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# HIGH-SPEED LOCOMOTIVE XBOM ONTOLOGY MODELING RESEARCH SUPPORTING MRO SEMANTIC KNOWLEDGE REPRESENTATION

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**Abstract:**
***The new trends of high-speed rail locomotive manufacturing set higher requirement for MRO knowledge representation and XBOM. Therefore, XBOM ontology modeling supporting MRO semantic knowledge representation has become an important research topic of the high speed railway locomotive manufacturing industry. This paper firstly expounds the model frame of high-speed locomotive XBOM ontology, then take the global ontology, the construction ontology and the maintenance plan ontology as examples; respectively carding and analyzing four approaches each ontology contains that class (concept), object, data attribute, and constraint rule and central with the supporting MRO semantic knowledge representation, the XBOM ontology conceptual model can be created; At last, High speed rail train MRO semantic knowledge representation was realized by using protégé4.1 ontology modeling of XBOM for high-speed locomotive.***

**Keywords:** *MRO; Semantic Knowledge; XBOM; Ontology Modeling.*

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## 1. Introduction

BOM (Bill of Material, covering the whole life of the product material, including raw materials, all kinds of parts, tooling, equipment, etc.[1]Usually the product will be followed by design, technology, manufacturing, operation and maintenance of the four processes. Also corresponding to a variety of material names are similar, but the BOM structure and the associated information of different materials list, respectively including, design BOM, configuration BOM, procurement BOM, manufacturing BOM, resume BOM, repair BOM, etc. These BOM, called XBOM. [1]Therein to, maintenance of BOM can be used to organize and manage the complex product MRO service stage of the huge MRO information resources, provide timely accurate information support for Product MRO service process [2-3]. The maintenance BOM information of equipment maintenance system EAM developed by SAP company is based on the material master record. Right now; it is limited to manage the operations related spare parts. Therefore, this maintenance BOM can provide information support to maintenance process and spare parts plan of

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maintenance function module, supporting enterprise operation and maintenance planning process to some degree, improved operation and maintenance systems management efficiency, but unable to provide comprehensive MRO service information support.[4]Muh-CherngWuet al. designed a method to maintain the BOM configuration that can effectively reduce the maintenance spare parts purchasing cost. [5]

MRO (maintenance, repair, operations) usually refers to maintenance, repair and operating supplies, mainly refers to the production facilities, operation and maintenance of spare parts , administrative office equipment, supplies and other parts and items [6].For large and complex equipment such as high-speed rail locomotives, MRO phase is an important longest in product life cycle and a stage that related interest parties are most closely related such as product users, manufacturers, services, etc. Therefore, continuous scientific maintenance, repair and operation for large complex equipment is significant to stakeholders of large complex equipment. Liu and others put forward a set of operation and maintenance early warning program in view of the large and complex equipment operation and maintenance process early warning mechanism is not comprehensive, unreliable problems. First, the five tuple is used to describe the general warning, realizing the comprehensive monitoring and early warning of the maintenance process. [7] Ren and others to improve the efficiency of MRO knowledge retrieval and reuse, BOM construction level in equipment for the skeleton and organization and representation of a system about MRO knowledge of maintenance procedures, maintenance history, and maintenance cases. On the basis of this, established MRO knowledge management framework based on ontology and knowledge in the field of multiple MRO service oriented view, realizing the flexibility of MRO knowledge application and the intelligent MRO service process. [8]

MRO knowledge representation is a kind of description of MRO knowledge and the first step of the MRO knowledge management. At present, the main method of knowledge representation can be classified into three categories. [9]: The first kind is the unconstructed knowledge representation; The second kind is the construction knowledge representation; The third kind is the knowledge representation method of semantic Web. The emergence and development of semantic Web technology will greatly promote the innovation and development of resource knowledge management technology. [10]At present, in the definition of ontology, the most popular is Gruber .T R given: “Ontology is an explicit specification of the conceptual model.”[11], He also puts forward five rules of ontology modeling including clarity and objectivity, consistency, completeness, maximum monotonic scalability, and minimal commitment. In addition, foreign universities and research institutions have developed a number of ontology construction tools including Onto Edit, KAON, Web ODE and Protégé, among them, the Protégé tool developed by Stanford University is the most powerful and widely used. Ontology is a conceptual model for formal description of resources on the semantic and knowledge level and is the core of the semantic Web, has become an important way of XBOM semantic modeling for MRO services.

This paper constructs a XBOM ontology model which supports MRO knowledge representation, realizing the semantic representation of MRO knowledge of high speed railway locomotive. Lay the foundation to effective support MRO service in order to make full use of the existing MRO knowledge of the enterprise. This article also to a high-speed locomotive as an example, doing XBOM ontology modeling based on the protégé software. These studies has a positive role in

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promoting to make full use of enterprise MRO knowledge, the high speed railway MRO service management to modernization and intelligence.

## 2. Framework Design of XBOM Ontology Model for High Speed Railway Locomotive

In this paper, we use the "seven steps" of the ontology modeling built by Stanford University to establish the XBOM ontology model of high speed railway locomotive for MRO knowledge representation.

High-speed locomotive XBOM ontology involves multiple areas of knowledge. In this paper, reference to the literature[13] putting forward the grid fault diagnosis knowledge ontology classification method, starting from the application requirements of MRO domain, the high speed railway MRO service is divided into equipment configuration, maintenance plan, operation monitoring, fault diagnosis and maintenance case area. About the construction of global ontology and domain ontology framework is shown in figure 1.

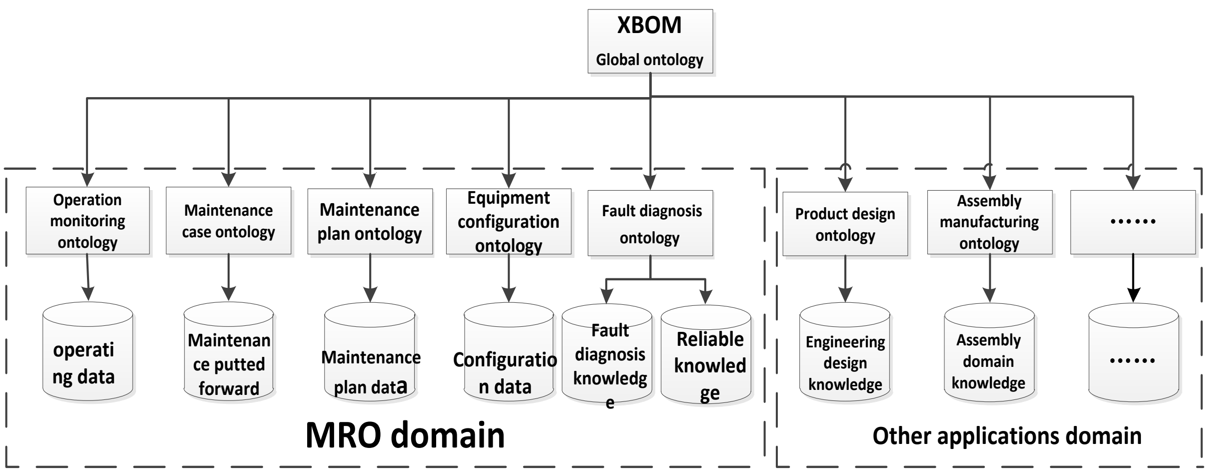


Figure 1: XBOM ontology model framework of large complex equipment

In this paper, the top-down method is used to classify the field concept: Starting with the largest concepts in the field, and then by adding the sub class to refine these concepts. After a concept in the field of classification with the hierarchical relationship is established, then add the corresponding attribute value to these concepts. Thus the relationship between the concept of the field and the relationship between the concepts and properties is described figuratively by the tree construction image. Each of them corresponds to an independent, modular knowledge model in the field of a subdivision.

## 3. XBOM Ontology Modeling Technology for High Speed Railway Locomotive Supporting MRO Knowledge Semantic Representation

### 3.1. Global Ontology Design of High Speed Railway Locomotive XBOM

May wish to Global Ontology referred to as GO, the global ontology can be expressed as follows:

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GO = {C,R,P,I,A}, among them, C represents a set of concepts, R represents a set of relationships, P represents a set of numeric properties, I represents an instance set, and A represents a set of rules.

### 3.1.1. The Concept of Global Ontology

Parts, information sets and other concepts into the global ontology classes, as shown in figure 2.

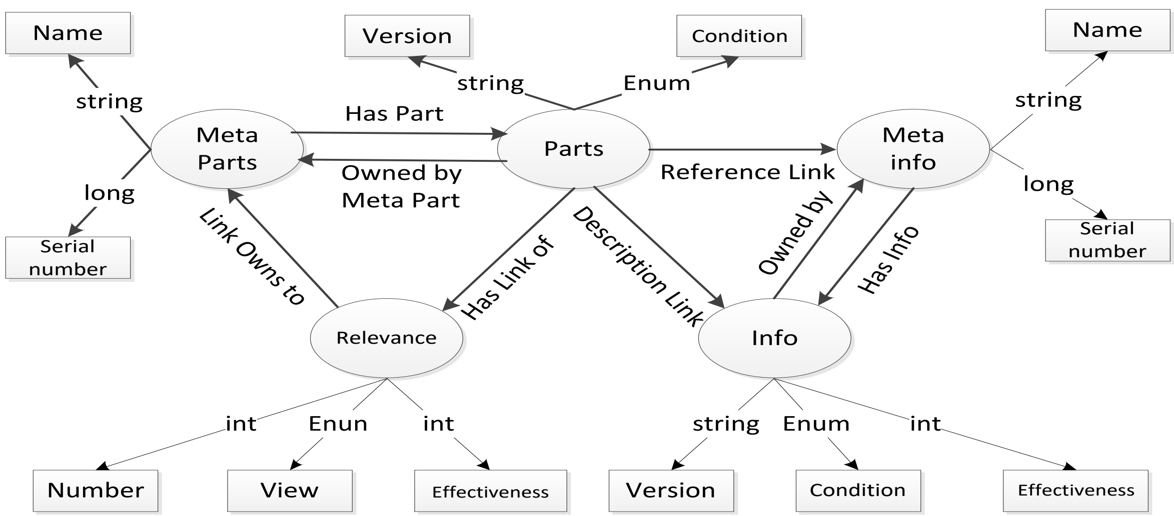


Figure 2: XBOM global ontology model

Global ontology basic classes include component parts, parts, association, meta information set, information set and view.

### 3.1.2. Object Properties of Global Ontology

The properties of the global ontology include the object properties see Table 1.

Table 1: The main object properties of global ontology

| **Object properties** | **domain** | **range** | **Object multiplicity** | |
|---|---|---|---|---|
| | | | **Domain classes** | **Range classes** |
| Reference Link | Part | Meta-info | 0..* | 0..* |
| Description Link | Part | Info | 0..* | 1..* |
| Has Part | Meta-part | Part | 1..1 | 1..* |
| Owned by Meta Part | Part | Meta-part | 1..* | 1..1 |
| Has Info | Meta-info | Info | 1..1 | 1..* |
| Owned by | Info | Meta-info | 1..* | 1..1 |
| Has Link of | Part | Relevance | 1..* | 0..1 |
| Link Owns to | Relevance | Meta-part | 1..* | 1..1 |
| View is | Part | View | 0..* | 1..1 |

This requires special description of the object properties are Link Reference and Link

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**Description**

Reference Link represents the relationship between Part and MetaInfo. Specifically, the Link Reference is associated with the meta-information set of the information set that will be referenced in parts and components maintenance support. The role of here Reference Link and MetaInfo is equivalent to the pointer in the relational database or index in the catalog, used to search for specific documents needed for positioning.

Description Link represents the association relation between Part and Info. Specifically, What Link Description related to is the information collection required for specific version, including all kinds of equipment configuration information, maintenance resource information, operation and maintenance business information.

### 3.2. Construction Ontology Design of High Speed Railway Locomotive

Construction configuration information of high speed railway is the basis of fault diagnosis, maintenance scheduling and spare parts management, etc. Scientific and reasonable construction of high speed railway locomotive will be able to support all MRO service effectively. The following will first define the construction ontology of the high speed rail locomotive. Equipment Construction Ontology abbreviated as ESO can be expressed as follows:

ESO={C,R,P,I,A},among them, C represents a set of concepts, R represents a set of relationships, P represents a set of data properties, I represents an instance set, and A represents a set of rules.

The data in the field of high speed railway locomotive construction is mainly the various levels of various locomotive equipment. The concept of parts has been defined in the global ontology. Monomer parts in the ontology construction of high speed railway locomotive can inherit and use concepts, properties and rules that are defined in the global ontology.

#### 1) The Definition of Class Construction Ontology

High-speed loco motive ontology construction mainly includes equipment, system, component, and monomer part and configuration type. The first four of the parent class is Par, the parent of the configuration type is Thing。

#### 2) Definition of Ontology Construction Object Properties

Added to describe the relationship between the constructions of the high-speed locomotive including “is_assembled_by, “configuration_ belongs to” etc. These relationships are expressed in the ontology object properties as follows:

Table 2: The main object properties of construction ontology

| **Object properties** | **domain** | **range** | **Object multiplicity** | |
|---|---|---|---|---|
| | | | **Domain classes** | **Range classes** |
| Is assembled by | Part | Part | 1..* | 0..* |
| Configuration is | Part | Configuration types | 0..* | 0..1 |
| is kind of | Part | Part | 1..* | 1..1 |

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### 3) Definition of Construction Ontology Rules

In the construction ontology, some rules are also introduced to constrain the structure of the class and the relation of the structure.

In the construction of the ontology, can be repaired parts $\cup$cannot be repaired = parts, repair parts $\cap$cannot be repaired parts =Null;
Device is composed of systems or components, Equipment= {System, Component};
System is composed of component, System= {Component, Component};
Component is composed of components or monomer parts, Component= {Component Monomer part}.

### 3.3. Design of Maintenance Plan Ontology for High Speed Railway Locomotive

Maintenance Plan Ontologyis a conceptual description about developing the business process and related knowledge of the maintenance plan, which is based on the distribution of maintenance personnel and spare parts. It is based on the maintenance spare parts, maintenance equipment tools, maintenance personnel and other maintenance resource requirements and some of the constraints, determined after the maintenance task and aiming at the lowest cost, etc.

Maintenance planning domain ontology can be formalized representation as follows:
MPO={C,R,P,I,A},among them, C represents a set of concepts, R represents a set of relationships, P represents a set of data attributes, I represents an instance set, and A represents a set of rules.

The specific meaning of each element in MRO is as follows:
C is a concept set of high speed railway locomotive MRO services Involved. The concept contained in it is MRO knowledge, for example, the maintenance plan development process involves the knowledge of MRO including the maintenance of the knowledge of the knowledge of maintenance resources, etc. These knowledge sets can be further subdivided by; define the concept of the field of maintenance planning by using the class of the ontology. There are three ways to define: First, by inheriting the class that has been defined in the global ontology, a new class is defined, such as "MRO business knowledge" and so on; Second, according to the requirements of the field of maintenance plan and the new definition of the class, such as maintenance task knowledge"; Third, by using the " equivalent to" function, the new class is equivalent to a class that already exists, for example, the definition of "structural knowledge" is equivalent to "parts and components" .

P is the data attribute of MRO knowledge, which is a quantitative or qualitative description of MRO knowledge. Such as maintenance spare parts data attributes including spare parts number, spare parts name and demand; P（Ci）|i$\in$ N represents the data attribute of the concept of the Ci-th knowledge (class).

R is the object properties of MRO knowledge, which describes the association relationship between knowledge. With a binary relation R(Ci,Cj）|I,j $\in$N to represent an association between the i-th and the j-th concepts, such as the association relationship between the parts and

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the maintenance called “Repair history link”. “Reference Link “expressed as R = {parts, maintenance history}, “Repair history link “inherited from the object properties in the global ontology “Reference Link ".

I said that the specific instantiation MRO knowledge for each of the high-speed rail locomotive in each repair activities. These MRO knowledge stored in the knowledge base can be directly mined, query and reasoning, to provide support for MRO services.

A represents a constraint on the concepts, relationships, and attributes of the ontology. When introduction of new concepts and relationships in the maintenance plan ontology also requires the following rules to regulate and constrain.

### 1) Turnover Parts, Key Parts and Parts Serial Number Association Rules

In order to realize the lean management and traceability of the turnover parts and key parts, the instantiated key parts and the turnover parts not only need to be related to the properties of the material code, but also have to be related to the properties of serial number (Serial number).So set the following rules: If an instantiated monomer part is a key part or a turnover part, then there is a sequence number, which is expressed as follows：

$$
\begin{aligned}
&if\ \ \forall i \in \{Turnover\ Parts, Key\ Parts\},\ p_i = \{Serial\ number\} \\
&then\ \exists\{n \mid n \in N\},\ p_i(i) = n
\end{aligned}
$$

### 2) Instance BOM View, Configuration BOM View And Association Rules of MRO Knowledge

As much as possible in order to facilitate the MRO knowledge retrieval and reduce data redundancy, configuration BOM and instance BOM, different BOM related to different MRO knowledge, so set the following rules:

- Instance BOM view and Association rules of MRO knowledge

Monomer parts of instance BOM views should establish some kind of relationship with the two class and their subclasses of "MRO business knowledge" and "MRO configuration knowledge". Also stipulate: Only above the instance BOM view of the relationship is effective. Below using the association rules between “Repair history info " and monomer parts of instance BOM views as an example to develop rules only:
If a monomer part belongs to the parts in the instance BOM view, then the parts must be associated with "Repair history info", can be expressed as follows：

$$
\begin{aligned}
&If\ \ \forall r_1 \in "View\ is",\ \ i \in part \\
&\quad \text{And}\ r_1.i = "Individual" \\
&Then\ \exists m \in "Repair\ history\ info", r_2 \in "Repair\ history\ link" \\
&And\ \ r_2.part\ = I, r_2.info = m
\end{aligned}
$$

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- Association rules of configuration BOM views and knowledge

Monomer parts of configuration BOM views should establish some kind of relationship with the two class and their subclasses of "MRO data knowledge" and "MRO resource requirement knowledge". Also stipulate: Only above the configuration BOM views the relationship is effective. Below using the association rules between "Repair process info " and monomer parts of configuration BOM views as an example to develop rules only:

If a monomer part belongs to the parts in the configuration BOM view, then the parts must be associated with “Repair process info ", can be expressed as follows:

$$
\begin{aligned}
&\textit{If} \quad \forall r_1 \in \text{"}\textit{View is}\text{"}, \quad i \in \textit{part} \\
&\quad \text{And } \; r_1.i = \text{"}\textit{Configuration}\text{"} \\
&\textit{Then } \exists m \in \text{"Repair Process } \textit{info}\text{"}, r_2 \in \text{"Repair Process } \textit{link}\text{"} \\
&\textit{And} \quad r_2.\textit{part} \; = I, r_2.\textit{info} = m
\end{aligned}
$$

## 4. Modeling of A Certain Type of High Speed Railway Locomotive XBOM Ontology Based on Protégé Software

This section will take the maintenance plan ontology as an example, introduces the method and process of modeling using protégé software.

First in the Class module, cited the " meta-parts", " meta-information " and "view" ontology are already defined in the global ontology in turn; The second step is adding "MRO resource", "maintenance tasks " and others as new class; Then in the defined class "MRO business information" ,"MRO resources demand information" and other subclasses on the basis of "meta-information". Finally on the basis of the subclasses define subclasses of subclasses, until detailed and cover all maintenance plan ontology concepts.

In the definition of a class, you need to use the enumeration class ,using the class "maintenance skills" as an example, First defined "Mechanical_Skill_1", "Electrical_Skill_1" and so on six kinds of instance maintenance skills in Individual module; Then use the "equivalent to" implement < maintenance skills ≡{Mechanical_Skill_1 Electrical_Skill_1... } (The enumeration class definition).

First in Object Properties module in turn reference relationships are already defined in global ontology, such as "Description Link" and "has Part", etc.; the second step is adding the "Part Task Link" and other new relationship in the maintenance plan. And then basis of the defined relationship define sub relationships, such as "Repair history” based on "Description Link”, until thinning and covering all relationships between the concepts of the maintenance plan ontology. When the definition "Repair history" setting up the domain of this relationship is "parts “and the range is “Repair history info”. In addition the protégé software provides some axioms and constraints can limit to the relationship, making the relationship description more precise and rigorous, such as "has Skill" and “Skill is Owned By " set to the inverse relationship.

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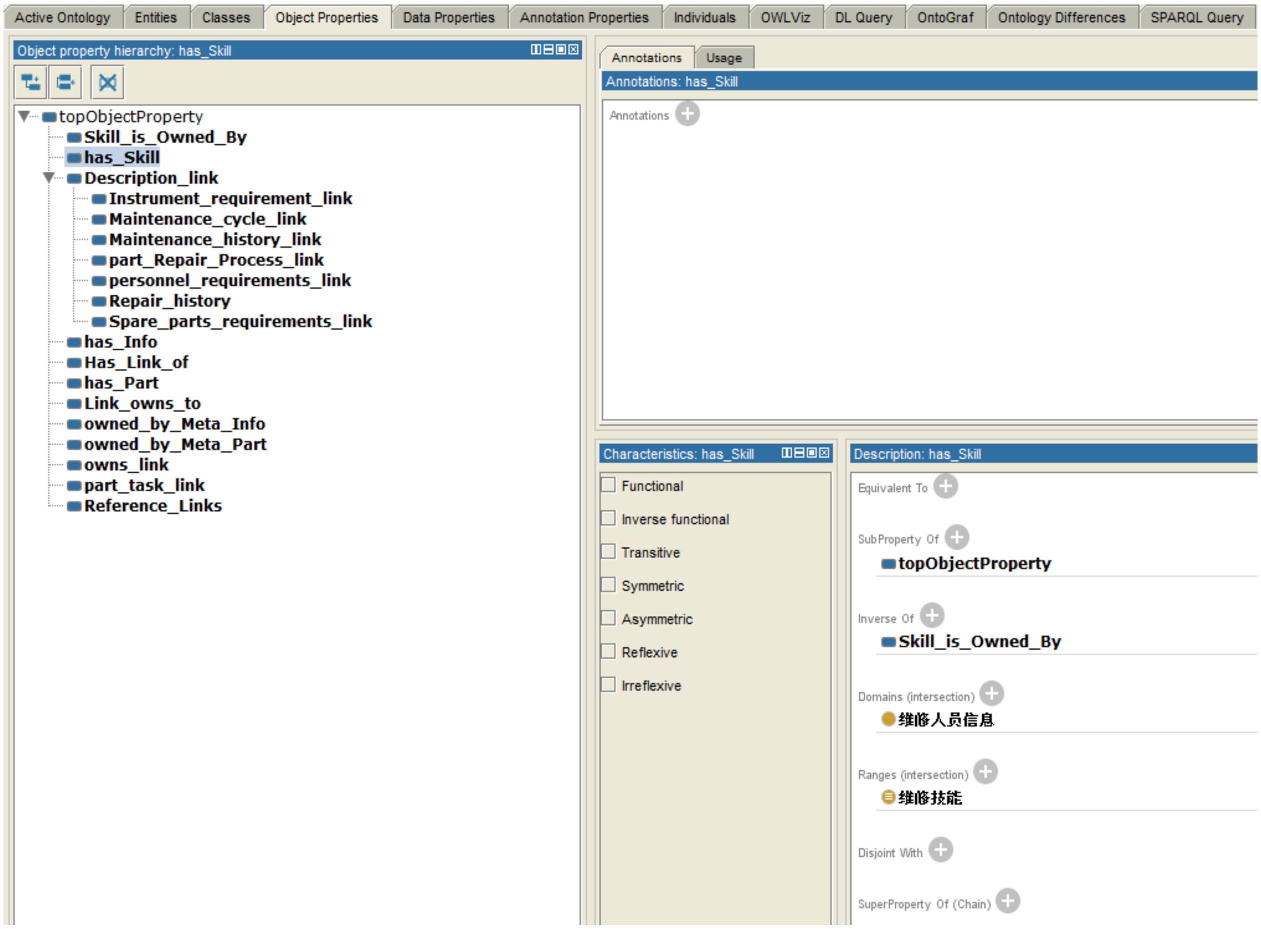

Figure 3: The build process of maintenance plan ontology object properties by protégé

First in Data Properties module in turn reference relationships are already defined in global ontology, such as "Info Descriptor“ and “Meta Part Descriptor ", etc. The second step is adding the “Servicer Descriptor " and other data attribute sets; And then on the basis of this to specific definition of "Servicer Name ", "Servicer ID ID" and other data attributes and add domain and range and other restrictions of these data attributes . Define data attributes one by one until thinning and covering all data attributes between the concept of the maintenance plan ontology.

After completing the steps described above, you can generate an OntoGraf diagram that represents the object's property relationship. Onto Graf is a plug-in of protégé4.1; it can realize "thinking is what you get". From the Onto Graf diagram, you can clearly see the relationship between classes, as well as the relationship between the attributes of the class, so that it is easy to modify and improve the properties of the class and the attributes of class established.

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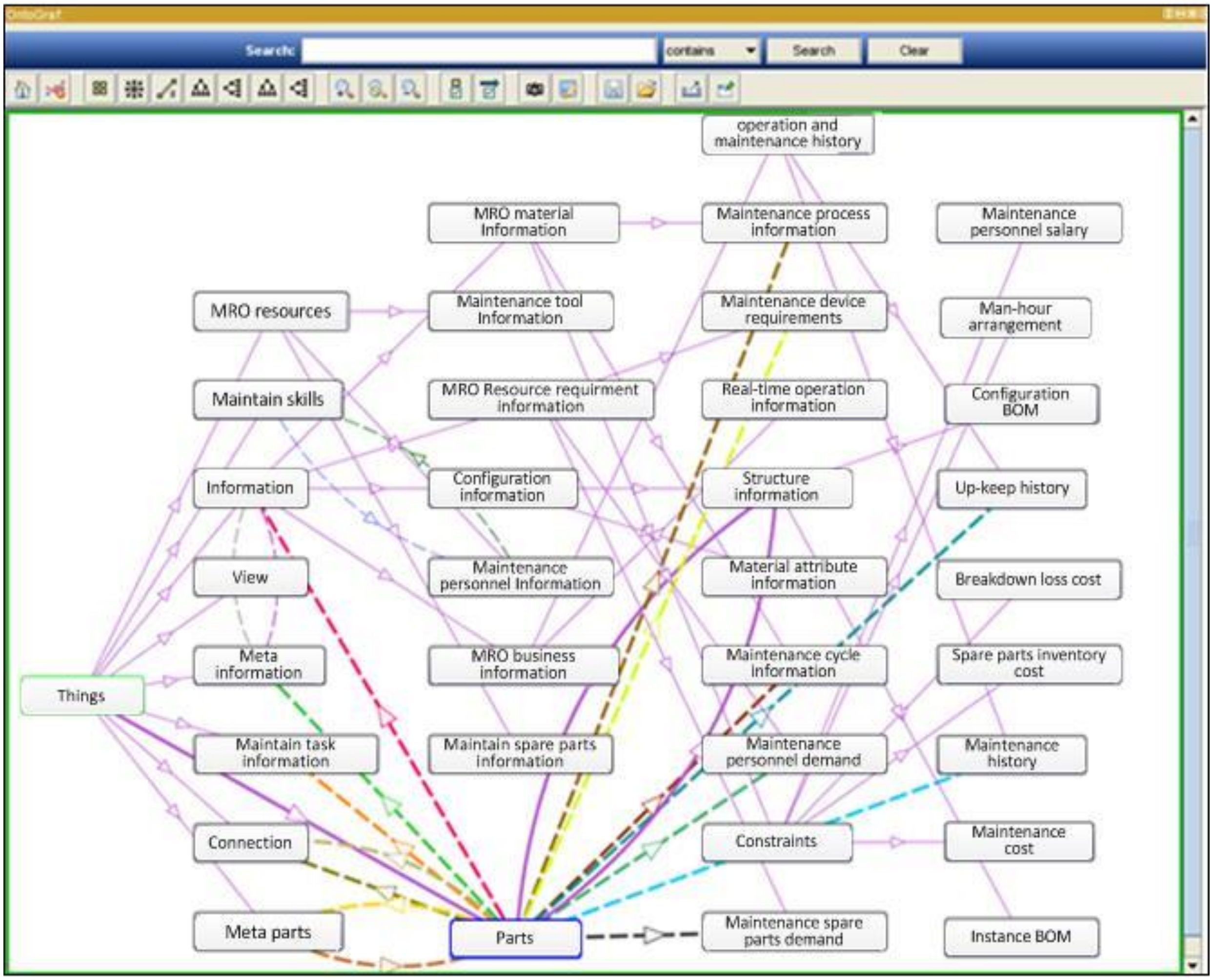

Figure 4: The onto Graf of high-speed train maintenance plan ontology

After the modeling is completed, it forms the OWL language that can be identified and edited by the computer. Here is not to do the show.

## 5. The Conclusion

This article combines high-speed locomotive XBOM and ontology modeling technology, designing a XBOM ontology model for high-speed railway high speed rail train MRO semantic knowledge representation. On the one hand the XBOM ontology model the advantages of the composite repair BOM model and mathematical model of XBOM mapping and this also ensure the MRO knowledge data consistency and traceability of the whole life cycle of the multi type high speed railway locomotive; On the other hand, the introduction of ontology overcomes the shortcomings of traditional high-speed railway train MRO information integration, which cannot realize at the semantic level of knowledge integration. It can adapt to the characteristics of high-speed rail locomotive MRO such as diversity, heterogeneity, dynamic, complexity and others underthe environment of Industry Internet, Internet of things, Big data. Laid a solid foundation for MRO knowledge in high-speed rail train manufacturers, service providers, operators seamless transfer, sharing and reusing based XBOM.

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