Category Integration Method for Maintenance Tools Based on Case Analysis and Grey Situation Decision-Making

Yabin Wang; Jianmin Zhao and **Xisheng Jia**

Department of Management Engineering, Mechanical Engineering College, Shijiazhuang, China

Sp. Issue 2013/ # Paper 3
Corresponding author:
Yabin Wang
Mailing address: No. 97, Heping Western Road, Shijiazhuang, Hebei, 050005, P. R. China
E-mail: wangyabin123@163.com
Tel: +86-311-87994622
Fax: +86-311-87993496

KEYWORDS

Maintenance tools; Integration; Case analysis; Grey situation decision-making; Case retrieval

ABSTRACT

As systems designed toward larger scale and more complex, more and more maintenance tools are needed in equipment support process. This, however, brings a greater difficulty in making decision to guarantee efficient equipment support actions. In this paper, a category integration analysis method for maintenance tools, which can classify the maintenance tools scientifically by its main characters, is developed. A maintenance tools integration strategy based on the grey situation decision-making method is also introduced. In this method, the integration flow and steps of implementation are given to improve the efficiency of the integration method. The effectiveness of the method is demonstrated via a numerical example.

Introduction

Maintenance activities are widely adopted in engineering practice as it is able to reduce the failure frequency of repairable systems, restore system performance, and prolong the systems' remaining life (Liu, *et al.*, 2010; Liu, *et al.*, 2012). Maintenance tools integration refers to unify and generalize different tools with the same or similar function in different kinds of equipments, to reduce the number of categories of different maintenance tools, so as to alleviate equipment support burden and improve the efficiency of equipment supports (Chu, *et al*., 2011).

With the increase of advanced technologies and complexity of equipments, there are increasing varieties of maintenance tools. As a result, the equipment support is becoming even more difficult (Derek, 2008). In order to enhance the support efficiency and alleviate the logistic support burden, the number of categories of maintenance tools should be significantly reduced by integrating similar ones from different equipment.

For example, maintenance tools for M1 tank have been reduced to 79 pieces in U.S., which thereby greatly reduces the logistical burden, as well as improving the mobility of maintenance support forces (Gan, *et al.*, 2005). However, the number of maintenance tools for M60 tank before conducting integration was 201.

To the best of our knowledge, expert judgment is the only way ever used to integrate maintenance tools in practice so far, and it lacks an effective theory and method to facilitate this work (Tang, 2010). To deal with this problem, the concept of maintenance tools category integration along with its principle and steps was developed in this paper. Category integration analysis and to make decision in the quantized perspective is drawing more and more attentions. A new integration method which based on case analysis and gray situation decision-making is employed in this paper. A numerical example is presented in this paper to illustrate the effectiveness of the proposed method.

Principle and Steps of Maintenance Tools Category Integration

(1) The Integration Principles

The basic principles of the maintenance tools category integration are shown as follows:

(1.1) For the function, after the integration, the maintenance tools can completely substitute the one before integration;

(1.2) For the costs, after the integration, the total costs of the maintenance tools must less than the one before integration;
(1.3) For the design, the function and performance of all maintenance tools should be sorted and analyzed from an integrated trade-off perspective;
(1.4) For the forms, the maintenance tools integrated is required to have the same meet, which can be used in the same equipment.

(2) The Integration Steps
Maintenance tools varieties integration was carried out by four steps. They are: characteristics description, characteristic value extraction, integration analysis and integration decision-making, as shown in Figure 1.

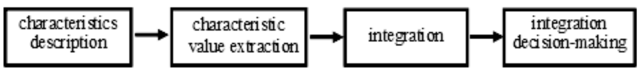

Figure 1: Process of Maintenance Tools Category Integration

Step1: Characteristics description. According to the maintenance tasks allocation table, the maintenance tools characterization was described by professionals in order to clarify the performance, which includes the function, performance, appearance, and use frequency of each maintenance tool.

Step2: Characteristic value extraction. Based on the characteristics description, the characteristic attributes of the case was marked by full use of expert knowledge and experience (Li, 2011), in order to determine the weight of the case characteristic properties.

Step3: Integration analysis. Knowledge base and inference engine were adopted for the maintenance tools case retrieval, which can filter out a collection of maintenance tools from the varieties of many tools of similar functions.

Step4: Integration decision. After the selection of maintenance tools with similar functions, a further selection decision was made based on the gray situation decision theory, so a maintenance tool which would be considered as the general tool is determined.

Based on the above integration steps, a detailed presentation of how the integration analysis and integration decision were used on a particular subject will be discussed.

Integration Analyses on Maintenance Tools Varieties

The key of maintenance tools varieties integration analysis includes two aspects. One is to filter out maintenance tools with similar functions or types from many maintenance tools, by the system analysis on its function; the other is to select a kind of "ideal" maintenance tools instead of other maintenance tools. That is, selection decisions should be made from a different point of view on a variety of maintenance tools, to ultimately get a satisfactory maintenance tools (Jeremy,1965).

(1) The Basic Idea of Integration Analyses
In order to carry out a variety of maintenance tools integration, the maintenance tools with similar functions should be selected from a mass of maintenance tools (Chen, *et al.*, 2012). Because the function of maintenance tools is generally available to be described by language, each type of maintenance tools can be regarded as a case. Hence, the knowledge base and inference engine can be used to the integration analysis of maintenance tools based on case. As a result, a set of maintenance tools with similar types of functions can be accurately selected from large varieties of maintenance tools.

For a single facility, the required maintenance tools for each functional unit of the facility can be confirmed through maintenance tasks allocation table. On this basis, we can descript the functionality, performance and other important attribute for each maintenance tools, and construct the corresponding reasoning model (inference mechanism) as different cases (Doc, 2006). In addition, similarity matching should be made in each case, by setting the similarity threshold to filter out similar functions or similar maintenance tools collection.

On the basis of the analysis in single facility, the same method can be used for multi-type facility group. In accordance with the classification of the maintenance tools, we can further extend to all the equipment, and filter out all kinds of similar maintenance tools ultimately.

The design of the maintenance tools varieties integration analysis is shown in figure 2.

(2) Integration Analysis of Maintenance Tools Varieties Based on Case

(2.1) Characteristics Description of Maintenance tools.

A series of characteristic attributes collection constitute a case (Wang, 2010). A maintenance tool cases includes at least the following information: description of tool function (P); description of the tool performance (T); description of tool use frequency (S); description of the tool dimensions (W); description of the tool interface attributes (J), and so on. Accordingly, the case can be expressed as C = (P, T, S, W, J, ...). A complete tool case = tool basic functional properties + tool basic performance attributes + tool use frequency + tool dimensions + tool interface attributes +……

The information mentioned above is detailed as follows:

(2.1.1) Function: the function description is at least composed of verbs and nouns, and the function enumeration must be clear and full.

(2.1.2) Performance: the maintenance tools prescribed performance index should be written-out as accurate as possible.

(2.1.3) Use frequency: use frequency refers to the maintenance tools utilization degree in practical use, for convenience of comparison, the use frequency can be briefly divided into three levels which is marked as high, medium and low respectively.

(2.1.4) Overall dimensions: overall dimensions mean the length, width and height size of a maintenance tool.

(2.1.5)Interface properties: interface refers to the attached form and specification between maintenance tools and equipment. And interface attributes includes the interface type, shape characteristics, size and interface versatility and compatibility.

(2.2) Maintenance Tool Case Description

In order to facilitate the maintenance tools case description, we need to classify the maintenance tools by attributes. There is a variety of classification for maintenance tools (Zhao, *et al.*, 2012). According to its properties, the maintenance tool is divided into mechanical, electronic, hydraulic, optical and other tools. To make it more comparative and easy to analyze, a normalized representation which can form a standard case format is needed for each maintenance tool. In this paper, the case is mainly described from the categories, classification, tool name, function, performance, frequency of use and other aspects. For example, the electronic service tool case representation is shown in table 1.

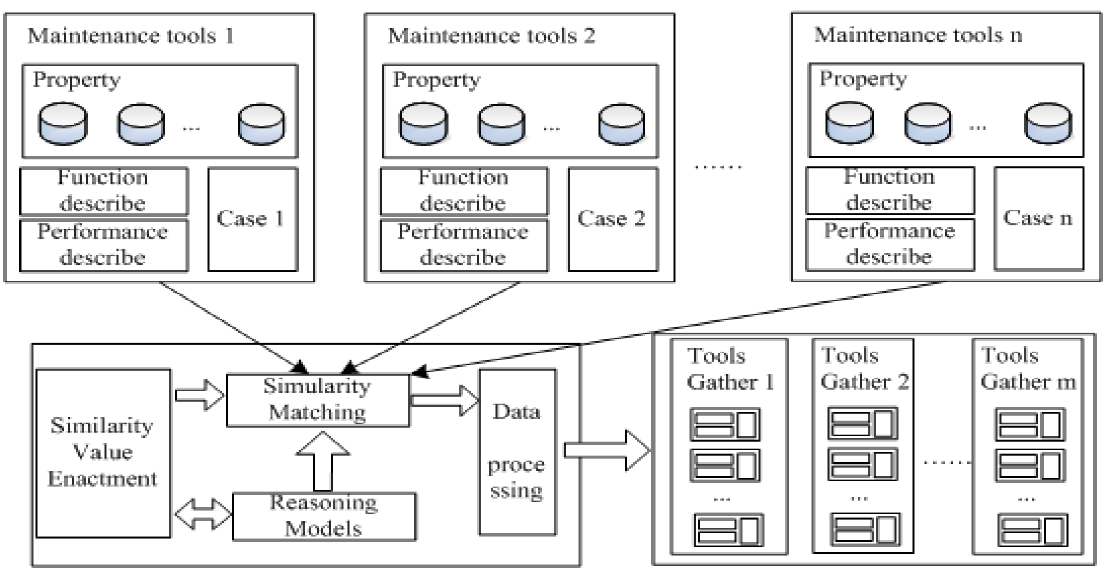

Figure 2: Design of Maintenance Tools Varieties Integration

Table 1: Knowledge Denotation for Maintenance Tools (example)

categories	classification	tool name	function	performance	use frequency
electronic	Electronic charge	X type cannon charge (GN-10)	charge the battery	rated voltage of 1.2V rated capacity of 10Ah	medium
	……	……	……	……	……

(2.3) Maintenance Tools Case Retrieval

(2.3.1) The Case Retrieval Strategy

From the case studies and application of the domestic and international situation (Zhang, *et al.*, 2012), the case search strategy commonly includes nearest neighbor strategy, inductive reasoning strategy, knowledge guide strategy, and template search strategy, which can be used independently or in combination.

According to the characteristics of the maintenance tools case, the combining of template search strategy and nearest neighbor strategy is more appropriate. In this paper, template search strategy is used to determine the categories for maintenance tool case. Then the nearest neighbor is matching to find similarity case in the same category of cases, which can shorten the search time and improve the retrieval efficiency. In accordance with this strategy, the maintenance tool case retrieval can be divided into sort classification, selection and confirmation stages.

(I) In classification sort stage, equipment maintenance tool case should be sorted and classified according to the characteristic properties of the categories and classification of maintenance tools, which means maintenance tools can be divided according to the categories and classification. For example, if there are i categories maintenance tools, each category has j classification. Then, the maintenance tool case set can be expressed as: $C_{ij} = \{C_{ij1}, C_{ij2}, \ldots, C_{ijp}\}$.

(II) In selection stage, a series of corresponding relationship between the case collections which are gained from the initial filtration need to be created, and a detailed analysis need to be conducted. We can choose the high similarity cases by a comprehensive comparison of the similarity between all selected cases.

In this phase, the characteristic attributes similarity between the various maintenance tools case need to be calculated based on the nearest neighbor strategy. We can use $S_{im}(Q^m, T^m)$ indicates the similarity degree of characteristic attributes m between the two cases Q^m and T^m, in which, $S_{im}(Q^m, T^m) \in [0,1]$. When a characteristic attributes of the two cases is equal, $S_{im} = 1$; otherwise, $S_{im} = 0$. The overall similarity of the two cases is as follows:

$$S_{IM}(Q,T) = \frac{\sum_{m=1}^{M} \omega_m \times S_{im}(Q^m, T^m)}{\sum_{m=1}^{M} \omega_m} \qquad (1)$$

Total similarity degree calculation should be aimed at maintenance tools, which compared with all the other maintenance tools in their respective categories one by one. The similarity degree may range from totally match, when $S_{IM}(Q,T)$ equals 1, which doesn't match at all when the corresponding similarity value is 0. In Eq. (1), M means the number of characteristic attributes in each case, and m means a certain characteristic attributes ($m \in [1, M]$), ω_m is the characteristic properties weight. Usually, we can determine the threshold α, and select the case $S_{IM}(Q,T) > \alpha$ as a comparative case.

(III) In confirmation stage, the maintenance tools with a greater similarity than a certain value can be selected from the comparison results by analysts based on the similarity of the cases.

(2.3.2) Case Retrieval Process

The determination of maintenance tools case feature attribute weights is very important for the case retrieval. As equipment maintenance expert knowledge and experience has been proved to be a critical basis for the determination of the feature attribute weights, we can make full use of this method. In this paper, expert scoring method was employed to determine the weights of the cases characteristic attributes.

In the case retrieval process of maintenance tools analysis, analysts are more familiar with the properties of the maintenance tools function, and the similar types of maintenance tools are not too many. Then through the case retrieval classification stage, we can basically confirm the similar tool case without having to go through the second phase. However, when the similar tool case can not be confirmed, the nearest neighbor policy will be considered to the cases selection in the second stage. Equipment maintenance tool case retrieval process is shown in Figure 3.

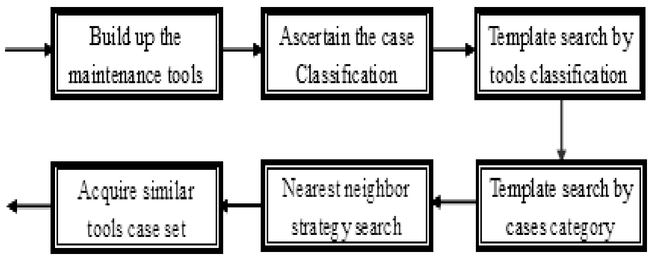

Figure 3: Retrieval Process of Maintenance Tools Analysis Case

Step1: Generate a maintenance tool case, that is *Q* = (equipment categories, classification, function, performance, and frequency of use).

Step2: Determine the tools category for current case *Q*. Tool case *Q* can be classified as (Q, C_L), in which, C_L = (machinery, electronics, ..., and others), *Q* represents maintenance tool case.

Step3: Retrieval of maintenance tools kinds. Using maintenance tools kinds to retrieve, we can limit the similar case to similar maintenance tools.

Step4: Nearest-neighbor policy retrieval. Using the nearest neighbor strategy, we can calculate the similarity of feature attributes (classification, function, performance and use frequency, etc.) between maintenance tool case Q and its similar cases. Through the similarity rank, we can select and analyze the maintenance tools cases with more close similarity.

Table 2: Question Case of Storage Battery (example)

Tools name	Classification		Function		Performance		Frequency	
	Category	Weights	Functional description	Weights	Performance description	Weights	Frequency description	Weights
X Type charger (6-TKA-140)	charger		charge the battery		Rated voltage 12V, Rated capacity 140Ah		medium	
Y Type Charger(6-TKA-155)	charger	0.2	charge the battery	0.3	Rated voltage 12V, Rated capacity 155Ah	0.3	medium	0.2
Z Type Charger (GN-10)	charger		charge the battery		Rated voltage 1.2V,Rated capacity 10Ah		high	
……	……		……		……		……	

Table 3: Concourse of Maintenance Tools Analysis Cases

Attribute	Search case of X type charger (6-TKA-140)	Search case of Y type charger(6-TKA-155)	Search case of Z type charger (GN-10)
Classification	charger	charger	charger
Function	charge the battery	charge the battery	charge the battery
Performance	Rated voltage 12V Rated capacity 140Ah	Rated voltage 12V Rated capacity 155Ah	Rated voltage 1.2V Rated capacity 10Ah
Frequency	medium	medium	high

(2.3.3) Case Similarity Calculation

Case similarity calculation is very important in the maintenance tools case retrieval process. Taking the charger as an example, the presentation of the case similarity calculation process is as follows.

Step1: The formatting of problem case. Taking battery function, performance, and use frequency as the characteristic properties, we can format the problem cases. In this problem cases, the individual properties are character type, and the sum of the weights determined by Expert Score for the respective characteristic properties is 1. In this case, the classification is 0.2, the functionality is 0.3, the performance is 0.3, and the use frequency is 0.2. The charger problem cases are shown in Table 2.

Step2: The description of maintenance tools analyzing case collection. Taking the battery as example, and following the method of case retrieval, the case collection for maintenance tools analyze is shown in Table3.

Step3: The calculating of the similarity of case feature attribute. Take X type howitzers charger (6-TKA-140) retrieving the case as example, firstly, the similarity between the retrieved cases and Y type howitzers charger (6-TKA-155) case in case base should be calculated. According to the characteristic attribute values in Table 3, the similarity calculation between the retrieved cases and its characteristic properties are shown as follows:

S_{im}(Properties 1)=S_{im}(Charger / Charger)= 1;

S_{im}(Properties 2)=S_{im}(charge the battery / charge the battery)= 1;

S_{im}(Properties 3)= [S_{im}(Rated voltage 12V/ Rated voltage 12V)+S_{im}(Rated capacity 140Ah / Rated capacity 155Ah)]/2= 0.5;

S_{im}(Properties 4)=S_{im}(medium / medium)= 1;

Similarity (problem cases, Y type howitzers charger (6-TKA-155) case):

$$S_{IM} = \frac{\sum_{m=1}^{4} S_{im}(\text{properties} \quad m)}{\sum_{m=1}^{4} \omega(i)} \times 100\% = \frac{3.5}{4} \times 100\% = 87.5\%$$

By the same method, we can got: the similarity (retrieved case, the case of the Z type artillery battery charger (GN-10)) = 50%.

Step4: The classifying of maintenance tools. If we take the similarity 85% as a determine threshold for the similar attributes of different tools, then it can be seen that the case of the Y type howitzers charger (6-TKA-155) mostly match the retrieved case from the calculation. So, it can be used as a set while Z type artillery charger (GN-10) casecan't because the similarity value is under the threshold.

Obviously, this method is easy to realize computerization. On the basis of maintenance tasks allocation table, and a description of the main properties of the maintenance tools, the classification combing of the similar maintenance tools can be easily and quickly realized by case retrieve. It can provide a basis for support for maintenance tools integration.

Integration Decision Making in Maintenance Tools Varieties

After filtering out a collection of maintenance tools with similar functions, we need to make selection decisions for each collection, which can integrate different maintenance tools into one. In the decision-making process, the various properties of maintenance tools are bound to be taken into account. And the integrate decision-making should be taken from different angles in order to get a satisfactory maintenance tool. This process involves multiple targets, and a variety of influencing factors and a number of options. As a result, it is difficult to be solved by the general numerical methods or operations research theory. However, gray situation decision-making has a very distinct advantage in solving multi-objective, multi-event, multi-game problem (Liu, *et al.*, 2008). Therefore, the theory of gray situation decision was employed to the quantification integration decision-making for maintenance tools.

(1) Relevant Definitions

Definition 1: in the decision-making process, the similar events used to be studied frequently, expecting to find the corresponding countermeasures (Chen, *et al.*, 2004). Then we can remember a as an event, and b as the countermeasures to deal with the event a. we can call the binary combinations S as a situation, in which $S = (a, b)$.

Definition 2: if we take t as the quantized value of b, then the binary combination $S = (a, b(t)$ was called a quantify situation, and b is the quantization strategy. Usually, a_i denotes the specific event, a refers to the whole event, and a_i belongs to a, that is $a_i \in a$. Similarly, b_i denotes specific countermeasure, b denotes the whole countermeasure, and b_i belongs to b, that is $b_i \in b$. Binary combinations of a_i and b_i can be noted as S_{ij}, it means the *ij-th* situation. The whole situation was called complexion.

Definition 3: when event a happens, a set of measures $\{b_j\}, j > 1$ are required to deal with. the best one in the multiple choices to deal with the event a is called a decision. Note a_i as event, b_i as countermeasure and $P(P = \{1,2,...,m\})$ as the target, then the countermeasures set can be expressed as B, where $B = \{b_j | j = 1,2,...\}$ and the effect for target p can be expressed as $r_{ij}^{(p)}$, where $r_{ij}^{(p)}$ is a correspondence for S_{ij}. It shows that any situation S_{ij} must have an effect r_{ij}, which can be remembered as $r : S_{ij} \rightarrow r_{ij}$.

(2) Decision Analysis

In practice, the choice of general maintenance tools was affected by many factors (Wang, *et al.*, 2009). In order to improve efficiency and reduce costs, it is generally believed that maintenance tool weight (Q), volume (V), price (C), performance (X), interface (J) are key factors to influence the choice. Moreover, the choice of general maintenance tools is also inseparable from the technical requirements of the production process.

(2.1) Weight. In the process of maintenance support, people hope that the weight of the maintenance tools should usually be moderate. When the weight is too large or too small, the implementation cannot take its advantage for maintenance and support.

(2.2) Volume. The volume of the different maintenance tools diverse from each other, and their requirements are not the same. For some, they may think that the smaller is better; however, it may just be the opposite for others.

(2.3) Price. The price is directly related to the total cost of maintenance and support. The maintenance tools price should be as low as possible without compromising quality.

(2.4) Performance. It mainly refers to the functions and parameters of the maintenance tools.

(2.5) Interface. As any other products, users often hope that the maintenance tools interface be as generic as possible, which can be applied to a variety of different types of equipment.

Of course, the influencing factors for all maintenance tools are more than the above aspects. We should make a specify analysis for different situations.

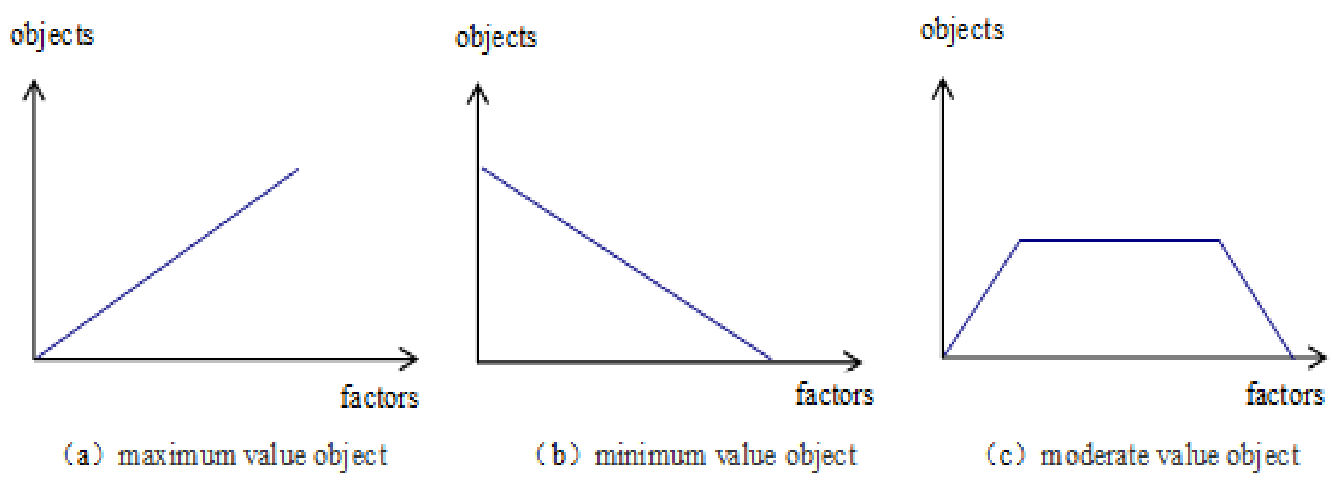

Figure 4: Sketch Map of Decision-Making Object

(3) Construction of the Decision-making Goals

According to the determine impact factors, we can take each factor as a decision-making goal. Then, a target system was constituted by all goals. For the target polarity, some use a maximum value as the target, i.e. the bigger the value is, the better the target would be, as is shown in Figure 4 (a); some use a minimum value as the target, i.e. the smaller the value is, the better the target would be, as is shown in Figure 4 (b); some use a moderate value as the target, i.e. the target value can neither be too small nor too large, as is shown in Figure 4 (c).

It is necessary to seek a scientific approach to the decision making for the polarity inconsistency of the target of candidate tools. The gray situation decision theory provides an effective solution for it (Liu, *et al.*, 2012).

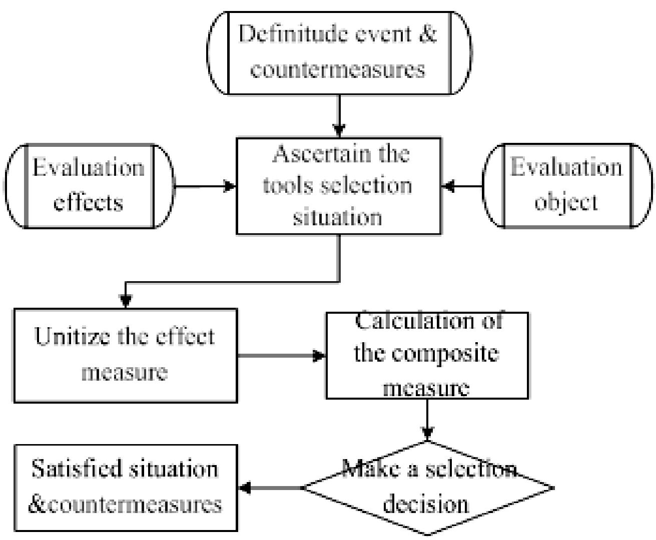

Figure 5: Flow of Grey Situation Decision-Making for Maintenance Tools

(4) Decision-Making Process

The gray decision-making process of the maintenance tools can be developed by the steps of gray decision-making, which is shown in Figure 5.

(4.1) Definitude the event and countermeasures

We mark the event that choose the best service tool as a, and the event set $A = \{a\}$; To select the maintenance tools 1, 2, …, n were denoted as countermeasures b_1, b_2, ... , b_n, and countermeasures set $B = \{b_1, b_2, ..., b_n\}$. Then S_j = {choose the best generic maintenance tools, maintenance tools j}, j = 1,2, ..., n, and the situation set $S = \{S_j = (a, b_j \mid a \in A, b_j \in B, j = 1,2, ..., n)\}$.

(4.2) Determine the evaluation objectives and effects

According to the evaluation target system mentioned above, we can determine the decision targets p (p = 1,2, ..., m) of each situation. And then the effect of the column can be obtained under various policy objectives which can be acquired by the polarity of the respective target (maximum, minimum or moderate). Take the i-th decision objective as an example, the effect of the column can be expressed as:

$$U^{(i)} = (U_1^{(i)}, U_2^{(i)}, \ldots, U_n^{(i)}) \quad (2)$$

(4.3) Unitize the effect measure

(4.3.1) Take a maximum effect measure for maximum target p:

$$r_{ij}^{(p)} = \frac{U_{ij}^{(p)}}{\max\limits_i \max\limits_j U_{ij}^{(p)}}, \quad i = 1,2,...,n; j = 1,2,...,n; p = 1,2,...,m \quad (3)$$

In the maintenance tools selection, a general maintenance tools was usually chosen from a variety of maintenance tools i.e. the set of events is fixed, and then the above equation can be simplified into:

$$r_j^{(p)} = \frac{U_j^{(p)}}{\max\limits_j U_j^{(p)}}, \quad j = 1,2,...,n; p = 1,2,...,m \quad (4)$$

(4.3.2) Take the lower effect measure for the minimum value of the target p:

$$r_{ij}^{(p)} = \frac{{}_{i} \quad {}_{j} \quad {}_{ij}}{U_{ij}^{(p)}}, \quad i = 1,2,...,n; j = 1,2,...,n; p = 1,2,...,m \quad (5)$$

Similarly, if the events set are fixed, then the above equation can be simplified as:

$$r_j^{(p)} = \frac{\min\limits_j U_j^{(p)}}{U_j^{(p)}}, \quad j = 1,2,...,n; p = 1,2,...,m \quad (6)$$

(4.3.3) Take a moderate effect measure for moderate value target p:

$$r_{ij}^{(p)} = \frac{\min\{U_{ij}^{(p)}, \ U_0^{(p)}\}}{\max\{U_{ij}^{(p)}, \ U_0^{(p)}\}}, \quad (7)$$

$i = 1,2,...,n; j = 1,2,...,n; p = 1,2,...,m$

In which, $U_0^{(p)} = \frac{1}{n}\sum_i \sum_j U_{ij}^{(p)}$. In the case of an event set fixed,

$$r_j^{(p)} = \frac{\min\{U_j^{(p)},\ U_0^{(p)}\}}{\max\{U_j^{(p)},\ U_0^{(p)}\}},\ U_0^{(p)} = \frac{1}{n}\sum_j U_j^{(p)} \quad (8)$$

Based on the above principles, we can calculate the effect measure for each index.

(4.4) Calculation of the composite measure

It is possible to calculate the combined effect measure of each maintenance tools after acquiring the effect measure of each index.

$$E_{r_{ij}} = \frac{1}{m}\sum_{p=1}^{m} r_{ij}^{(p)} \quad (9)$$

In the case of the event set is fixed, the above equation can be simplified as:

$$E_{r_j} = \frac{1}{m}\sum_{p=1}^{m} r_j^{(p)} \quad (10)$$

After a comprehensive measure in accordance with a variety of indicators for each maintenance tools, we can get a set of comprehensive measures.

(E) Make a selection decision

We can compare various maintenance tools measure values by comprehensive measures set, and select the maximum one as the satisfied situation. The corresponding counter measures are the satisfied ones. By this method, we can choose a general maintenance tool, which can meet the requirements.

In the above decision-making process, it should be noted that decision-making objectives, effects, and extreme values can be adjusted accordingly based on the actual situation.

Numerical Examples

(1) Problem Description

Portable charger is a regular tool in the process of the equipment maintenance. For example, there are seven different models of portable charger in an equipment support system. In order to facilitate the support and reduce costs, we want to select one as a universal charger under the conditions that it must be feasible technically. With a combination of experience, we have chosen weight, volume, price, average life expectancy, performance index, and interface universal as the goals of decision analysis. The effect of each indicator was denoted as polarity respectively, which is shown in Table 4.

(2) Primary Data Collection

Through a research process, we have collected the relevant parameters of the charger in accordance with the above-identified indicators. Parameters of selected charge machine are shown in the Table 5.

(3) Decision-Making Process

When the preparation work is ready, we can determine the gray decision of situation sets. By determining the effect of columns, unfirming the effect measure, and calculated on the five objectives respectively, the calculation results can be obtained after the uniform measure of plurality target for the various situations, which is shown in Table 6.

Based on Eq. (10), the similarity degree is acquired:

$S = \{0.667, 0.629, 0.688, 0.698, 0.767, 0.780, 0.757\}$.

It is not difficult to see that the situation 6 is satisfied with the situation, for $S_j^* = S_6 = 0.780$. Similarly, the corresponding countermeasure 6 is the satisfaction measures because $b_j^* = b_6$. Therefore, we should choose the 6th charger as the universal charger after the integration.

In fact, among the seven chargers, the 6th charger is one with a moderate weight, smaller volume (little than average), lower unit price (the rank is 5), mean average life, moderate performance parameters, and high degree of common interface. Therefore, to select the 6th charger as the universal charger is more realistic by comprehensive factors.

Table 4: Index of Selection Decision Analysis for Charge Machine

Index	Decipherment	Polarity
Weight(Kg)	support personnel hope the chargers should with a moderate weight	moderate
Volume(dm^3)	support personnel hope the chargers volume should as small as possible	minimum
Unit Price (1000Yuan)	purchase price of the charger should as low as possible	minimum
Average life(h)	support personnel hope that the average life of the charger is as long as possible	maximum
Performance index(%)	the main performance parameters of current, voltage, charging time can moderate	moderate
Interface universal(%)	the charger interface type, shape, size should be able to apply to a variety of different types of equipment, security staff who want to try universal	maximum

Table 5: Parameters of Selected Charge Machine

No.	Type	Weight (Kg)	Volume (dm^3)	Unit Price (￥1000)	Average life (1000h)	Performance index(%)	Interface universal (%)
1	WZF-10	20	13.3	33.41	15	85	90
2	WZF10-2	25	40.5	9.58	18	97	92
3	GFT-4500	25	45.2	4.22	16	90	95
4	WGF-15B	38	19.8	39.02	40	93	98
5	DFT-120A	18	16.2	2.62	10	90	89
6	DFT-125A	21	18.5	2.84	12	92	95
7	DFT-3.5A	12	10.7	2.75	9	88	85

Table 6: Result of Multi-object Unify Effect Measure

No.	Weight (Kg)	Volume (dm^3)	Unit price (￥1000)	Average life (1000h)	Performance index(%)	Interface universal(%)
1	0.880	0.805	0.08	0.375	0.94	0.92
2	0.908	0.264	0.27	0.450	0.94	0.94
3	0.908	0.237	0.62	0.400	0.99	0.97
4	0.597	0.540	0.07	1.000	0.98	1.00
5	0.793	0.660	1.00	0.250	0.99	0.91
6	0.925	0.578	0.92	0.300	0.99	0.97
7	0.529	1.000	0.95	0.225	0.97	0.87

Results

The concepts, principles, procedures and methods of maintenance tools varieties integration were studied in this paper. In the meta-analysis process, a basic idea of the maintenance tools integration was provided. And a case-based retrieval maintenance tools process was put foreword. In accordance with the properties of the main features of the maintenance tools, the scientific classification of the various maintenance tools were achieved. On this basis, the maintenance tools varieties of integrated decision-making methods and procedures were proposed by the use of gray situation decision theory. Finally, a numerical example was illustrated to verify the feasibility and effectiveness of the integrated approach, which provides a foundation for the determination and optimization of the number of maintenance tools.

References

Chen D; Zhang S; and **Chen M** (2004) Research of Gray General Situation Decision and its Application. *Systems Engineering and Electronics*, **26** (4): 423-425.

Chen L; Chen Z; and **Zeng H** (2012) Study on Case Retrieval of Case-based RCM Analysis System. *Computer Engineering and Design*, **33** (02): 581-585.

Chu D; Wang X; Wang Z; and **Xu X** (2011) Personalized Requirement Oriented Virtual Service Resource Aggregation Method. *Chinese Journal of Computers*, **34** (12): 2370-2380.

Derek TD (2008) *Heuristic ALgorithm for US Naval Mission Resource Allocation*. ADA488672.

Doc P (2006) *Maintenance Planning and Scheduling Handbook*. McGraw Hill Press, New York, USA.

Gan M; Kang J; and **Gao Q** (2005) *Maintenance Engineering Science for Military Equipment Use*. National Defense Industry Press, Beijing, pp20-30.

Jeremy AL (1965) Optimization of Maintenance Resources. *European Journal of Operational Research*, **13**(6): 1007-1019.

Li F (2011) *Intelligent Decision Making Case Based Reasoning Technology*. Anhui University Press, Hefei, pp52-60.

Liu S; and **Xie N** (2008) *Gray System Theory and its Application.* Science Press, Beijing, pp24-37.

Liu, Y; Huang HZ; and **Zhang X** (2012) A Data-driven Approach to Selecting Imperfect Maintenance Models. *IEEE T Reliab*, **61** (1): 101-112.

Liu Y; and **Huang HZ** (2010) Optimal Replacement Policy for Multi-state System under Imperfect Maintenance. *IEEE T Reliab*, **59** (3): 483-495

Liu Y; Jeffrey F; and Zhao H (2012) Multi-objective Grey Situation Decision Making Method Based on Prospect Theory. *Systems Engineering and Electronics*, **34** (12): 2514-2519.

Tang K (2010) *Research on Techniques of Inventory Management for Manufacturer of Civil Aircraft Spare Parts*. Nanjing University of Aeronautics and Astronautics, Nanjing, China, (Unpublished PhD Thesis).

Wang J (2010) *Research on Case Based Reasoning in Decision Support System*. Hefei University of Technology, Hefei, China, (Unpublished Master's Degree Thesis).

Wang Y; and **Dang Y (**2009) New Method in Situation Decision Making Based on Entropy. *Systems Engineering and Electronics*, **31** (6): 1350-1352.

Zhang Y; Luan L; and **Fu Z** (2012) Research on Integrated Design of Miner's Protection and Rescue Tools. *Packaging Engineering*, **33** (20): 45-47.

Zhao, X, Li, Y, and Qi, J (2012). Integration of management accounting tools based on integrated innovation theory, *Journal of Tianjin University (Social Sciences)*, **14** (02): 107-110