A Knowledge Management Framework for Remote Maintenance

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Abstract—**Plant maintenance is a critical role in the success of manufacturing enterprises. The concept of remote maintenance (or e-maintenance) n the industry refers to the integration of the information and communication technologies to service for plant maintenance remotely. Remote maintenance is characteristic of knowledge intensive and collaborative. To improve the efficiency of knowledge management and so as to improve the quality of remote maintenance work, a knowledge management framework was proposed. In the model, maintenance business ontology provides a common understanding for maintenance business to share information for knowledge management, and knowledge integration network describes the relationships among role knowledge, task knowledge and equipment knowledge, to achieve the integration of maintenance business and knowledge resources. At last, the paper illustrated the application of the proposed model. Results of this study can improve the level of knowledge management for remote maintenance.**

Index Terms—**remote maintenance, knowledge management, knowledge integration network, ontology**

I. INTRODUCTION

Remote maintenance (or e-maintenance) is the totality of all maintenance, repair, overhaul and operation in the stage of use and maintain equipment remotely. It is a critical role in the success of manufacturing enterprises, and also is the core of the manufacturing services support technology [1]. Remote maintenance integrates maintenance theory in the information technology, communication, and enterprise management method to service for plant maintenance [2].

Remote maintenance is characteristic of knowledge intensive [3]. Each of Maintenance tasks requires employing of various knowledge and experience. Member of remote maintenance alliance has the willing to share knowledge, so as to cooperate with other members and finish the remote maintenance work. The key to successful remote maintenance is full understanding and effective sharing of knowledge throughout the remote maintenance cycle. Consequently, knowledge management approach capable of supporting the accumulation knowledge and experience in a distributed environment is one of the important guarantees to the successful execution of remote maintenance.

The research of knowledge management for remote maintenance has been emphasized in manufacturing industries, and many researches provide theories and methods for knowledge sharing of remote maintenance [4-9]. However, in addition to the effective sharing, knowledge also requires effective integration model to rapidly respond to the demand of maintenance work [10]. Few studies have focused on this issue.

According to the characteristics of business-driven and distributed cooperation, this paper proposes knowledge management framework for remote maintenance. In the framework, maintenance business ontology provides a common understanding for maintenance business to share information for knowledge management, and knowledge integration network describes the relationships among role knowledge, task knowledge and equipment knowledge, to achieve the integration of maintenance business and knowledge resources. The model can support the overall view of knowledge resources in remote maintenance, and to achieve the effective organization and application of maintenance knowledge.

II. REMOTE MAINTENANCE PROCESS CHARACTERIZATIONS

Remote maintenance concept model is shown as in Figure1. Remote maintenance is an approach to integrating resources from different enterprises to overcome the problem in plant maintenance and the tools/systems can be quickly and easily reconfigured by adding, adapting, adjusting and deleting individual tools/systems as needed. These tools/systems run on various platforms, which may be located in dispersed locations. Remote maintenance has the following characterizations:

Alliance Organization: organization structure of remote maintenance is maintenance alliance. Maintenance alliance is a virtual organization in which different enterprise share the processes, activities and resources of maintenance to provide a value-add maintenance services.

Business-centered: Participants in a remote maintenance process works together on a business with a commonly agreed time frame and have a common goal and well-defined responsibilities. Maintenance business is a process that consists of series of activities. An activity also can be further divided into lower level activities. This forms the hierarchical structure of processes.

Remote and On-line working: In addition to the necessary on-site operation, maintenance works are carried out by network remotely.

Distributed and cooperativeness: maintenance resources may be located in dispersed locations, and maintenance worker who take chare of the maintenance task may come from difficult enterprise. Individual activities performed together with other activities to achieve higher-level goals through communication and coordination.
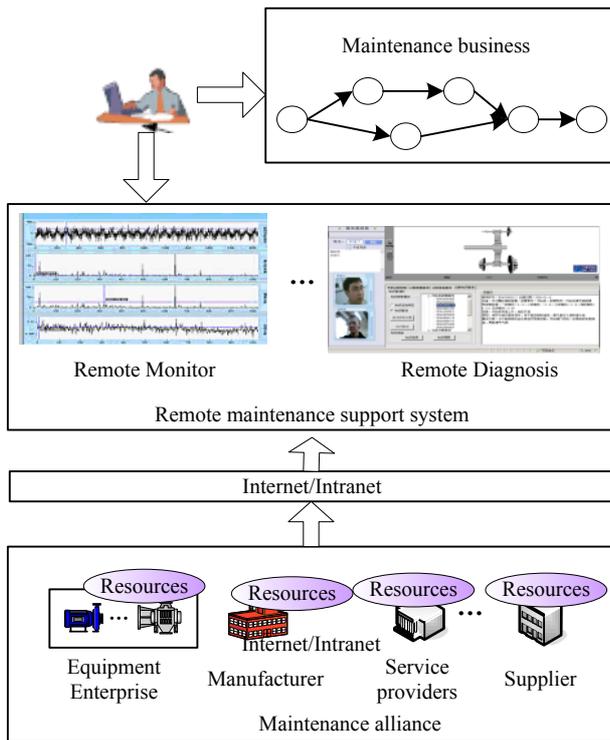
Figure 1. Remote maintenance concept model

Equipment-faced: remote maintenance processes are configured dynamically based on Mechanical Equipment characteristics and Mechanical Equipment maintenance life cycle.

III. KNOWLEDGE MANAGEMENT FRAMEWORK FOR REMOTE MAINTENANCE

According to the characterizations of remote maintenance, the framework of knowledge management is shown as in Figure 2. This framework is made up of Maintenance Business Ontology (MBO), Maintenance Knowledge Description Model (MKDM), and Knowledge Integration Network (KIN). Each part defined as follows:

Maintenance Business Ontology (MBO): The MBO is a sharable ontology built by the dominant enterprise to provide a common understanding for operational model of maintenance business. The MBO enables the federation members to share information on business for knowledge integration.

Maintenance Knowledge Description Model (MKDM): The MKDM is knowledge description model to provide registration specification for knowledge management. A collaborative enterprise registers a sharable knowledge object based on the MKDM and then knowledge management system integrate the knowledge item into knowledge network automatically.

Knowledge Integration Network (KIN): The KIN is made up of the logical relationships to achieve the integration of maintenance business and knowledge resources. The KIN is made up of Knowledge Object Graph (KOG), Enterprise Knowledge Node Graph (EKNG), Alliance

Knowledge Node Graph (AKNG. The KOG is made up of knowledge objects and their relations which defined by maintenance alliance. The EKNG is the mapping of the MBO and is made up of knowledge nodes and their relations within a collaborative enterprise. Each Alliance Knowledge Node (AKN) is the mapping of the concept in the MBO and links with one or more Enterprise Knowledge Nodes. Each Enterprise Knowledge Node (EKN) is the mapping of the concept in the MBO and links with one or more Knowledge Objects (KO). By using the knowledge integration mechanism, distributed EKNGs are integrated into the AKNG established by the dominant enterprise, hereby creating a global knowledge network with address connected physical knowledge. Thus, collaborating enterprises can share their own knowledge with other knowledge workers in collaborating enterprises to increase knowledge value.

IV. ESTABLISHMENT OF KNOWLEDGE MANAGEMENT FRAMEWORK

A. Establishment of MBO

Ontology [11] is an explicit, shared and formal description of important concepts and their relationships. The purpose of ontology ies to define knowledge concepts within a specific domain using an interoperable format both humans and machines can understand, thereby realizing knowledge sharing and reuse. With the appropriate use of ontology, it is easy to realize semantic information exchange in knowledge management. Enterprise ontology is a collection of terms and definitions relevant to an enterprise to ensure that all parties involved have a shared understanding of the relevant aspects of an enterprise [12]. Enterprise ontology plays a crucial role in enterprise's knowledge management [13]. To establish a process-oriented knowledge supply model, enterprise ontology is also adopted to enable the e-maintenance federation to share commonsense concepts used in knowledge supply.

MBO can be expressed as:
$$MBO = (C, R).$$
Where C is ontology concept set, and R is ontology relation set.

Top level concepts and relations of MBO are shown as in Figure 3. Maintenance Activate Ontology (MAO) describes the activity concept and the relationship in the maintenance business. Maintenance Role Ontology (MRO) describes the role and relationship of the federation and maintenance members. Mechanical Equipment Ontology (MEO) describes the concept and relationship of equipment and its parts and reflects the hierarchy and structures of equipment parts.

B. Establishment of MKDM

MKDM can provide the overall view of the resources for knowledge management. MKDM is represented as follows:

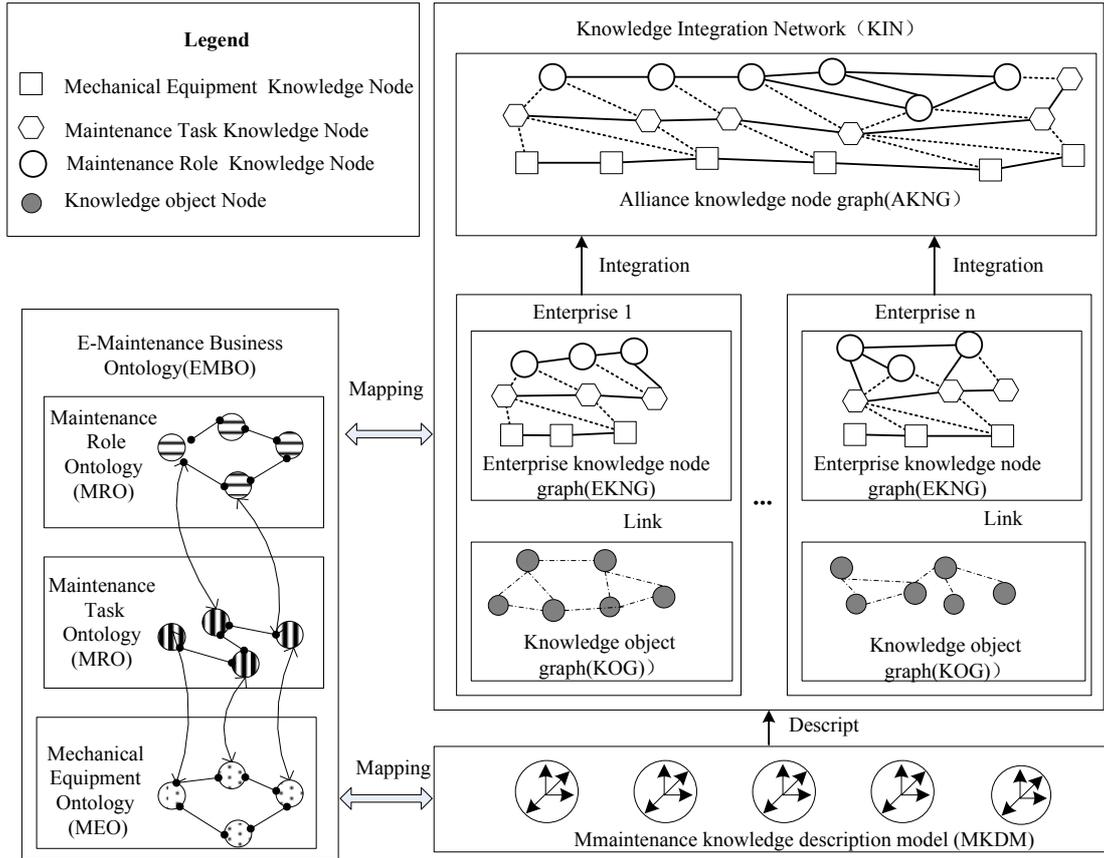$$MKDM = (Background, Content, Application).$$

Figure 2.   Knowledge Network Model for E-Maintenance
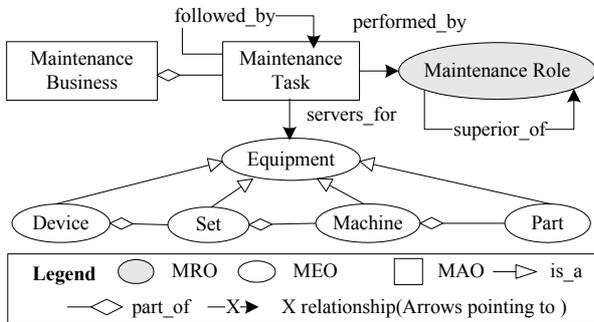

Figure 3.   Top level concepts and relations of EMFO

Where *Background* is knowledge background, which has the basic information of the knowledge; *Content* is knowledge content, which describes the content of knowledge; *Application* knowledge application, which describes the applicable scope of the knowledge.

Background describes the background information of knowledge object. Background is represented as follows:

Background = (*Owner, Author, CreationDate, Modify-Date*).

Where, *Owner* is owner of knowledge object; *Author* is author of knowledge object; *CreationDate* is the date when knowledge object is created; *ModifyDate* is the date when knowledge object is modified.

Content describes function of knowledge content. *Content* is represented as follows:

Content= (*Category, Level, Version, Keywords, Abstract, Evaluation, Location*).

Category is classification of knowledge function, and is defined by maintenance alliance. *Level* reflects different structures and storage forms of knowledge. *Level* classifies knowledge into five knowledge levels of "Description", "Rule", "Procedure" and "Case". *Version* is the version of knowledge object. *Abstract* is abstract description of knowledge object. *Keywords* is a collection of words, which descript the function of knowledge object. *Evaluation* is evaluation value of knowledge quality. *Location* is the location of knowledge object.

Application is expressed as:

Application = (*MRS, MTS, MES*).

MRS is the role set, which describes the suitable roles of knowledge. $MRS = \{ROC_1, ROC_2, \cdots, ROC_n\}$, ROC_i (1≤i≤n) is the concept of the MRO. *MTS* is the task set, which describes the suitable takes of knowledge. $MTS = \{AOC_1, AOC_2, \cdots, AOC_m\}$, AOC_j (1≤j≤m) is the concept of MAO. MES is the equipment sets, which describes the suitable the suitable equipments of knowledge. $MES = \{EOC_1, EOC_2, \cdots, EOC_p\}$, EOC_k (1≤k≤p) is the concept of MEO.

C.   Establishment of knowledge network model

1. Knowledge node graph is directed graph which describes the knowledge nodes and their relationships. Knowledge node graph is defined as:

$$G^{KN} = (V^{KN},\ E^{KN}),$$

V^{KN}: Set of Knowledge Nodes (KNs),

E^{KN} : Set of relations between Knowledge Nodes and $E^{KN} \in R$.

G^{KN} includes G^{EKN} and G^{AKN}。G^{EKN} is Enterprise Knowledge node graph which describes the Enterprise knowledge nodes(EKN) and their relationships；G^{AKN} is alliance knowledge node graph which describes the Alliance knowledge nodes (EKN) and their relationships.

Definition 1：Knowledge Core (KC) is EMBO concept contained in knowledge node and each knowledge node has a KC.

Definition 2：Knowledge Inventory (KI) is amount of knowledge contents within knowledge node. For AKN, KI is amount of EKNs within one AKN. For EKN, KI is amount of KONs within one EKN.

AKN is defined as:

$$AKN= (AKNID, KC, KI, P_{AKN})$$

AKNID is the unique number of alliance knowledge node which maintenance alliance assign; *KC* is Knowledge Core of *AKN*; *KI* is Knowledge Inventory of *AKN*; P_{AKN} is set of alliance knowledge node features, developed by maintenance alliance according to the application.

2. Knowledge object graph is Directed graph which describes the knowledge objects and their relationships. Knowledge object graph is defined as:

$$G^{KON}=(V^{KON},\ E^{KON})\ ,$$

V^{KON}: Set of Knowledge Objects (KNs);

E^{KON}: Set of relations between Knowledge Objects. *The types of R^{KON} is defined in Table2.*

EKN is defined as:

$$EKN= (EKNID, EID, KC, KI, P_{EKN})$$

EKNID is the unique ID number of alliance knowledge node which enterprise alliance assign; *EID is* ID number of enterprise; *KC* is Knowledge Core of *EKN*; *KI* is Knowledge Inventory of *EKN*; P_{EKN} is set of enterprise knowledge node features, developed by enterprise according to the application.

3. Knowledge link graph includes G^{AEKN} and G^{NO}.

G^{AEKN} is the link sets between alliance knowledge nodes and enterprise knowledge nodes. G^{AEKN} is defined as:

$$G^{AEKN}=\{ael_{ij},\ 1\leqslant i\leqslant n\ ,\ 1\leqslant j\leqslant m\ \},$$

ael_{ij} is the link between one alliance knowledge node and one enterprise knowledge node.

$$ael_{ij}=(akn_i,\ ekn_j),$$

akn_i is alliance knowledge node and ekn_j is enterprise knowledge node.

G^{NO} is the link sets between enterprise knowledge nodes and knowledge object nodes. G^{NO} is defined as:

$$G^{NO}=\{nol_{ij},\ 1\leqslant i\leqslant n\ ,\ 1\leqslant j\leqslant m\ \},$$

nol_{ij} is the link between one enterprise knowledge node and one knowledge object node.

$$nol_{ij}= (ekn_i,\ kon_j),$$

ekn_i is enterprise knowledge node and kon_j is knowledge object node.

KON is defined as:

$$KON= (KONID, EID, KOL)$$

KONID is the unique ID number of knowledge object node which enterprise assign; *EID is* ID number of enterprise; *KOL* is location of knowledge object which link with knowledge object.

Based above define, the data structure of the model is shown as in Figure 4.

V. APPLICATION

Based the knowledge management framework for remote maintenance, a knowledge management system had been developed (Figure 5).

Functions of system are as follows:

1. The Ontology Management supports the construction and maintenance of MBO. The system uses Protégé to develop the MBO and Jena [14] to enable creation, modifying, maintenance of ontology. Figure 6 is Protégé development interface of MBO.
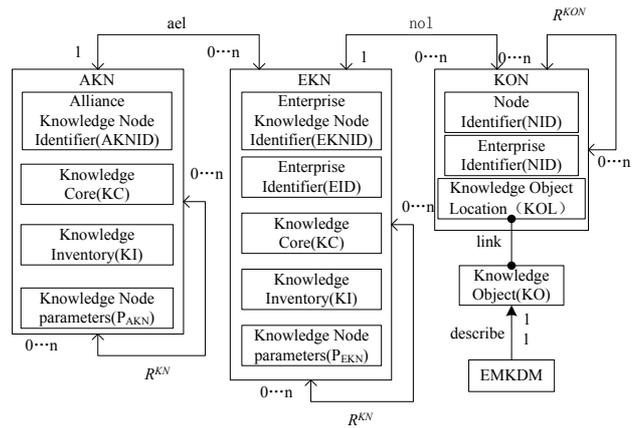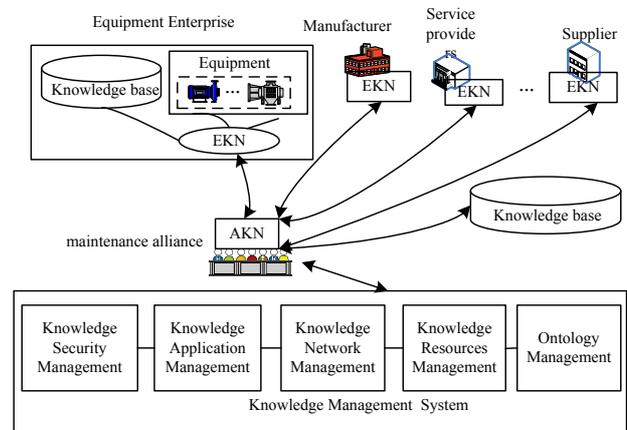

Figure 4. Data structure of the model
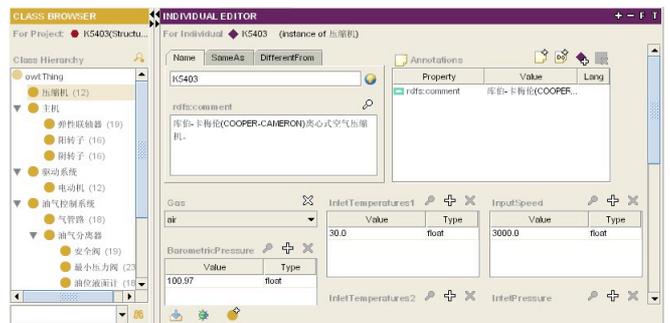

Figure 5. Knowledge management system

Figure 6. Protégé development interface of MBO

2. The Knowledge Resources Management supports registration, query and maintenance of knowledge object. Figure 7 is Knowledge object register interface.

3. The Knowledge Network Management supports creation, deletion and integration of knowledge nodes. Knowledge node search interface is shown as in Figure 8

4. The Knowledge Application Management takes business process as the core and integrates knowledge resources in order to adapt to the maintenance business operation. Its development is based process-oriented knowledge supply model [3] which the author had been developed.

5. The Knowledge Security Management takes business process as the core to protect the knowledge. Its develop-ment is based business-process-context-based knowledge access control model [15] which the author had been developed.

VI.   CONCLUSION

Knowledge is one of core e-maintenance resources and critical support element of maintenance process. The knowledge management framework is proposed to achieve the integration of maintenance business and knowledge resources. From the application, it is known that the model can support the navigation knowledge, supply activities, and improve the efficiency of knowledge management.
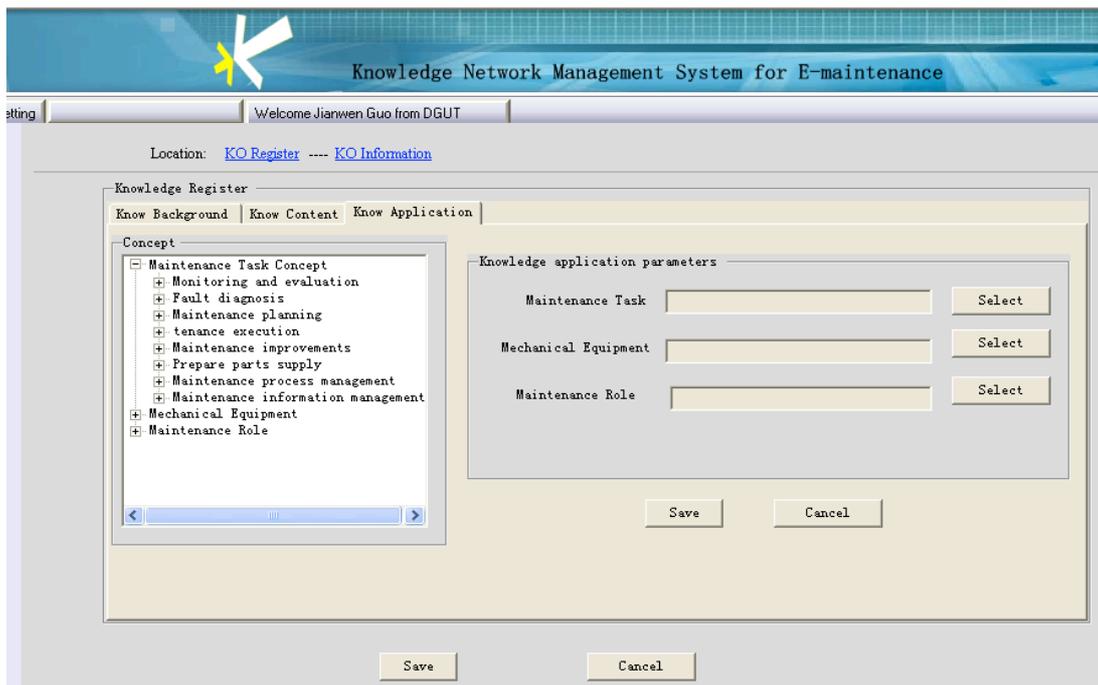

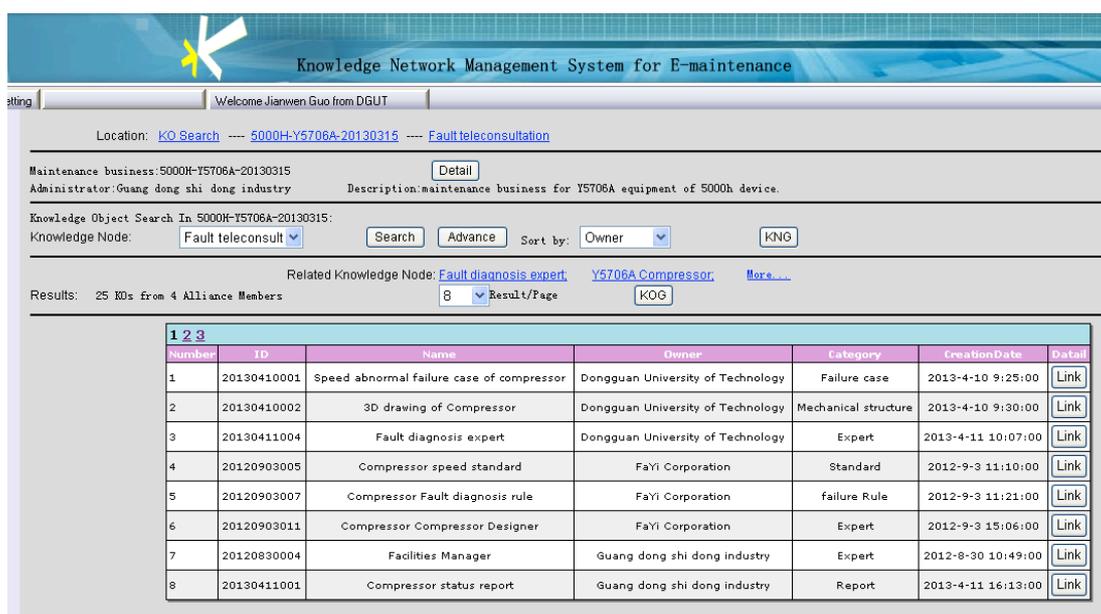
Figure 7. Knowledge object register interface

Figure 8.   Knowledge node search interface

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