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Bridge Cranes Energy-Saving Index Reduction based on Rough Set Theory

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Abstract

Bridge crane is one of the most widely used cranes in our country, which is indispensable equipment for material conveying in the modern production. The most important indicator of crane performances is energy-saving. So it is of importance to research on the bridge cranes energy-saving assessment. Thus the establishment of assessment index system is a necessary task. In this paper, establishing the index system of the bridge crane based on the full life cycle of the bridge crane firstly. Secondly, defining the decision attribute and the condition attributes. Thirdly, using rough set theory reduce the index system of the bridge crane. Finally, an optimized index assessment system of the bridge can be obtained. The research lays the foundation for solving weight for the next step. And the efficiency of the bridge crane energy-saving evaluation can be improved, thus the energy consumption minimum bridge crane can be fast optimized by the evaluation personnel.

Keywords: *bridge crane, rough set, attribute reduction, energy-saving assessment*

1. Introduction

Rough set theory is a mathematical theory tool that deals with incompletion and uncertainty, which is put forward by Z. Pawley in1980s [1-2]. After 30 years' development, rough set theory has become an important data processing method in analyzing and processing data expression, summarization and incomplete information, such as incompletion and uncertainty.

Attribute reduction and "core" are the most important of the two basic concepts in the rough set theory, and the "core" is an indispensable part of an information system. By calculating the "core" we can weed out redundant attributes in the information system. Therefore, attribute reduction and "core"are the essence of rough set theory. Using the similar idea, Zhang et al. [3-4] discussed approaches to attribute reduction in inconsistent and incomplete information systems. In reference [5], Chu gave judgment theorems of consistent attribute sets and approaches to attribute reductions in information systems with fuzzy decision.

With the total power of bridge crane as decision property, this article discreetnesses condition property on the basis of national standards, historical data and expert opinions, and then gets rid of redundant index of index system with the help of attribute reduction in rough set theory, thus obtain the simplified index system which can provide support for decision-making.

2. The Basic Concepts of Rough Set Theory

2.1. The Rough Set

Set U for uncertain domain, R is the equivalence relation defined on the U; $[x]_R$ is the equivalence relation on the generated-equivalence class; X is a subset of the U ; $R\_(X)$

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referred to $X \subset U$ as the lower approximation, $R^{-}(X)$ referred to $X \subset U$ as upper approximation, and there are:

$$R_{\_}(X) = \{ x \in U \mid [x]_R \subseteq X \}$$
$$R^{-}(X) = \{ x \in U \mid [x]_R \subseteq X \neq \phi \}$$

Set on $R_{\_}(X)$, $R^{-}(X)$,known $X \subset U$ as the rough set.

2.2. The Information System

Set $S = \{U, A, V, f\}$ is an information system, U as the theory of domain, $A = C \cup D$ is the set properties, Subset of C and D respectively referred to as the condition attribute and decision attribute sets; $V = \bigcup_{a \in A} V_a$ is the set attribute value; $f : U \times A \rightarrow V$ is an information function,each object in the specified attribute's value.

Set each attribute subsets B define a indiscernibility binary relation that is the equivalence relation $IND(B)$, $IND(B) = \{(x,y) \in U^2, \forall a \in B, f(x,a) = f(y,a)\}$.

By the type, the equivalence relation $IND(B) = \bigcap_{b \in B} IND(\{b\})$ the equivalence relation $IND(B)(B \subseteq A)$ Constitute the universe a partition of U, write for $U / IND(B)$.

Table 1 as a concrete example of information system, theory of the domain $U = \{u_1, u_2, u_3, u_4, u_5, u_6\}$ set of properties $A = \{a, b, c, d, e\}$. Among them, condition attribute set $C = \{a, b, c, d\}$,decision attribute set $D = \{e\}$, $V = \{0,1\}$.

Table 1. The Information System

UA	a	b	c	d	e
U1	0	0	0	0	0
U2	1	0	1	1	1
U3	0	1	0	0	0
U4	1	1	1	1	1
U5	0	0	0	1	0
U6	1	0	0	0	0

3. Attribute Reduction Method using Rough Set Theory

The most important step of applying rough set theory to dealing with information system is to reduce the abundant information. Reduction is consisted of attribute reduction and value reduction. Attribute reduction can delete properties which have little effect on decision-making classification and retain properties which have great. There are many related researches about attribute reduction at home and abroad. Current studies are listed as data analysis reduction algorithm, attribute reduction algorithm based on feature selection, discernibility matrix reduction algorithm, attribute reduction algorithm based on mutual information, indicators screening methods, attribute reduction algorithm based on the search strategy, inductive attribute reduction algorithm and so on. Among them, the most frequently-used method is discernibility matrix [6-9]. The followings are how to use the algorithm of discernibility matrix to reduce attribute reduction.

Definition 1: Set $S = \{U, A, V, f\}$ as a decision system, U is a finite universe $U = \{U_1, U_2 \cdots U_n\}$,attribute set $A = \{C_1, C_2 \cdots C_n, D\}$,in which $C = \{C_1, C_2 \cdots C_n\}$ as condition attribute set, $D=\{D\}$ as decision attribute set, and there set c(x) is the sample x on the value in the property Ci, the distinguish matrix is expressed as follows:

$$C_{ij}\begin{cases}\{c\mid c\in A, c(x_i)\neq c(x_j)\} & D(x_i)\neq D(x_j)\\ 0 & D(x_i)=D(x_j)\end{cases}$$

When the decision-making table is incompatible, the distinguish matrix can be defined as follows:

Definition 2: Set $S=\{U,A,V,f\}$ as a decision system, U is a finite universe $U=\{U_1,U_2\cdots U_n\}$, attribute set $A=\{C_1,C_2\cdots C_n,D\}$, in which $C=\{C_1,C_2\cdots C_n\}$ as condition attribute set, $D=\{D\}$ as decision attribute set, and there set $C(x)$ is the sample x on the value in the property Ci, the distinguish matrix is expressed as follows:

$$C_{ij}\begin{cases}\{c\mid c\in C, c(x_i)\neq c(x_j)\} & D(x_i)\neq D(x_j)(x_i,x_j)\notin ind(D)\ \text{and}\ x_i,x_j\ \text{at least a part of}\ pos_c(D)\\ 0 & D(x_i)=D(x_j)\ \text{and others}\\ 1 & D(x_i)\neq D(x_j), c(x_i)=c(x_j)\end{cases}$$

Set Rec(U) as a new index set which is obtained by calculating attribute reduction of decision table S. C0 is a core set of attributes.

Step 1: Judge whether the decision table is compatible or not. If the decision-making table is compatible, adopt definition 1 to define and to distinguish matrix. If it is not, adopt definition 2 to define and to distinguish it.

Step 2: According to the above distinction matrix, find out the nuclear attribute, and grant the simplified new set of indexes with the nuclear attribute C0, ie Rec(U)={C0}. Also delete elements that contain the core of the attribute in the distinguish matrix.

Step 3: Find out all elements neither 0 nor 1 in the distinguish matrix. Calculate the number of occurrences of these elements in the condition attribute Ci and record. Elect the highest number of occurrences of attribute and record as Ci.

Step 4: Grant the new set of properties Rec(U) with Ci obtained in Step 3, ie $\mathrm{Re}\,c(U)=\mathrm{Re}\,c(U)\cup\{C_i\}$. Then delete elements which contain the condition attributes Ci in the distinguish matrix.

Step 5: Judge whether there are only elements which contain 0 or 1 in the distinguish matrix. If not, go to Step 3. If it is empty, then end.

Step 6: Rec (U) is reduction result.

4. Analysis on Bridge Cranes Energy-saving Index Reduction based on Rough Set Theory

As important foundation equipment for economic construction, crane is widely used in all walks of life. Its security situation is directly related to people's lives and property and its energy consumption situation can directly reflect the management level of energy utilization. In our research, taking the bridge cranes as an example, energy-saving indexes of the bridge crane is reduced and reestablished applying attribute reduction method in rough set theory with redundant indexes optimized.

4.1. The Bridge Crane Energy Saving Index System

Through several discussion of the Group of Experts, bridge crane energy index system based on the full life cycle is obtained as follows (Table 2).

Table 2. Bridge Crane Energy Index System

Target layer	Criteria layer	Evaluation Index	Mark
cranes energy saving evaluation index system(A)	lightweight factors （B1）	plate thickness variable cross-section	C1
		aspect Ratio	C2
		plate thickness	C3
		around the degree	C4
		variable cross-section of the belly of the fish beam	C5
		weight of Run institutions	C6
		weight of Lifting body	C7
		climbing height	C8
	electrical energy factors （B2）	the decelerator power loss	C9
		motor power loss	C10
		inverter power loss	C11
		coupling power loss	C12
		brake power loss	C13
		the pulley system power loss	C14
		steel wire rope power loss	C15
		big wheel bearings power loss	C16
	cost factors （B3）	design costs	C17
		the cost of energy-saving materials	C18
		the cost of energy-saving technology	C19
	depreciation factors （B4）	crane maintenance plan duty rate	C20
		crane new degree coefficient	C21

4.2. Establish Bridge Crane Evaluation Information Table

When collecting data, use 10 different bridge type crane to get objective information based on laboratory test data, site data, simulation data and then combine them with expert opinion as subjective information ,obtain various indicators data. Specific statistical results are shown in Table 3 [10-12].

Table 3. The Actual Index Value for each Indicator

Number	C1 (t)	C2 (t)	C3 (t)	C4 (mm)	C5 (t)	C6 (t)	C7 (t)	C8 (mm)	C9 (%)	C10 (%)
1	17.1	17.8	17.8	0.038	18.2	24.4	24.4	0.038	88	91
2	17.2	17.6	17.9	0.039	18.4	25.1	25.1	0.038	87	92
3	18.9	18.4	18.1	0.037	18.7	24.1	24.1	0.0127	92	94
4	17.1	18.9	18.2	0.036	18.6	24.3	24.3	0.038	86	95
5	18.1	19.1	18.0	0.041	18.5	24.2	24.2	0.0126	84	92
6	17.2	18.2	17.4	0.044	18.1	25.2	24.1	0.0127	88	82
7	17.4	18.4	17.5	0.041	17.9	25.5	24.2	0.0126	89	84
8	17.4	18.1	17.9	0.035	18.6	25.8	25.4	0.0127	80	85
9	17.5	18.7	17.8	0.044	18.5	24.1	24.1	0.0144	87	91
10	17.2	18.4	18.1	0.041	18.4	24.2	25.6	0.0127	87	88

Structural design factors in the sub-indicators: according to bridge crane design drawings, specifications weight and the Bridge Crane lightweight design, including on the cover plate thickness, web plate thickness, lower cover plate thickness, tendons Banban thick and the optimized design of the weight of the main beam by the finite element software HyperWorks. Again using the finite element software HyperWorks increases for the bridge crane girder structure analysis, get the supreme arch and arch the main beam in its own weight and hanging heavy under flexural deformation under around and climbing height [10-12].

Energy factors of the respective sub-indicators: The efficiency is obtained to monitor input power and output power when the bridge crane is working.

Cost factors: Combining manufacturing standards, design standards, as well as crane design side and consumer-related historical cost data to determine.

Depreciation factors: determine site usage of the overhead crane and a crane to use the historical operation data.

Table 3(continue). The Actual Index Value for each ndicator

C11 (%)	C12 (%)	C13 (%)	C14 (%)	C15 (%)	C16 (%)	C17 (RMB)	C18 (RMB)	C19 (RMB)	C20 (%)	C21
84	86	88	89	88	82	1000000	740000	940000	86	0.8
82	88	86	86	87	84	700000	750000	950000	88	0..9
83	84	94	96	86	85	1000000	840000	700000	89	0.8
88	94	85	88	85	83	740000	770000	710000	78	0.4
86	82	86	94	84	84	880000	890000	740000	91	0.7
85	89	88	93	88	88	940000	900000	730000	94	0.6
92	86	89	84	82	91	960000	980000	700000	89	0.9
84	84	84	82	81	94	980000	960000	720000	86	0.8
86	88	82	80	80	89	790000	100000	710000	77	0.2
89	80	81	81	86	98	970000	970000	780000	88	0.7

4.3. Establishment of Indicators of the Evaluation Criteria

After obtaining various index data, process indexes discretion is carried out. For efficiency indexes,

Suppose as follows, $U=\{U_1,U_2\}=\{common,excellent\}=\{0,1\}$.For cost type indexes, $U=\{U_1,U_2\}=\{low,high\}=\{1,0\}$ and decision attribute as $U=\{U_1,U_2\}=\{common,excellent\}=\{0,1\}$.Specific statistical results are shown in Table 4 and Table 5.

Table 4. Evaluation Criteria of each Index

Grade	C1 (t)	C2 (t)	C3 (t)	C4 (mm)	C5 (t)	C6 (t)	C7 (t)	C8 (mm)
0	>17.5	>17.5	>17.5	>0.036	>17.5	>24.2	>24.2	>0.00127
1	≤ 17.5	≤ 17.5	≤ 17.5	≤ 0.036	≤ 17.5	≤ 24.2	≤ 24.2	≤ 0.00127

Table 4(continue). Evaluation Criteria of each Index

C9 (%)	C10 (%)	C11 (%)	C12 (%)	C13 (%)	C14 (%)	C15 (%)	C16 (%)	C17 (RMB)	C18 (RMB)	C19 (RMB)	C20 (%)	C21
<90	<90	<90	<90	<90	<90	<90	<90	<800000	<800000	<800000	<80	<0.5
≥90	≥90	≥90	≥90	≥90	≥90	≥90	≥90	≥800000	≥800000	≥800000	≥80	≥0.5

Table 5. Bridge Cranes Energy-saving Index Statistics

Number	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	1	1	0	0	0	0	0	0	0	1
2	1	1	0	0	0	0	0	0	0	1
3	0	0	0	0	0	1	1	1	1	1
4	1	0	0	1	0	1	1	0	0	1
5	0	0	0	0	0	1	1	1	0	1
6	1	0	1	0	1	0	1	1	0	0
7	1	0	1	0	1	0	1	1	0	0
8	1	0	0	0	0	0	0	1	0	0
9	1	0	1	1	0	1	1	0	0	1
10	1	0	0	0	0	1	0	1	0	0

Table 5(continue). Bridge Cranes Energy-saving Index Statistics

C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	energy
0	0	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	1	0	0	1	1	1
0	0	1	1	0	0	0	1	1	1	1	0
0	1	0	0	0	0	1	0	1	0	0	1
0	0	0	1	0	0	0	1	1	1	1	1
0	0	0	1	0	0	0	1	1	1	1	0
1	0	0	0	0	1	0	1	1	1	1	1
0	0	0	0	0	1	0	1	1	1	1	0
0	1	0	0	0	0	1	1	1	0	0	0
0	0	0	0	0	1	0	1	1	1	1	1

4.4. Energy Saving Indexes Reduction of Bridge Crane

Data that have any two equal condition properties and different decision attribute do not exist in the preceding table. Therefore this decision table is compatible. According to distinguish matrix definition, the decision table is a 10*10 square. As the distinction matrix is a symmetric matrix, now only the non-zero elements of the upper triangular or lower triangular need to be considered. Use C (i, j) to represent the i-Th row and j-Th column element. Nonzero elements of the distinguish matrix are listed below.

C(1,2)={c17} C(1,4)={c2,c4,c6,c7,c12,c17,c19,c20,c21}

C(1,5={1,2,6,7,8,14,18,19} C(1,7)={c2,c3,c5,c7,c8,c10,c11,c16,c18,c19}

C(1,10)={c2,c6,c8,c10,c16,c18,c19}

C(2,3)={c1,c2,c6,c7,c8,c9,c10,c13,c14,c17,c18,c19}

C(2,6)={c2,c3,c5,c7,c8,c10,c14,c18,c19} C(2,8)={c2,c8,c10,c16,c17,c18,c19}

C(2,9)={c2,c3,c4,c6,c7,c12,c18,c19,c20,c21}

C(3,4)={c1,c4,c8,c9,c13,c14,c17,c18,c20,c21}

C(3,5)={c13} C(3,7)={c1,c3,c5,c9,c10,c11,c13,c14,c16}

C(3,10)={c1,c7,c9,c10,c13,c14,c16,c17}

C(4,6)={c3,c5,c6,c8,c10,c12,c14,c17,c18,c20,c21}

C(4,8)={c4,c6,c7,c8,c10,c12,c16,c17,c18,c20,c21}

C(4,9)={c3,c18} C(5,6)={c1,c3,c5,c6,c10}

C(5,8)={c1,c6,c7,c8,c10,c14,c16} C(5,9)={c1,c3,c4,c8,c12,c17,c20,c21}

C(6,7)={c11,c14,c16} C(6,10)={c3,c5,c6,c7,c14}

C(7,8)={c7} C(7,9)={c4,c5,c6,c8,c10,c11,c12,c16,c17,c20,c21}

C(8,10)={c6} C(9,10)={c3,c4,c7,c8,c10,c12,c16,c17,c20,c21}

From the distinction matrix above ,the core set of attributes is core(D)={c6,c7,c13,c17}. According to the steps of the attribute reduction, remove the elements with only a core attribute and the elements containing the core attribute of the distinguish matrix. After the first reduction, the rest of the elements in the distinguish matrix is:

C(4,9)={c3,c18} C(6,7)={c11,c14,c16}

In this case, c3, c18, c11, c14, c16 appears with a frequency of 1. Select any one element from c3, c18, c11, c14, c16 and add it to the core attributes. In this example, c3 is selected to add to the core attributes core(D)={c3,c6,c7,c13,c17}. Repeat the above steps until all the elements are 0 in the distinguish matrix. At last the reduced attribute set is Red={c3,c6,c7,c11,c13,c17}. After reduction the crane energy-saving indexes are the thickness of the crane girder, hoisting mechanism weight, operating organization weight, motor power loss, inverter power loss and design costs.

4.5. Results Analysis

In the above-mentioned bridge crane, the important attributes of the 21 energy saving indexes that affect crane energy consumption are the thickness of the crane girder, hoisting mechanism weight, operating organization weight, motor power loss, inverter power loss and design costs. Other indexes have little effect on energy-saving of cranes and can be deleted. Besides, weights of these indexes can be calculated thus the bridge crane in the design and manufacture can be improved.

5. Conclusion

We have introduced in this paper the concept rough set and Attribute reduction algorithm. We have also puts forward bridge cranes energy saving evaluation index system. And Rough set theory knowledge is adopted to reduce the index of the bridge crane energy saving evaluation index system.Via calculation and analysis, optimal design of energy saving of bridge can be obtained and meanwhile it can provide a reference for the bridge crane design and manufacturing.

The main results of this research can be concluded as follows:

1. Rough set theory knowledge is adopted to reduce the index of the bridge crane energy saving evaluation index system. The optimized bridge crane energy saving index system can be obtained after reduction. With a solid mathematical foundation and clear mathematical meaning, this method can be handled with mathematical methods, and its calculated amount is relatively small.
2. Rough sets theory, with a better objectivity and practicability, can analyze the truth hidden in the data, rather than any additional information about the data.
3. Rough sets theory provides a new technical support for solving the problem of bridge crane energy-saving evaluation, whose application value still needs to be further studied and developed.

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