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Research Article

An Ontology and AHP Based Quality Evaluation Approach for Reuse Parts of End-of-Life Construction Machinery

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Effective reuse and recycling of end-of-life (EOL) products are essential for improving resource efficiency and protecting environment. Currently, many parts of construction machinery in EOL stage can still be reused directly because they are designed with extreme high strength to meet the bad working conditions, which minimizes the impact on the environment. In this context, a quality evaluation approach for reuse parts is proposed in this paper. Ontology model is built for representing evaluation information with semantic properties and constructing the semantic relevance among the various concepts involved in parts reusing domain, thus achieving the integrating, sharing, and reusing of evaluating parts knowledge. On that basis, analytic hierarchy process (AHP) is put forward to quantify the reusability degree of the parts of EOL construction machinery. Furthermore, combined with ontology, rule-based-reasoning method is utilized to get suggested strategies for reuse parts. In addition, a web-based system is developed to assist manufacturers in managing reuse parts, and a case study is analyzed to demonstrate the proposed quality evaluation approach.

1. Introduction

With growing awareness for environmental protection and economic benefits, sustainable EOL products management has become a vital issue around the world, especially in vehicles industry, many researches have been conducted not only to improve parts recyclability, but also to reduce their damage of original value [1–5]. For example, Shameem Ahmed et al. [1] proposed a decision-making method in selecting the best compromise EOL vehicles management alternative (e.g., reuse, remanufacturing, and recycling) with respect to the sustainable criteria based on decision-making trial and evaluation laboratory and fuzzy AHP method. Meanwhile, due to the economic benefits and the environmental consciousness, more and more countries have been devoting themselves to establish legislations that enforced the equipment manufacturers to accept responsibility of the complete life cycle of vehicle and urged firms to disassemble, recycle and reuse components of EOL vehicles. The European Union forced the respective countries to achieve the recycling target of 85% and a total recovery of 95% by 2015 [6].

Construction machinery is a kind of engineering vehicle, whose parts in EOL stage have several important recovery strategies with little environmental damage and energy waste, such as reuse, remanufacturing, recycling, etc. Pengxing Yi et al. [7] focused on the optimal design of a retailer oriented closed-loop supply chain network for the EOL construction machinery remanufacturing based on genetic algorithm. Aiming at maximizing resource utilization and produce profits, Haolan Liao et al. [8] applied an optimizing mathematical analysis to the EOL engineering machinery recovering in a joint manufacturing system.

Compared with other vehicles, components of construction machinery are designed and manufactured with extreme high strength to meet the bad working conditions. In this context, many parts of construction machinery in EOL stage are able to still be reused directly as new parts or be repaired with less manufacturing process. Hence, direct reuse of parts in the EOL construction machinery has great economic profits and is worth our research.

In order to realize direct reuse of parts in the EOL construction machinery, a specific quality evaluation approach needs to be proposed to quantify the reusability degree of the parts, which determines whether the components can be reused directly. Many researches have been conducted on evaluation approach in construction machinery domain and other industries. Jun Zhou et al. [9] presented a quality evaluation model to quantify the reusability degree of the recycling parts on the EOL wheel loader (a kind of construction machinery) based on the fuzzy AHP. Tsai Chi Kuo et al. [10] put forward a recyclability evaluation method based on case-based reasoning and AHP. Che-Wei Tsui et al. [11] proposed a hybrid multiple criteria group decision-making method based on AHP to assist the manufacturer in choosing four polarizer suppliers. Kuo Chang et al. [12] proposed a green fuzzy design analysis approach that comprises simple and efficient procedures to evaluate product design alternatives based on environmental consideration and AHP. Shahed Shojaeipour [13] evaluated a sustainable manufacturing process planning schema through identifying and quantifying the environmental impacts based on AHP. Ying Xiang et al. [14] proposed the improved fuzzy AHP method to analyze and evaluate brittle source of the key procedure in increasing the stability during complex parts' manufacturing.

Inspired by previous work, AHP is applied into the quality evaluation approach in this paper; however, this method has drawbacks as follows:

(1) It is difficult to propose a universal quality evaluation model for reuse parts of all EOL construction machineries, because the types of construction machineries are diverse, such as wheel loader, crawler excavator, bulldozers, etc., which leads to many quality evaluation methods for different reuse components in various construction machineries.

(2) It is hard to reuse the existing quality evaluation model of reuse parts. Numerous scholars have to reestablish models and methods during the study of the quality evaluation, resulting in waste of research energy.

Ontology is the solution for two defects proposed above, which is a mechanism that describes concepts and their system relationships [15, 16]. On the one hand, for the highly expansibility of ontology model, the classes, properties, and individuals in the ontology model can be continually updated and enhanced [17, 18]. The quality evaluation for reuse parts of different engineering machineries can be realized by changing the knowledge in the ontology model dynamically, thus realizing a universal quality evaluation approach. On the other hand, ontology can enable the computer to easily understand and integrate the knowledge, which achieves the sharing and reuse of quality evaluation knowledge [19, 20]. In this way, existing quality evaluation model of reuse parts can be reused. Hence, ontology concept will be exploited to overcome two problems mentioned above in this paper.

With the rapid development of knowledge technology, ontology has been applied into areas like evaluation approach. Yu-Jun Wang et al. [21] developed an ontology-based cold chain logistics monitoring and decision system. The system makes evaluation and decision support for the monitored cold chain quality. Vanessa Ayala-Rivera et al. [22] introduced a measurement scheme, based on ontologies, to quantitatively evaluate the quality of value generalization hierarchies, aiming at producing higher-quality anonymizations. Xiaomin Zhu et al. [23] proposed an ontology-based knowledge model to evaluate water quality through using rule-based reasoning method. Chau K.W. et al. [24] presented an ontology-based knowledge management system for water quality evaluation. Xiao-Ci Huang et al. [20] proposed an ontology modelling approach to evaluate the river water quality based on rule-based reasoning method. Edward Corry et al. [25] built an ontology-based performance evaluation model for the environmental and energy management of buildings.

At present, combining ontology and AHP is few studied in the quality evaluation for reuse parts of EOL construction machinery and this paper is aimed to fill up this gap.

The ontology model is built for representing quality evaluation parameters of reuse parts with semantic properties and constructing the semantic relevance among the various concepts involved in quality evaluation domain. On that basis, AHP is put forward to quantify the reusability degree of the parts of EOL construction machinery to determine whether the components can be reused directly. Furthermore, rule-based reasoning method is utilized to realize decision support for reuse measures. In addition, a web-based system is developed to assist in managing reuse parts, and a case study is analyzed to demonstrate the proposed quality evaluation approach.

The remainder of this paper is organized as follows: Section 2 mainly focuses on quality evaluation approach for reuse parts of EOL construction machinery; Section 3 is the case study to demonstrate the proposed quality evaluation approach; Section 4 is the discussion about advantages of proposed methods; Section 5 is the conclusions.

2. Methodology

This paper mainly focuses on quality evaluation approach for reuse parts of EOL construction machinery to help users determine whether the components can be reused directly based on ontology and AHP. Figure 1 shows the overall framework of quality evaluation approach.

Firstly, the ontology model is the core part of this method, which is used for representing related quality evaluation information of reuse parts with semantic properties. Secondly, ontology querying based on Sparql (Simple Protocol and RDF Query Language) is executed to query related quality evaluation information. Thirdly, AHP is proposed to quantify the reusability degree of the parts. Then, SWRL rules are constructed to reason the suggested actions about how to deal with reuse parts. Finally, a web-based system is developed on the visual studio 2017 platform with program language C# to assist users in managing reuse parts.

2.1. Structure of Ontology Model. The ontology has highly expansibility and can enable the computer to easily understand the knowledge, which makes a formalised definition to the knowledge of parts reusing. All related information of evaluating parts is expressed and stored into ontology model. Protégé [26] software builds ontology model because of its friendly interface, powerful tools, and data checking feature [27]. In the Protégé editor, the construction of ontology

Table 1: Main classes in the ontology model.

No	Class	Subclass	Description
1	Equipment		Indicate the basic information of reuse parts
2	Parameters	ImportantDimension SubordinateDimension GeometricTolerance NonSurface AppearanceDamage PhysicalDefect AssemblyTolerance	Indicate seven judging features for quality evaluation model of reuse parts. These features are derived from reference [9] and related testing standards of mechanical parts
3	ReuseLevel		Indicate the reusability degree of the parts
4	Actions		Indicate suggested reuse/remanufacturing/recycle/ strategies, etc

Table 2: Object properties in the ontology model.

No	Data property	Domains	Ranges	Description
1	Has_Part	Equipment	Parameters	Evaluation features belong to reuse parts
2	Has_Cause	Parameters	ReuseLevel	Evaluation features decide the reusability degree of the parts
3	Has_Level	Equipment	ReuseLevel	Indicate parts' reusability level
4	Has_Action	Equipment ReuseLevel	Actions	Reuse/ recycle/dispose strategies should be exploited in the parts

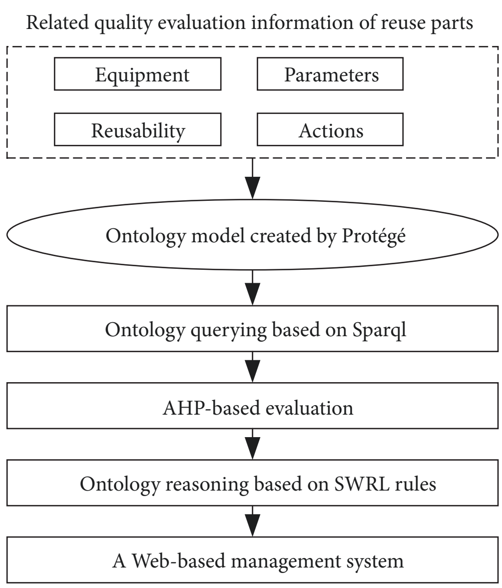

Figure 1: Development flow of quality evaluation approach of reuse parts.

model can be decomposed to the definitions of a series of classes, object properties, and data properties [28, 29].

(i) Define Classes and Class Hierarchy. Firstly, Table 1 shows the classes that the ontology contains. These classes involve equipment (*Equipment*), parameters (*Parameters*), reusability degree (*ReuseLevel*), and suggested reuse/remanufacturing/ recycle/ strategies (*Actions*). The four subclasses of class *Parameters* are derived from [9], and other subclasses are described as follows.

Appearance Damage. It is usually measured from those factors including surface roughness, thickness of coating, coating strength, coating material, surface wear, welding procedure, and so on, which has great important effect on the usage and service life of reuse parts.

Physical Defect. It mainly contains material corrosion, crackle, dent, plaque, etc. Moreover, the defects of surface treatment including fragment, surface crack, and un-even texture also potentially affect the safety of reuse parts. Hence, the physical defect is the utmost important evaluation feature.

Assembly Tolerance. Relative to geometric tolerance, assembly tolerance represents the coordination accuracy of assembled holes and axes, which plays a great role in the assembly of reuse parts. Although other evaluation features are fine, parts are not able to be reused directly once assembly tolerance of parts does not meet the requirements. Therefore, the assembly tolerance is another important evaluation element.

(ii) Defining Object Properties. As shown in Table 2, each object property has its corresponding domains and ranges.

(iii) Defining Data Properties. As shown in Table 3, each data property similar to object property also has its own domains and ranges.

After the three steps mentioned above, structure of the ontology model can be constructed, as shown in Figure 2. It can be clearly seen that the ontology is composed of the classes, the object attributes, and the data attributes. Among them, "classes" represent a set of individuals in the reuse parts domain; "object properties" construct the semantic relevance among the various classes; "data properties" provide varied descriptions to the classes.

Table 3: Data properties in the ontology model.

No	Data property	Domains	Ranges	Description
1	typeScore	Parameters	float	Indicate the importance of each evaluation feature's type for determining reusability degree of parts
2	deviationScore	Parameters	float	Indicate the significance of damage degree of each evaluation feature for deciding parts reusability degree
3	locationScore	NonSurface AppearanceDamage PhysicalDefect	float	Record the essentiality of locations of three evaluation features(non-working surface damage, appearance damage, physical defect) for evaluating parts reusability level
4	hasMaxValue	ReuseLevel	float	Indicate maximum value of reusability degree
5	hasMinValue	ReuseLevel	float	Record minimum value of reusability degree
6	madeFactory	Equipment	string	Indicate manufacturers of reuse parts
7	madeTime	Equipment	dataTime	Record manufacturing time types of reuse parts

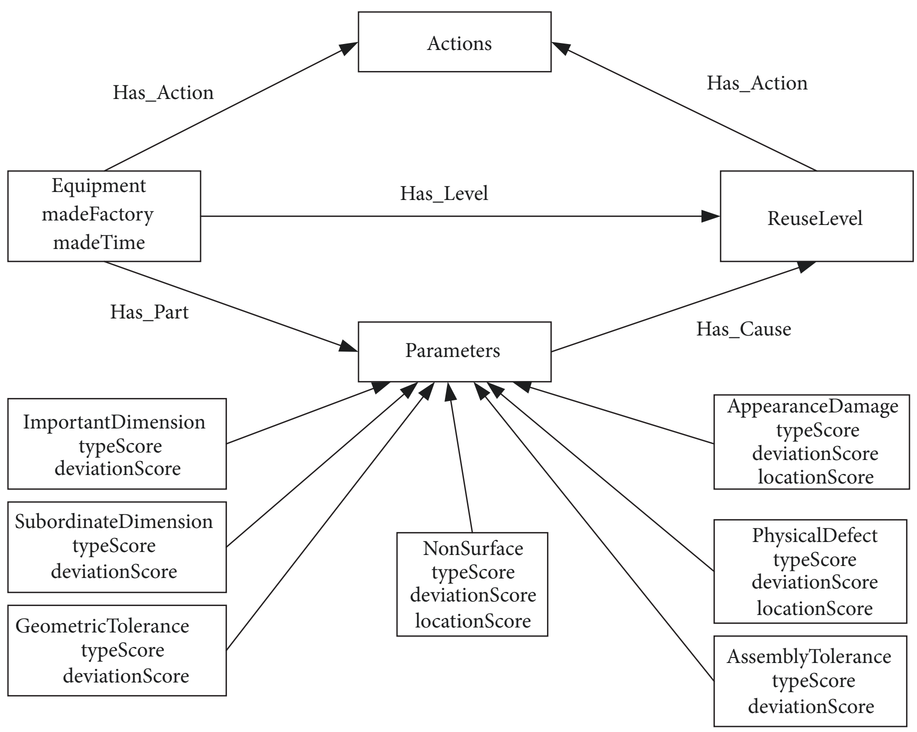

Figure 2: Structure of ontology model.

2.2. Ontology Querying Based on Sparql. According to Figure 1, ontology parsing is precondition of ontology querying. Jena is an open source Java software for the development of application programs in semantic web, and it contains an ontology subsystem supporting OWL, DAML+OIL, and RDFS. Moreover, Jena can parse ontology model. On that basis, Jena API is used to parse ontology model through using "com.hp.hp1.jena.ontology" package. Using Jena API in the Visual Studio 2017 development platform mainly includes the following three steps: first, Jena package is imported into Visual Studio 2017, and the corresponding namespaces should be inserted into the program; secondly, ontology model is instantiated based on "createOntologyModel()" mode; finally, the .owl document describing ontology model is read. With three steps mentioned above, the analysis of the ontology model is completed.

After the achievement of ontology parsing, ontology querying is used to obtain the related evaluation information in the ontology model based on Sparql which is a language that enables the query of information in the RDF model. This article mainly takes advantage of Sparql's query function to get the related evaluation information. The results that Sparql quires are stored into the.txt file, and then the information is extracted from the.txt file according to demand. Sparql mainly adopts four kind of forms to query information through using the pattern matching method to get the RDF graph or result set. The features of four querying forms are listed as follows:

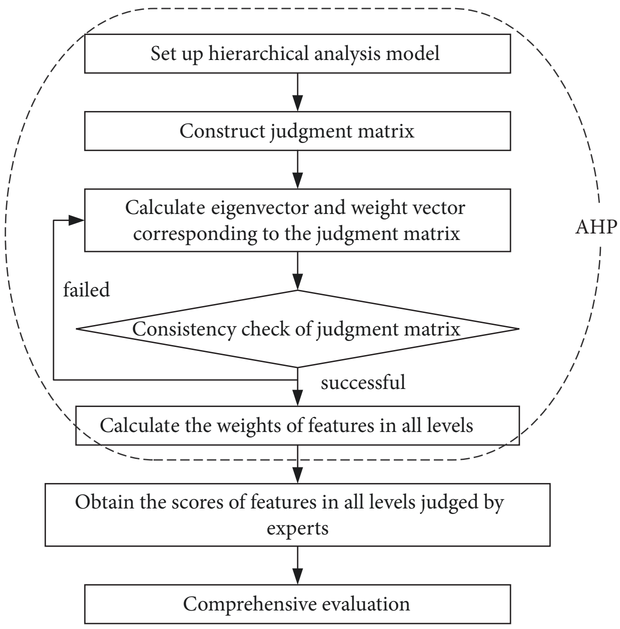

Figure 3: Quality evaluation process of reuse parts.

CONSTRUCE: the output is displayed in the form of a RDF diagram.

ASK: whether the query results match is indicated by a Boolean.

DESCRIBE: the information found is returned.

SELECT: all or part of the information that binds variables in querying mode is obtained.

The SELECT querying form of Sparql is used to obtain the required evaluation information in the data attributes and object properties of the ontology model. Next, combined with queried evaluation information, the quality evaluation and advisable reuse strategies are realized based on AHP and rule-based reasoning.

2.3. Quality Evaluation Model of Parts Reusability. AHP method is used to calculate the priority weight of each evaluation feature. After that, the score of feature for evaluating part is adopted, which is set by expert's experience compared with the standard part. Finally, a comprehensive evaluation result is achieved. Quality evaluation process of reuse parts is shown in Figure 3.

(1) Setting Up Hierarchical Analysis Model. The hierarchical analysis model is shown in Figure 4, where the first level evaluation feature is made up of seven subclasses of class *Parameters* in the ontology model, and the second level evaluation feature includes seven subclasses' data properties *typeScore*, *deviationScore*, and *locationScore* of the built ontology model. Hence, structure of hierarchical analysis model is derived from the ontology querying to acquire the priority of evaluation feature in each level.

Table 4: RI values table.

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

(2) Constructing Judgment Matrix A. The judgment matrix A is used to calculate the relative importance of evaluation features in each hierarchical level. A is constructed by using a nominal scale from 0 to 9 with the value a_{ij}, which is assigned to represent the judgment concerning the relative importance of evaluation element a_i over a_j. This important comparison between evaluation features constructs the matrix $A = \{a_{ij}\}$.

(3) Calculating Eigenvector Vector Corresponding to Judgment Matrix A. The eigenvector vector (or weight vector) can be obtained by the normalization process for judgment matrix A, which is described as $W = (w_1, w_2, \ldots, w_i)^T$, where i denotes numbers of evaluation features in each level.

(4) Consistency Check of Judgment Matrix. CI is usually used as an indicator of consistency deviation for checking judgment matrix, which has the following relationship:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad (1)$$

where n is the order of judgment matrix A and $\lambda_{\max}$ is the root of maximum eigenvector value. Meanwhile, $\lambda_{\max}$ is calculated as follows:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}, \quad (2)$$

where A is judge matrix, W is eigenvector vector, n is numbers of evaluation features in each level, and W_i is the weight of *ith* evaluation features.

Furthermore, CR is introduced to check consistency efficiently, and it is shown in the following formula:

$$CR = \frac{CI}{RI}, \quad (3)$$

where CR is the ratio of consistency check, RI is reference criterion, and the value of RI is shown in Table 4. If the value of CR is less than 0.10, the consistency check is successful.

(5) Calculating the Weight of Evaluation Features in Each Level. If consistency check of judgment matrix is satisfied, then the obtained eigenvector vector is the weight of evaluation features in each level; otherwise, eigenvector vector has to be calculated. According to four steps mentioned above, the weights of evaluation features in two levels can be calculated. If $W_{first} = \{C_i\}$, $W_{\text{second}} = \{C_j\}$, then the weight of the lowest level feature is described as follows:

$$C_{ij} = C_i * C_j, \quad (4)$$

where C_{ij} indicates the weight of *jth* feature in second level relative to the weight of *ith* feature in first level.

(6) Obtaining the Score of Evaluation Features in All Levels. The scores of evaluation features in all levels are set by

Table 5: The parts reusability degree of comprehensive evaluation.

Reusability degree M	$0 \leq M < 3$	$3 \leq M < 5$	$5 \leq M < 7$	$7 \leq M < 9$	$9 \leq M \leq 10$
Reusability level	I	II	III	IV	V
Suggested action	Discard	Recycle	Complex remanufacturing	Simple remanufacturing	Direct reuse

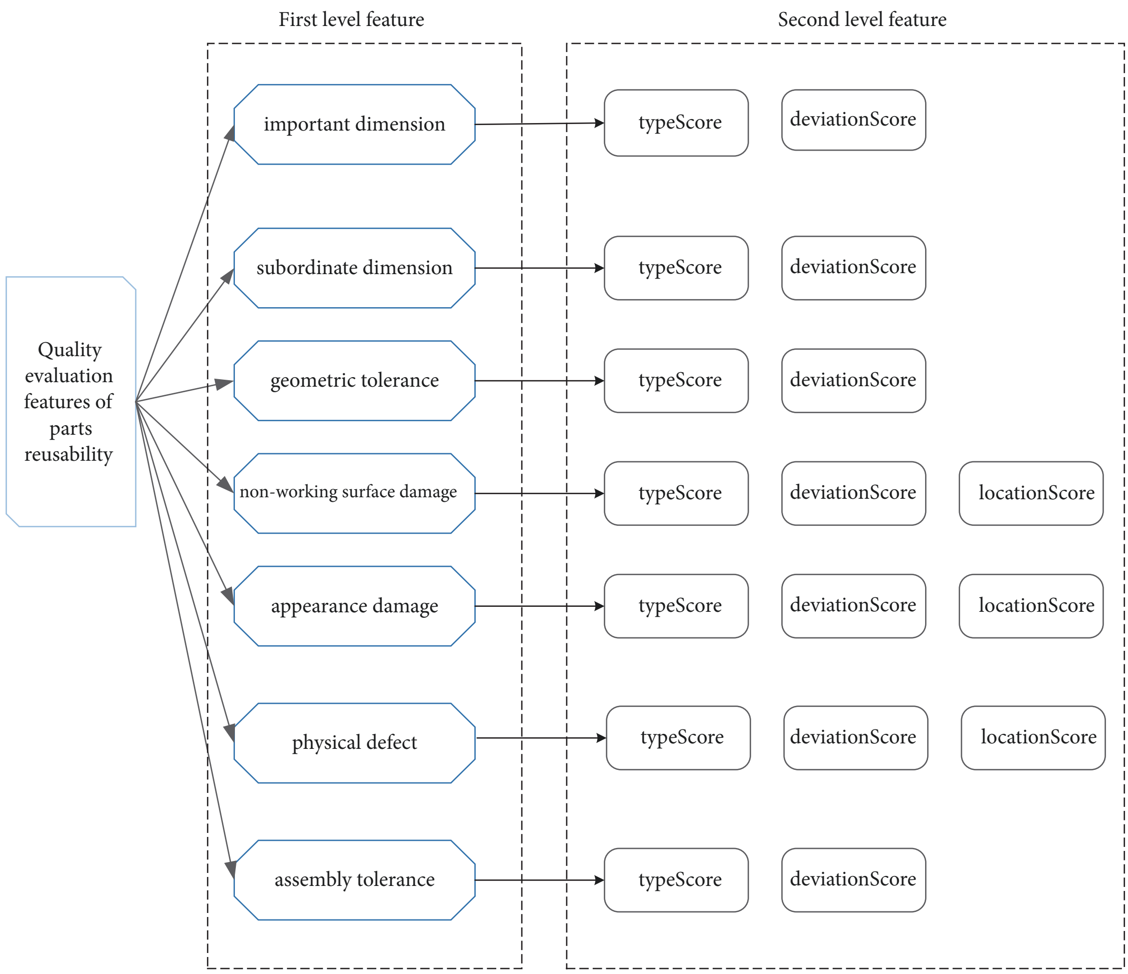

Figure 4: Hierarchical analysis model of AHP.

expert's experience compared with the standard part, and they are obtained through querying data properties *typeScore, deviationScore,* and *locationScore* of the built ontology model. Moreover, the experts score evaluation features according to professional knowledge about construction machinery and actual state of reuse parts.

(7) Comprehensive Evaluation. Combining AHP method and the scores of evaluation features obtained by ontology querying, a comprehensive evaluation is realized. Supposing $S_{ij}(0 \leq S_{ij} \leq 10)$ is the score of *jth* feature in second level relative to the score of *ith* feature in first level. The comprehensive evaluation score M is described as follows:

$$M = \sum_{i=1}^{p}\sum_{j=1}^{q}\left(C_{ij} * S_{ij}\right), \qquad (5)$$

The parts reusability degree of comprehensive evaluation is shown in Table 5. The bigger value of M is, the better parts reusability degree is. The threshold of parts reusability degree M is composed of data properties *hasMaxValue* and *hasMinValue* in the ontology model, and each manufacture also can determine more proper threshold values of M defined by their own experts to decide whether the part is worthy of reusing and recycling. Reusability level corresponds to the instances of class *ReuseLevel*.

2.4. Decision Support for Recommended Strategies of Reuse Parts. As shown in Table 5, the recommended actions depend on reusability level of parts in this paper because the biggest goal of this paper is to inform manufacturers about the reusability degree of the parts of EOL construction machinery. On the basis of reusability level of parts, in order to obtain recommended actions based on the relationships among *Has_Part*, *Has_Cause*, *Has_Action*, and *Has_Level*, Jena reasoner is used as tools for reasoning, together with custom rules described by SWRL (Semantic Web Rule Language). The SWRL rule is presented in the form of a pair of antecedents and consequents, that is, "antecedents ⟶ consequents". Each SWRL rule means that if the conditions specified in the antecedents are true, then the term described in the consequents must be true [30]. The antecedents and the consequents in the SWRL rule can be composed of more than one element, and a group of elements can be written as $a_1 \wedge a_2 \ldots \wedge a_n$. The variable in the SWRL rule is generally an instance of class or a value of its data property. For variables in the SWRL rule, a question mark (?) must be added before each variable as a prefix, for example, "?x" [31]. Two basic elements of the SWRL rule are shown as follows [30]:

(1) C (?x): if variable x is an instance of class C or a value of its data property, then C (?x) is valid.

(2) P(?x, ?y): if variable x is connected to variable y by using the property P, then P(?x, ?y) is found.

Based on the SWRL rule description mentioned above and the analysis of classes and properties in the ontology model, the SWRL rules built for Jena reasoner are as follows:

Rule1: Has_Part(?x,?y) ∧ Has_Cause(?y,?z) ⟶ Has_Level(?x, ?z)

Rule2: Has_Level(?x,?y) ∧ Has_Action(?y,?z) ⟶ Has_Action(?x, ?z)

Rule3: Has_Part(?x,?y) ∧ Has_Cause(?y,?z) ∧ Has_Action(?z,?m) ⟶ Has_Action (?x, ?m)

In order to simplify the discussion here, we will only explain rule1 which means that if equipment x has evaluation features y, and y can lead to reusability degree z, then equipment x has reusability degree z.

Since related evaluation information with semantic properties and the semantic relevance among the various concepts has been defined in ontology model, the suggested reuse/remanufacturing/recycle/dispose strategies for reuse parts are the results of comprehensive consideration of ontology model and reasoning rules described above.

2.5. Development of a Web-Based Management System for Reuse Parts. In order to obtain reusability degree results and manage whole processing procedures related to suggested reuse/remanufacturing/recycle/dispose strategies conveniently, a web-based management system is developed based on ASP.NET MVC website development technology on the visual studio 2017 platform with program language C#.

The web-based system is developed to provide user interface for users including manufactures, experts, and administrators. Manufactures can know how to deal with reuse parts of EOL construction machinery through managing sustainable EOL products. Experts are responsible for scoring the evaluation features based on their professional knowledge and actual state of reuse parts. Administrators have super authority to manage all reuse parts owned by manufactures.

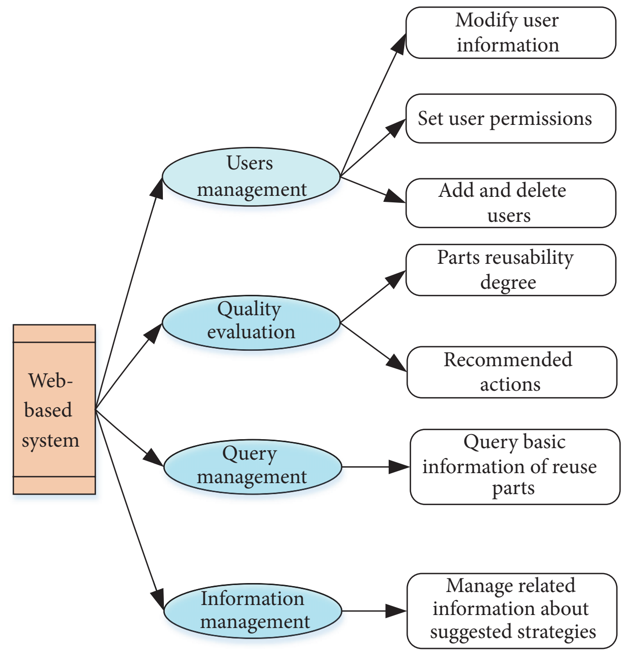

Figure 5: Functional modules of web-based management system.

As shown in Figure 5, the web-based system contains the following functional modules: users management, information management, quality evaluation, and query management.

(1) Users management: Only administrators have the privilege to use this functional module which contains modify user information, set user permissions, add users, and delete users.

(2) Information management: It offers web-based user interface to manage related information about reuse/remanufacturing/recycle/dispose strategies.

(3) Quality evaluation: It provides users with comprehensive evaluation results which consist of parts reusability degree and recommended actions for reuse parts.

(4) Query management: Users can query basic information of reuse parts, such as manufacturer of reuse parts and manufacturing time of reuse parts.

3. Case Study

This section takes five parts of EOL wheel loader and crawler excavator as examples to verify the validation of the proposed quality evaluation approach. Based on ontology and AHP, the technical route of parts quality evaluation for case study is shown in Figure 6. Firstly, based on structure of ontology model, the reuse parts ontology model is built after instantiation. Secondly, related quality evaluation information of reuse parts is queried based on ontology querying method. Thirdly, AHP is applied to calculate all weights of second level evaluation features to quantify the reusability degree of the comprehensive evaluating parts. Fourthly, rule-based-reasoning method is used to reason the decision support for suggested actions about how to deal with reuse parts. Fifthly, a web-based system is developed to assist users in managing

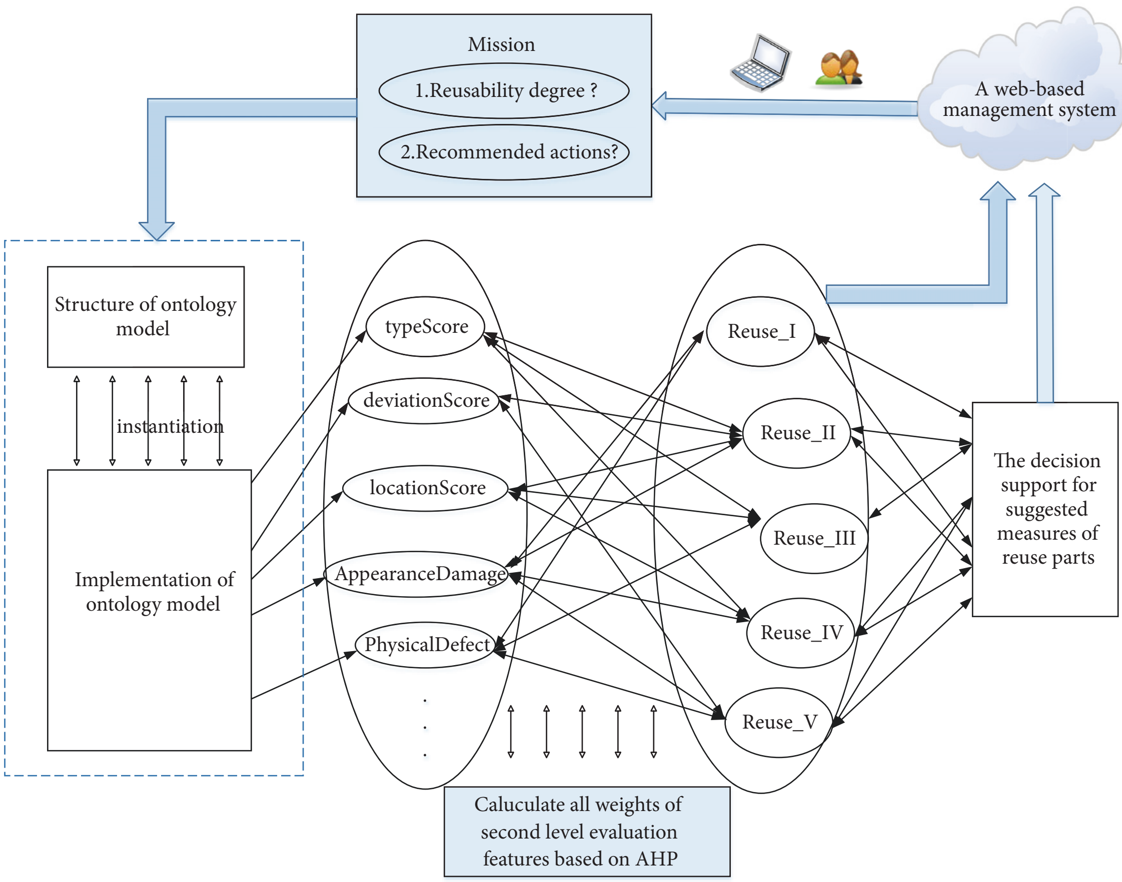

Figure 6: Technical route of parts quality evaluation for case study.

reuse parts of EOL construction machinery. Finally, the users complete the missions for achieving reusability degree of the parts and recommended actions (reuse parts directly, or reuse parts after remanufacturing, or recycle parts, or dispose parts) through using the web-based system based on Internet and computer.

Step 1 (implementation of ontology model). Implementation of ontology model needs to initiate classes in the structure of ontology model. Five instances of *ReuseLevel* are created in this paper to represent different kinds of parts reusability levels, and they are *Reuse_I*, *Reuse_II*, *Reuse_III*, *Reuse_IV*, and *Reuse_V*. From *Reuse_I* to *Reuse_V*, evaluating parts have higher reusability degree. The *Equipment* class has instances including *Transition_Joint*, *Piston_Rod*, *Bracket_Battery*, *Left_Fender*, and *Boom*. Each subclass of *Parameters* has five instances corresponding to each instance of *Equipment* class. The instances in class *Actions* are *direct_reuse*, *simple_remanufacturing*, *complex_remanufacturing*, *recycle*, and *discard*. So far, the ontology model has been established, and Protégé software is used to build the ontology model, as shown in Figure 7. Classes, instances, and properties are listed in order from left to right of Figure 7.

Step 2 (comprehensive evaluation based on AHP). Then, a comprehensive evaluation is realized based on AHP. There is a transition joint, which is used to connect the priority valve and the hydraulic pipe of EOL wheel loader as an example. The hierarchical analysis model is built based on the classes and data properties of ontology model, as shown in Figure 4. With the scale of 1 to 9 and results of mutual comparison about importance of evaluation features in first hierarchical level, judgment matrix A is constructed as follows:

$$A = \begin{bmatrix} 1 & \frac{5}{3} & \frac{5}{7} & 5 & \frac{5}{4} & \frac{5}{9} & \frac{5}{6} \\ \frac{3}{5} & 1 & \frac{3}{7} & 3 & \frac{3}{4} & \frac{1}{3} & \frac{1}{2} \\ \frac{7}{5} & \frac{7}{3} & 1 & 7 & \frac{7}{4} & \frac{7}{9} & \frac{7}{6} \\ \frac{1}{5} & \frac{1}{3} & \frac{1}{7} & 1 & \frac{1}{4} & \frac{1}{9} & \frac{1}{6} \\ \frac{4}{5} & \frac{4}{3} & \frac{4}{7} & 4 & 1 & \frac{4}{9} & \frac{2}{3} \\ \frac{9}{5} & 3 & \frac{9}{7} & 9 & \frac{9}{4} & 1 & \frac{3}{2} \\ \frac{6}{5} & 2 & \frac{6}{7} & 6 & \frac{3}{2} & \frac{2}{3} & 1 \end{bmatrix} \quad (6)$$

And then, the eigenvector vector of A is as follows:

$$W = [0.1429, 0.0857, 0.2000, 0.0286, 0.1143, 0.2571, 0.1714]^T \quad (7)$$

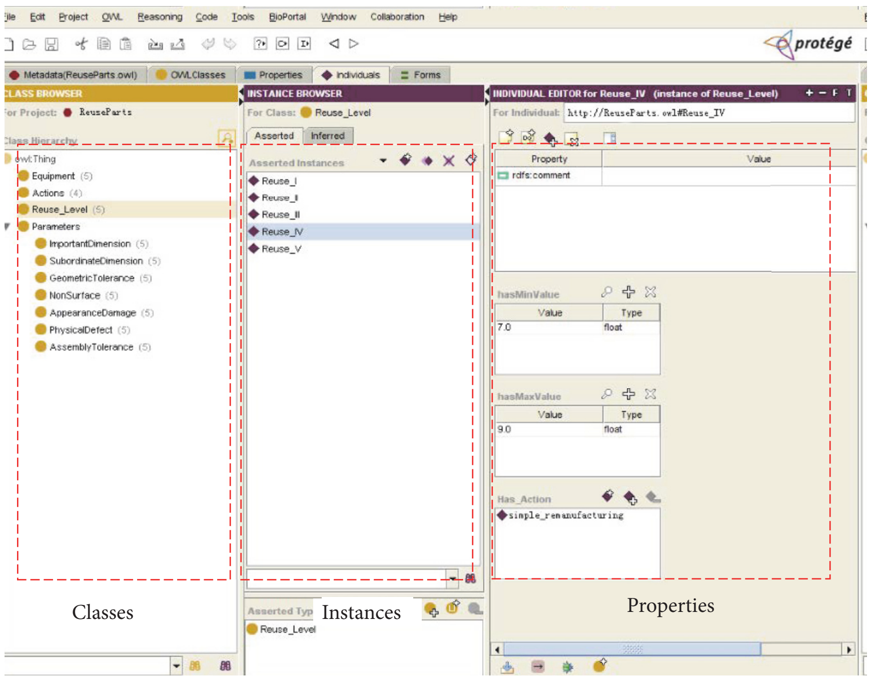

Figure 7: Reuse parts ontology model built in the Protégé software.

The root of maximum eigenvector value is as follows:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} = 7 \qquad (8)$$

The ratio of consistency check is as follows:

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{(n-1) * RI} = \frac{7-7}{(7-1) * 1.32} = 0 < 0.10, \qquad (9)$$

where value of CR means that consistency check of judgment matrix is satisfied, thus obtaining the weights of evaluation features in the first level:

$$(0.1429, 0.0857, 0.2000, 0.0286, 0.1143, 0.2571, 0.1714) \qquad (10)$$

Repeating above calculation processes, seven eigenvector vectors of the second level features are obtained. According to (4), all the weights of *jth* feature in second level relative to the weight of *ith* feature in first level are as follows:

$$(0.0536, 0.0893, 0.0171, 0.0686, 0.0750, 0.125, 0.0063, 0.0117, 0.0105, 0.0336, 0.0454, 0.0605, 0.0756, 0.0454, 0.1361, 0.0343, 0.1371) \qquad (11)$$

The scores of evaluation features in the second hierarchical level are judged by professional experts according to actual states of evaluated parts, which is obtained by querying data properties *typeScore*, *deviationScore*, and *locationScore* of the built ontology model, as shown in Table 6.

According to (4), the comprehensive evaluation score M is as follows:

$$M = 7.7492 \qquad (12)$$

Combined with *hasMaxValue* and *hasMinValue* of class *ReuseLevel* in Table 5, reusability level of comprehensive evaluating parts is in fourth grade *Reuse_IV*.

Step 3 (recommended treatments for reuse parts). Finally, with the quality evaluate result, the proposed approach could further go on the reasoning task with the defined SWRL rules and the ontology model to get the recommended treatments for reuse parts. The result of the reasoning process for transition joint is illustrated in Table 7. Quality evaluation results for five reuse parts of EOL construction machinery are displayed in Figure 8.

With the same steps mentioned above, ontology and AHP based evaluation results for five reuse parts of EOL construction machinery are listed in Table 7. It can be seen that the quality evaluation results for reuse parts of EOL construction machinery can be obtained through using the ontology and AHP based method proposed in this paper.

4. Discussion

In order to improve resource efficiency and protect environment, the study in this paper concentrates on the reuse parts

Table 6: Quality evaluation of a transition joint of EOL wheel loader.

No	All the weights of 1st level evaluation feature	All the weights of 2nd level evaluation feature relative to 1st level feature	Scores of 2nd level evaluation feature judged by professional experts
1	important dimension (weight:0.1429)	typeScore(0.0536)	6
		deviationScore(0.0893)	9
2	subordinate dimension (weight:0.0857)	typeScore(0.0171)	8
		deviationScore(0.0686)	7
3	geometric tolerance (weight:0.2000)	typeScore(0.0750)	8
		deviationScore(0.0125)	7
4	non-working surface damage (weight:0.0286)	typeScore(0.0063)	3
		deviationScore(0.0117)	4
		locationScore(0.0105)	6
5	appearance damage (weight:0.1143)	typeScore(0.0336)	9
		deviationScore(0.0454)	8
		locationScore(0.0605)	9
6	physical defect (weight:0.2571)	typeScore(0.0756)	7
		deviationScore(0.0454)	9
		locationScore(0.1361)	7
7	assembly tolerance (weight:0.1714)	typeScore(0.0343)	6
		deviationScore(0.1371)	8

Table 7: Ontology and AHP based evaluation results for reuse parts of EOL construction machinery.

Results	Transition joint	Piston rod	Bracket of battery	Left fender	Boom
Evaluation score M	7.7492	9.1902	6.8432	2.7703	4.4363
Reusability level	Reuse_IV	Reuse_V	Reuse_III	Reuse_I	Reuse_II
Suggested treatments	Reuse part after only simple remanufacturing process	Reuse part directly	Reuse part after complex remanufacturing process	Dispose part	Recycle part

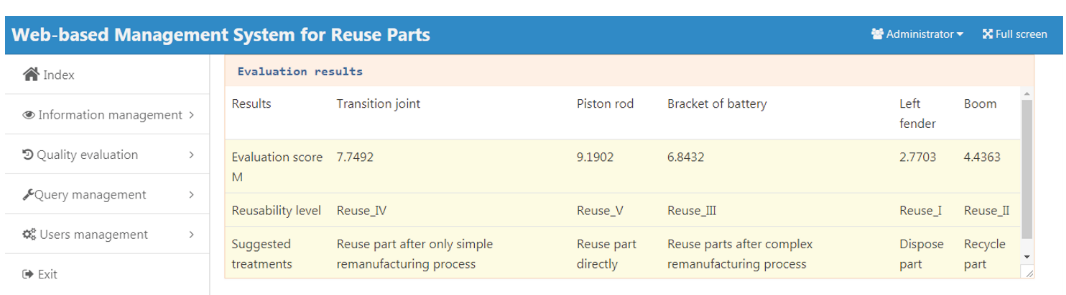

Figure 8: Quality evaluation results for five reuse parts in web-based system.

of EOL construction machinery and builds an ontology and AHP based quality evaluation model. The ontology model is responsible for representing and querying related quality evaluation of reuse parts. The AHP aims to quantify the reusability degree of the parts. On the basis of reusability degree, rule-based-reasoning method is put forward to get suggested strategies of reuse parts. Compared with other related methods [9–14], the proposed approach has following advantages.

(1) Based on the fuzzy AHP, Jun Zhou et al. [9] put forward a quality evaluation model to quantify the reusability degree of the parts. Although this approach is able to realize quality evaluation of reuse parts on the EOL wheel loader, it does not propose a universal quality evaluation model for reuse parts of all EOL construction machineries. However, the ontology model in our proposed approach can express various reuse parts of all construction machineries in different granularity. Moreover, the classes, properties, and individuals in the ontology model and reasoning rules can be continually updated and enhanced. Hence, the ontology-based method presented in this paper is highly expansible, which can achieve quality evaluation for reuse part of all kinds of engineering machineries and even has potential to be applied to mechanical products.

(2) Tsai Chi Kuo et al. [10] proposed a recyclability evaluation method based on case-based reasoning, which makes fully use of experiences knowledge to calculate the recyclability rate of a designed product. The experiences knowledge need to be represented and integrated effectively because of its complex, distributed, and heterogeneous characteristics, but Tsai Chi Kuo's research does not focus on this issue. In our paper, ontology is the solution for this issue because ontology not only enables the computer to easily understand and integrate the knowledge, but also eliminates the ambiguity and heterogeneity of concept expression. Further, the approaches proposed in the references [11–14] cannot be shared and reused directly by others. Numerous scholars have to reestablish their methods during the study of the quality evaluation, resulting in waste of research energy. In this paper, all represented knowledge can be interweaved together in the ontology model, which achieves the sharing and reusing of knowledge. This shared and reused information not only saves research resources, but also is helpful to provide knowledge basis for manufacturers making optimal parts recycling strategy.

(3) Although these studies [10–14] made some important conclusions in components recovery domain, but no software program was been developed to show the research results and manage the whole recovery process for different users. In our work, a web-based management system is developed, through which users can obtain evaluation results and manage whole processing procedures related to suggested strategies conveniently. Consequently, it is not only good for enhancing the management work efficiency, but contributive to parts reusing information shared by the corporation and the government.

Beyond all that, our research can provide manufacturers with decision support for making profits and protecting environment practices, such as:

(1) When the parts of EOL construction machinery can be reused directly, manufactures will make huge profits and protect environment well. On the one hand, reuse parts are able to be applied and assembled directly in other new construction machineries by manufactures, thus reducing capital, material, production, machine operation, and labor costs greatly. Also, reuse parts can be sold to other manufacturers, retailers, corporations, and waste stations in high sale, which have enormous economic benefit with the increasing market demands of the construction machinery. On the other hand, it is clear that the reuse parts prevent fossil fuel and poisonous material polluting our environment due to disposal parts in landfills. Moreover, reuse parts reduce more carbon emissions compared with remanufacturing and other recycling strategies. Hence, there are great economic profits and environmental protection significance in direct reusing of parts in the EOL construction machinery.

(2) Once the parts cannot be reused directly, the suggested remanufacturing/recycle/dispose strategies are helpful to make main directions of parts recover ways for manufactures. Based on suggested strategies of all parts on the construction machinery, manufactures understand and distinguish clearly which parts should be reused or be remanufactured, or be recycled, or be disposed. Manufactures are able to make proper decisions for dealing with all parts of EOL construction machinery in the execution of making profits and protecting environment practices.

5. Conclusions

This article proposes an ontology and AHP based quality evaluation approach for reuse parts of EOL construction machinery. Ontology model is built for representing evaluation information with semantic properties and constructing the semantic relevance among the various concepts involved in parts reuse domain, thus achieving the integrating, sharing, and reusing of parts reusing knowledge. On that basis, AHP is put forward to quantify the reusability degree of the parts. Furthermore, combined with ontology, rule-based-reasoning method based on SWRL is utilized to get suggested strategies of reuse parts. In addition, a web-based system is developed to realize the proposed method, and a case study is used to verify its validity.

However, this paper does not take into account the detailed information (such as public behavior, economic development, recycling facilities, local policies, management activities, financial support, new investments, carbon emissions, etc.) for reasoning the best suggested actions of reuse parts. Moreover, how to select the proper recycling actions is of great importance, which can give manufacturers greater guidance on making profits and protecting environment.

In the next step, we will make joint efforts on choosing the more suitable recommended action for parts of EOL construction machinery based on existing study of this paper. Firstly, many topics about 3R principle (reduce, reuse, and recycle) are inserted into the proposed ontology model. Secondly, reasoning rules are be updated and enhanced to deduce all proper suggested ways based on much more previous experience and knowledge. Finally, the best recommended action is realized based on multiobjective genetic algorithm which combines the profit maximization with the environmental impact minimization.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] S. Ahmed, S. Ahmed, M. R. H. Shumon, M. A. Quader, H. M. Cho, and M. I. Mahmud, "Prioritizing strategies for sustainable end-of-life vehicle management using combinatorial

multi-criteria decision making method," *International Journal of Fuzzy Systems*, vol. 18, no. 3, pp. 448–462, 2016.

[2] S. Sawyer-Beaulieu and E. K. L. Tam, "Maximizing Automotive Parts Reuse, Remanufacturing, and Recycling Through Effective End-of-Life Vehicle Management: A Different Perspective on What Needs to be Done," *SAE International Journal of Materials and Manufacturing*, vol. 8, no. 1, pp. 118–127, 2015.

[3] J. Tian and M. Chen, "Sustainable design for automotive products: Dismantling and recycling of end-of-life vehicles," *Waste Management*, vol. 34, no. 2, pp. 458–467, 2014.

[4] J. Gan and L. Luo, "Using DEMATEL and Intuitionistic Fuzzy Sets to Identify Critical Factors Influencing the Recycling Rate of End-Of-Life Vehicles in China," *Sustainability* , vol. 9, no. 10, p. 1873, 2017.

[5] M. Hedayati and A. Subic, "A framework for extended end-of-life vehicle (ELV) recovery rate based on a sustainable treatment option," *International Journal of Sustainable Design*, vol. 1, no. 4, p. 381, 2011.

[6] B. Ruffino, S. Fiore, and M. C. Zanetti, "Strategies for the enhancement of automobile shredder residues (ASRs) recycling: Results and cost assessment," *Waste Management*, vol. 34, no. 1, pp. 148–155, 2014.

[7] P. Yi, M. Huang, L. Guo, and T. Shi, "A retailer oriented closed-loop supply chain network design for end of life construction machinery remanufacturing," *Journal of Cleaner Production*, vol. 124, pp. 191–203, 2016.

[8] H. Liao, Q. Deng, and Y. Wang, "Optimal acquisition and production policy for end-of-life engineering machinery recovering in a joint manufacturing/remanufacturing system under uncertainties in procurement and demand," *Sustainability*, vol. 9, no. 3, 2017.

[9] J. Zhou, P. Huang, Y. Zhu, and J. Deng, "A quality evaluation model of reuse parts and its management system development for end-of-life wheel loaders," *Journal of Cleaner Production*, vol. 35, pp. 239–249, 2012.

[10] T. C. Kuo, "Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies," *Expert Systems with Applications*, vol. 37, no. 8, pp. 5558–5563, 2010.

[11] C.-W. Tsui and U.-P. Wen, "A hybrid multiple criteria group decision-making approach for green supplier selection in the TFT-LCD industry," *Mathematical Problems in Engineering*, vol. 2014, Article ID 709872, 13 pages, 2014.

[12] T.-C. Kuo, S.-H. Chang, and S. H. Huang, "Environmentally conscious design by using fuzzy multi-attribute decision-making," *The International Journal of Advanced Manufacturing Technology*, vol. 29, no. 5, pp. 419–425, 2006.

[13] S. Shojaeipour, "Sustainable manufacturing process planning," *The International Journal of Advanced Manufacturing Technology*, vol. 78, no. 5-8, pp. 1347–1360, 2015.

[14] Y. Xiang, R. Mo, and H. Qiao, "An Evaluation Method for Brittle Source of the Key Procedure in Complex Parts' Manufacturing," *Mathematical Problems in Engineering*, vol. 2018, 2018.

[15] R. Elhdad, N. Chilamkurti, and T. Torabi, "An ontology-based framework for process monitoring and maintenance in petroleum plant," *Journal of Loss Prevention in the Process Industries*, vol. 26, no. 1, pp. 104–116, 2013.

[16] S. Verstichel, F. Ongenae, L. Loeve et al., "Efficient data integration in the railway domain through an ontology-based methodology," *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 4, pp. 617–643, 2011.

[17] S. Chen, J. Yi, H. Jiang, and X. Zhu, "Ontology and CBR based automated decision-making method for the disassembly of mechanical products," *Advanced Engineering Informatics*, vol. 30, no. 3, pp. 564–584, 2016.

[18] A. Zhou, D. Yu, and W. Zhang, "A research on intelligent fault diagnosis of wind turbines based on ontology and FMECA," *Advanced Engineering Informatics*, vol. 29, no. 1, pp. 115–125, 2015.

[19] H. Panetto, M. Dassisti, and A. Tursi, "ONTO-PDM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment," *Advanced Engineering Informatics*, vol. 26, no. 2, pp. 334–348, 2012.

[20] X. Huang, J. Yi, S. Chen, and X. Zhu, "A wireless sensor network-based approach with decision support for monitoring lake water quality," *Sensors*, vol. 15, no. 11, pp. 29273–29296, 2015.

[21] Y. Wang, J. Yi, X. Zhu, J. Luo, and B. Ji, "Developing an ontology-based cold chain logistics monitoring and decision system," *Journal of Sensors*, vol. 2015, 2015.

[22] V. Ayala-Rivera, P. McDonagh, T. Cerqueus, and L. Murphy, "Ontology-based quality evaluation of value generalization hierarchies for data anonymization," *Computer Science*, 2015.

[23] Z. Xiaomin, Y. Jianjun, H. Xiaoci, and C. Shaoli, "An Ontology-based Knowledge Modelling Approach for River Water Quality Monitoring and Assessment," in *Proceedings of the 20th International Conference on Knowledge Based and Intelligent Information and Engineering Systems, KES 2016*, pp. 335–344, UK, September 2016.

[24] K. W. Chau, "An ontology-based knowledge management system for flow and water quality modeling," *Advances in Engineering Software*, vol. 38, no. 3, pp. 172–181, 2007.

[25] E. Corry, P. Pauwels, S. Hu, M. Keane, and J. O'Donnell, "A performance assessment ontology for the environmental and energy management of buildings," *Automation in Construction*, vol. 57, pp. 249–259, 2015.

[26] I. Smeureanu and B. Iancu, "Source code plagiarism detection method using Protégé built ontologies," *Informatica Economica Journal*, vol. 17, no. 3, pp. 75–86, 2013.

[27] P. Alderfer Clayton, "Clarfing the meaning of Mentor-Protégé relationships," *Consulting Psychology Journal Practice & Research*, vol. 66, no. 1, pp. 6–19, 2014.

[28] D. Yang, R. Miao, H. Wu, and Y. Zhou, "Product configuration knowledge modeling using ontology web language," *Expert Systems with Applications*, vol. 36, no. 3, pp. 4399–4411, 2009.

[29] D. Yang, M. Dong, and R. Miao, "Development of a product configuration system with an ontology-based approach," *Computer-Aided Design*, vol. 40, no. 8, pp. 863–878, 2008.

[30] X. Wang, T. N. Wong, and Z.-P. Fan, "Ontology-based supply chain decision support for steel manufacturers in China," *Expert Systems with Applications*, vol. 40, no. 18, pp. 7519–7533, 2013.

[31] I. Horrocks, P. F. Patel-Schneider, S. Bechhofer, and D. Tsarkov, "OWL rules: A proposal and prototype implementation," *Journal of Web Semantics: Science, Services and Agents on the World Wide Web*, vol. 3, no. 1, pp. 23–40, 2005.