintenance, repair and overhaul (MRO) solution finding. Requirement analysis technologies are used to identify the final important rating and the technical targets of engineering characteristics (ECs), and reduce the redundant ECs. An ontology-based knowledge representation is developed to represent, accumulate and collect knowledge and experience emerged during the MRO services, which realizes the knowledge originated from the service process and served operations. An initial attemp has been made to demonstrate the role of PSS as a decision support tool for MRO in the aerospace manufacturing business.

Keywords: PSS, MRO, Requirement Analysis, Knowledge Management, Aerospace manufacturing.

1 Introduction

Companies that direct their efforts toward meeting their customer requirements (CRs) produce higher-quality products, provide customized services, ensure a higher degree of customer satisfaction, and earn more revenue. All these benefits are achieved by minimized internal conflicts, cut down turn around time, and made the greater market penetration. The concept of Product Service System (PSS) has been proposed and investigated to better exploit the potential benefits of integrating product development with related services. Practical industrial cases implementing PSS have been investigated in recent years. For example, William [1] applied PSS in the automotive industry. Meier and Krug [2] proposed a PSS solution to the integration of the development and supply of products and services. Mittermeyer [3] applied PSS in health care. Qu [4] applied PSS to serve as a production process. In the aerospace industry, maintenance, repair and overhaul (MRO) services are normally provided during product usage. Given that an airplane is a durable product with a life span of over 30 years, opportunities abound for the application of PSS in aviation maintenance, repair and

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overhaul. The profitability of the aviation industry is not just from the sale of aircrafts, but also from maintaining them for an anticipated lifespan. This research will focus on applying PSS in the aviation industry to specifically support the MRO services.

In the current practice of manufacturing industry, MRO services seriously depend on individuals' experience, which makes the services unstable and uncontrollable. It is realized that knowledge obtained from previous projects is hosted by individual experts, and in turn, individual experts use previous knowledge into new MRO services and obtain new knowledge from them. This makes knowledge sharing and reuse in the service team and related personnel inefficient and ineffective, and thus makes the project risky. To solve such problems during product service activities, the needs of knowledge representation in the process of product services are discussed in this paper, and an ontology-based knowledge representation method for product service process is proposed. To better manage the ontology, a solution for ontology management is developed for ontology definition and building, and evaluation of semantic similarities of concepts among ontology domain. The logical structure and details of the knowledge involved in the product service process are described by ontology building. An ontology-based knowledge representation framework has been developed for the reuse of knowledge unambiguously, which realizes the knowledge originated from the current and previous service processes.

Some of the service offering approaches used in service business include full services, solution selling and total care solutions [5]. The PSS proposed in this research can be regarded as a kind of outsourcing service, which is designed to support decision making in MRO services. In the current industrial environment, manufacturing enterprises are asked to respond rapidly and adjust dynamically to external market and customer requirement changes. The PSS development is a systematic and cross-functional design activity [6]. Although product design and service design focus on different aspects, both product and service should be considered to satisfy the requirements of customers. Quality function deployment (QFD), as an effective customer-driven design tool, has been used successfully to translate CRs into ECs in product or service design. It can be translating CRs into ECs in PSS development. Rough set theory is a relatively new and intelligent knowledge discovery tool. It is widely used to find data dependencies, evaluate the importance of attributes, reveal data patterns, reduce the number of redundant objects and attributes, and seek the minimum subset of attributes [7-10,]. In this research, the Rough set theory approach has been mainly used to reduce the number of redundant ECs, which created by translating from CRs. The analytic network process (ANP) approach has been used to prioritize ECs in order to overcome the shortcomings of the traditional QFD models [11-13]

The main aim of this project is to develop a PSS, and apply it in the aerospace manufacturing industry focusing on the MRO services. To meet the customer requirements emerged during the use phase of product, a framework of PSS based on the requirement analysis is put forward, which integrates Quality Function Development (QFD), rough set theory, ANP approach and ontology-based knowledge reasoning methods. The mapping relationships between customer requirements and engineering characteristics are identified based on QFD-ANP analysis, as well as the weight of characteristics. An ontology-based knowledge reasoning method is used to find the semantically similar generalized product service cases. The PSS configuration scheme set is obtained by optimizing and assessing the selected cases. The reference service solutions for the specific customer requirements will be created using the proposed PSS. The proposed methodology will be developed using web technology to provide lifecycle services and supports, which can be easily accessed through the internet at all times and places. An initial attempt is made to describe the potential value of the PSS in the aerospace manufacturing industry and also to describe how to provide lifecycle services and supports in industry based on the proposed web-based PSS framework.

2 Current Limitations and Objectives of This Research

PSS was first proposed by Goedkoop [14] who described a PSS as a system of products, services, networks of 'players' and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models. The general category of PSS includes product-oriented PSS, use-oriented PSS, and result-oriented PSS [15, 16]. Many systemic and scientific frameworks for modeling PSS have been proposed. However, most researchers only focused on product-orientated PSS. Only a few reported use-orientated PSS and result-orientated PSS, where service is considered as the core part whilst physical products are only carriers for service delivery.

Due to the increasing interests on environmental problems and government regulations for recycling and reusing, considering product lifecycle factors on service activities as well as customer requirements is increasingly more important than in the past. However, only a few QFD works have considered product lifecycle requirements into the process of QFD in spite of its importance [17]. Moreover, most researchers only consider quantitative correlations among engineering characteristics in original QFD. Even though some engineering characteristics have a positive or negative effect on each other, the original QFD method oversimplifies this correlation in the prioritization of engineering characteristics.

In this research, a requirement-oriented PSS will be developed using requirement analysis and knowledge management methodologies, which is suitable for use-orientated PSS and result-orientated PSS. The customer and product lifecycle factors will be incorporated in this research, and exert their significant impacts to the implementation and performance of PSS. The positive and negative effects among different engineering characteristics will be analyzed; a systemic decision-making approach will be used to identify the relative prioritization of engineering characteristics.

3 The Proposed Methodology

Currently, manufacturing enterprises are making more efforts to provide high value added services in addition to their traditional design and manufacturing business, engender a higher degree of customer satisfaction, and earn more revenue. A requirement-oriented PSS has been developed using requirement analysis and knowledge management technologies. The proposed PSS will be regarded as a decision support tool and offer a means of supporting decision-making for MRO services solution in this research. The reference service solutions for the specific customer requirements will be created using the proposed PSS. Figure 1 is the general approach of providing supports and services by the Web-based PSS, which can be divided into 4 steps which are described below.

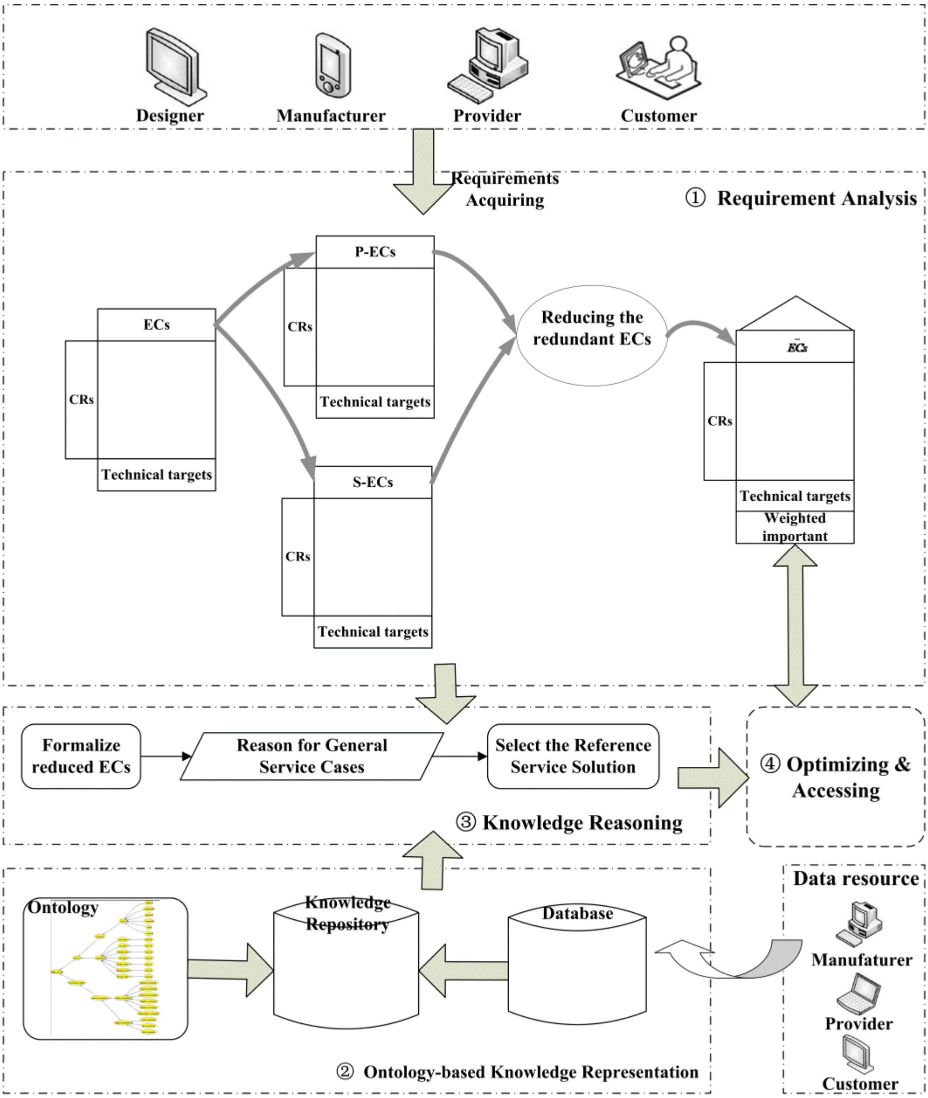

Fig. 1. General approach of providing supports and services by the proposed PSS

- Step 1: Requirements management: to acquire the requirements, and identify satisfactory ECs using requirements analysis methodologies. The redundant ECs will be reduced, and the important weight of reduced ECs will be defined accurately.
- Step 2: Service knowledge representation based on ontologies: Service ontology is build to represent, accumulate and store knowledge and experience emerged during service activities. Ontology-based knowledge representation is proposed to collect and formalize service cases and store them as knowledge in the knowledge repository.
- Step 3: Knowledge reasoning by ontology-based knowledge representation: the knowledge-based method is used here to help and support users for service solution finding. When the service activities are formalized by referring to the predefined ontologies, the formalized services will be reasoned in the knowledge repository to find semantically similar generalized service cases.
- Step 4: Optimizing and accessing: the technical targets which are identified by requirements analysis will be used to evaluateand access the reference service solutions and find the optimal solution for the specific requirements.

4 Technologies for Implementing the Proposed PSS

Three key techniques used in the proposed PSS are introduced in depth in this section, i.e., how to determine the final important ratings of ECs by analyzing the requirements; how to represent the MRO activities and the relationships between them by ontology; how to reuse the service knowledge which are collected from service cases, and use the reasoning method to find the similar generally service cases in the knowledge repository.

4.1 Requirement Analysis

It is not easy to identify satisfactory engineering characteristics because the information in the early stage of product service system planning is subjective, qualitative, and even uncertain to engineers. As a well-known planning and problem-solving methodology, QFD is used to support product service system design in this research. A step by step proceduce, starting from requirements acquiring until the prioritization stage, is described below.

Acquire customer voices or requirements from customer and market. The mentioned requirements here are including internal requirements and external requirements. The former consists of the requirements emerged during different phases of product life cycle, e.g., design, manufacturing, usage, disposal. The external requirements are not only customers' requirements, but also providers' and partners' requirements. The methods of acquiring are mainly including survey, interview, self-report, observation and so on. For complete or near complete sentences, begin with a capital letter and end with a full stop. Acquire customer voices or requirements from customer and market.

Identify general requirements and the relationship among these requirements. Firstly, three distinct types of information must be identified from requirements acquiring, e.g., Jobs, Outcomes, Constraints. Jobs represent what the customers are trying to get done when using the product or MRO service. Outcomes indicate what the customers are trying to achieve when performing these jobs. Constraints describe the roadblocks that stand in the way of them performing a specific job. After identifying general requirements, there may be three kinds of relationships between any two requirements: a positive relationship, a negative relationship, and a non-relationship, respectively. Then, the positive and negative effects between these requirements will be analyzed, and the important weightings of CRs will be calculated by ANP method.

Develop ECs from CRs based on House of Quality (HoQ) model in QFD. HoQ model is primarily used to describe the relationships between and within CRs and ECs. The functional requirements (FRs) will be identified by analyzing the customer requirements (CRs). Then, the FRs in the functional domain will be translated into engineering characteristics (ECs) using QFD approach, including product-related ECs (P-ECs) and service-related ECs (S-ECs). A set of ECs candidates will be determined, some of the ECs candidates may be redundant, and the conflict relationship between the ECs candidates may also exist. Therefore, the further selection from the ECs candidates is essential.

Reduce the redundant ECs. To identify the most important characteristics and remove the unnecessary ones in the EC set. Rough set theory as a relatively intelligent knowledge discover tool is used to evaluate the important of ECs, reduce the number of redundant ECs, and seek the minimum subset of ECs. The new EC set, which produced by attribute reduction, can fully characterize the knowledge, such as EC set is called a reduct. The reduct can be thought of as a sufficient set of engineering characteristics.

Determine the relative weightings between CRs and the reduced ECs. A relationship between CRs and ECs is defind as “a decision matrix”. A decision matrix is created combining the result of the computation with calculated CRs. QFD method is used to obtain the importance weights of ECs based on CRs and relationships modeled in the HoQ. In order to accurately define the importance weights of ECs, the inter-dependency relationships between CRs and ECs (including P-ECs and S-ECs), the inter-dependency relationships between P-ECs and S-ECs, and the inner-dependency relationships among these three clusters should also be taken into consideration in QFD analysis.

Calculate the overall weight of each ECs. To define the importance weights of ECs accurately, ANP method is used to form a network considering the interactions at different levels. Moreover, the relative weights of each EC will be calculated by ANP method.

Determine the final important rating of ECs. The final weights of ECs are obtained based on QFD and HoQ. The technical targets of ECs are also determined. The most important ECs will be formalized by referring to a set of predefined ontology, and reasoned in the knowledge repository of the proposed PSS to find semantically similar generalized MRO service cases. The technical targets will be used to evaulate and access the reference service solution and find the optimal solution for the specific requirements.

4.2 MRO Services Knowledge Representation

Advanced computing methods and related technologies are changing the way engineers interact with the information infrastructure. Knowledge management (KM) is widely used in service activities, and helpful to enhance enterprises' service capabilities. As the basis of KM, knowledge representation formalisms and methods perform a decisive role in KM.

As an appropriate representation scheme, ontology is adopted to effectively define the knowledge hierarchies in service activities and the relationships between them. Ontology describes the concepts in a domain of interest and the relationships that hold between those concepts [18, 19], as well as providing powerful tools for querying and information retrieval and automatic causality extraction using semantic similarity [20, 21]. Ontology is also used to address the semantic shortcomings and matchmaking difficulties associated with semantic Web technology [22, 23]. In this research, service ontology is developed to represent the semantic information and relationships between functional modules and process modules. Moreover, the relationship information between service functions and processes will be represented by ontology to provide the inputs, outputs and constraints for MRO processes design. The service engineering characteristics and product engineering characteristics are classified by knowledge representation to fit the ontology structure. The solution for ontology management is shown in Figure 2, which mainly involves ontology defining and modeling, and semantic similarity evaluation.

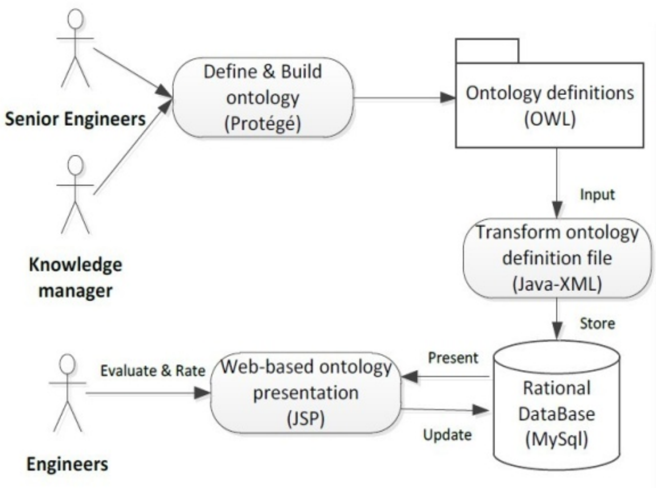

Fig. 2. Solution for Ontology Management

*Ontology Defining and Modeling***.** The concepts used in the MRO process will be defined by knowledge manages and senior engineers. The mentioned concepts here, involve two parts, i.e. the predefined part and extended part. The former one can be considered as general engineering concepts, which is normally in higher level of abstraction. The extended part means the specifically concepts, which is used in the company and generated based on the predefined concepts.

Suppose that the formalization of ontology can be described as: O=(S, RS, I). O represents the ontology; S represents the collection of all concepts, each concept in S can be regard as a class, and the class is inherited by subclass; I represents the instances of the class; RS represents the relationship between every two concepts, i.e. part_of, has_part, Sibling_of, attribute_of, has_attribute, instance_of, has_instance, and so on. Protégé is adopted as an ontology editor to formalize predefined ontology in computer language, which was developed by Stanford University and used in the academic area for ontology development. By using the tool, the ontology is formalized with OWL2 specifications. Physically it is stored in a XML file. The ontology definition file is processed and transformed using java technologies. The transformed ontology will be stored in a rational database, and be used with other parts of the system.

*Evaluation of Semantic Similarities of Concepts***.** The main aim of this step is to evaluate and rate semantic similarities between concepts. The rated ontology will be used in the knowledge repository management, and used to find the solution and support decision making in the other parts of the system. The evaluating and rating work will be conducted by engineers in the related departments. The rules of evaluation and rating are described below, which are carried out in two steps: (1) Evaluate and rate semantic similarities between the parent concept and its child concepts. (2) Evaluate and rate semantic similarities between sibling concepts.

Suppose that S represents a set of services: S = {S1, S2, S3 … Sn}. Where S1 consists of a set of MRO services and their functions. P represents the process of MRO service: P = {P1, P2, P3, …, Pn}. F represents the function of MRO service: F = {F1, F2, F3, …, Fn}. SP represents the sub-process of service, P1 consists of {SP11, SP12, SP13, …, SP1n}. Since P1 is the parent of SP11 and SP12, S1 is the parent of P1 and F1, P1 and F1 are siblings, which are described as: SP11 $\in$ P1; SP12 $\in$ P1 and P1 $\in$ S1; F1 $\in$ S1. Suppose that the number of engineers who are going to evaluate and rate the similarities between concepts is m. Each engineer will be given the credibility by knowledge manager according to their engineering experience, which represented as C = {C1, C2, C3, …, Cm}, more experienced engineers have higher credibility. Taking an example of rating semantic similarities between S1 and P1. The final result of semantic similarity Sim (S1, P1) can be represented as Equation (1). The similarity of the sibling classes (F1 and P2) can be represented as equation (2).

$$\mathrm{Sim}(S_1, P_1) = \frac{\sum_{i=1}^{m} C_i \times Sim\,(S_1, P_1)_i}{\sum_{i=1}^{m} C_i} \tag{1}$$

$$\mathrm{Sim}\,(\mathrm{F1},\mathrm{P2}) = \left\{ \begin{aligned} & \frac{\sum_{i=1}^{m} C_i \times Sim\,(\mathrm{F_1},\ \mathrm{S_1})_i}{\sum_{i=1}^{m} C_i} \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(\mathrm{S_1},\ \mathrm{S})_i}{\sum_{i=1}^{m} C_i} \\ & \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(\mathrm{S},\ \mathrm{S_2})_i}{\sum_{i=1}^{m} C_i} \times \frac{\sum_{i=1}^{m} C_i \times Sim\,(\mathrm{S_2},\ \mathrm{P_2})_i}{\sum_{i=1}^{m} C_i} \end{aligned} \right\} \qquad (2)$$

Ontology-based Knowledge Representation. To represent, accumulate and store knowledge and experience emerged during the MRO services, an ontology-based knowledge representation framework has been proposed to collect and formalize service cases from engineers' everyday work and store them as knowledge in the knowledge repository, as shown in Figure. 3.

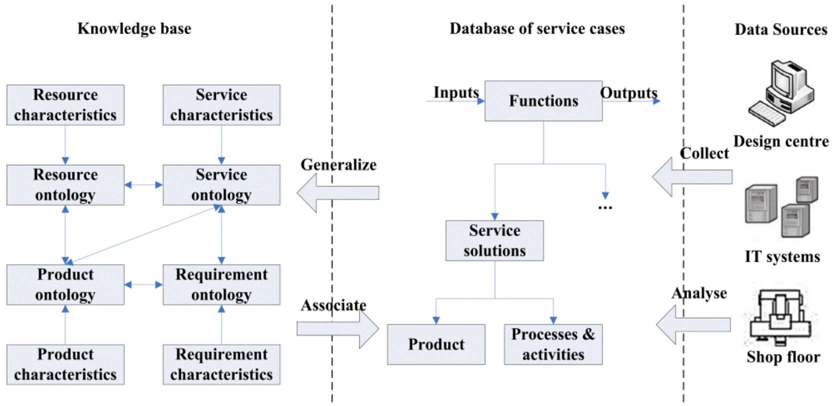

Fig. 3. The Framework of Ontology-based Service Knowledge Representation

The proposed system is developed for the reuse of knowledge unambiguously, which realizes the knowledge originated from the service process and served service process. In this system, service cases are collected from various sources including different information systems and functional departments. The service cases are formalized in a hierarchical way, which clarifies the functions the service case is to address. Moreover, the service cases can be further decomposed into components and characteristics. Therefore, the predefined ontology can be used to tag each element of the functional model and then the service case with tagged semantic meaning can be stored in the knowledge repository. The knowledge representation method will be applied to enable the proposed PSS that can provide users with various functions that are searching, sharing, and reusing information in the distributed environments.

4.3 A Knowledge-Based Method Support for Service Solution Finding

A knowledge-based method is used here, to help and support engineers for service solution finding. When the mission and objectives of MRO service are identified by requirement analysis, the MRO service will be formalized by referring to the predefined ontology. Then the formalized MRO service will be reasoned in the knowledge repository to find semantically similar generalized service cases. Therefore, specific service cases that are associated with generalised service cases can be retrieved. These selected service cases will be used as reference solutions for the current CRs.

The aim of formalizing MRO activities is to formalize the service function model and the component where the service occurs. In this research, formalizing service activity is not only formalizing the service activity itself, but also formalizing inputs, outputs, resources, constraints, relationships between service functions and service processes. Figure 4 shows the MRO service model formalized by the pre-defined ontology. Product ontology defines the type of product and consists of system ontology and component ontology. A product is composed of several subsystems such as flight control system, fuel system, electrical system, propulsion system and oxygen system, and each sub-system is composed of many components. Service ontology defines the methods, processes, activities, and organization in the MRO services. It can be divided into function ontology and process ontology. Flow ontology defines the type of the flow. The characteristic ontology defines the properties of the product and service activities.

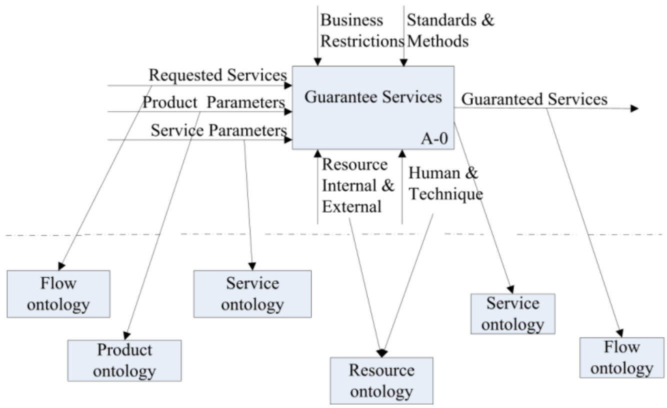

Fig. 4. Formalization of the MRO Model

An ontology-based knowledge reasoning method is proposed to find semantically similar generalized service cases. The MRO activity is decomposed into inputs, outputs, resources, constraints, relationships between service functions and service processes, each of them will be tagged with predefined ontology. The reduced characteristics of components and services which are identified by requirements analysis will be considered as important factors, and are also formalized with predefined ontology. After formalizing concepts for each parts of the decomposed service activity, the semantic similar service case will be retrived by knowledge reasoning. These selected service cases will be used as reference solutions for the current CRs.

5 Conclusions and Further Work

This paper presented on-going research into the development of a Web-based Product Service System using requirement analysis and knowledge management technologies. A service-centric PSS have been proposed which is suitable for result-orientated PSS and use-orientated PSS. The proposed PSS is used as a decision support tool and offer a means of supporting decision-making for MRO solution finding. QFD-ANP are used to identify the relationship among CRs, FRs and ECs, as wll as the final important rating and the technical targets of ECs. Rough set theory is used to reduce the redundant ECs. Furthermore, Ontology-based knowledge representation has been developed to represent, accumulate and collect knowledge and experience emerged during the MRO services. Predefined ontologies have been stored in the knowledge repository of the proposed PSS. The most important ECs which are determined by requirements analysis, will be formalized by referring to a set of predefined ontology, and reasoned in the knowledge repository of the proposed PSS to find semantically similar generalized MRO service cases. The technical targets will be used to evaulate and access the reference service solution and find the optimal solution for the specific requirements. The emphasis of further work will be on the development of the proposed PSS for evaluating and accessing the effectiveness of the operation, and applying the proposed PSS in the real industrial company. In the next stage of this research, integrating with other enterprise systems will be developed to acquire knowledge regarding contributions that previous cases made to related requirements.

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