# A Method For Condition Evaluation Based On DSmT

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*Abstract*—**Condition-based maintenance (CBM) is an optimal maintenance strategy due to improved planning for rehabilitation or replacement based on current evaluation of condition.In this paper, a new method of information fusion-DSmT(Dezert-Smarandache Theory) developed from DST(Dempster-Shafer Theory) and Bayesian theory is introduced to dealing with condition evaluation. With the research and analysis of condition evaluation ,the model of condition evaluation based on DSmT is presented in which the generalized basic belief assignment and the rule of information fusion are built. The performance is compared with DSmT and DST for challenging realistic condition evaluation.The result shows that the DSmT enhance the performance of condition evaluation by reducing the time on computing and increasing the quality of fusion result.**

***Keywords- Condition Evaluation; information fusion; DSmT; DST; CBM***

## I. INTRODUCTION

Condition-based maintenance (CBM) is a maintenance strategy that makes maintenance decisions based on the information collected through condition monitoring.It consists of three main steps:data acquisition,data processing and maintenance decision-making.[1]In CBM,the condition of each unit,such as vibration or heat,is monitored at equidistant time intervals,and the maintenance action is taken dynamically on the basis of this observed condition character parameters of the system. CBM is a decision-making program where the decision to perform maintenance is reached by observing the condition of the system . Thus in order to implement the CBM,a key step is to evaluating the current condition of system. A grey model of condition evaluation for equipment in power plant based on grey space relational grade is constructed in [2].Reference [3] proposed a synthetic evaluation method of equipment conditions in power plant based on fuzzy judgment.Yam et al.[4] presented a recurrent neural network to predict the machine condition.Dong et al.[5] applied a grey model and a BP neural network to estimating the machine condition. All of these models achieve some success in evaluation, but the result is not good when some condition character parameters conflict.

DSmT (Dezert-Smarandache Theory) proposed by Jean Dezert (French) and Florentin Smarandache (American) based on Bayesian theory and DS (Dempster-Shafer) theory come forth since 2003, which is a general, flexible and valid arithmetic of fusion.[6] As a information fusion technology,DSmT can perfectly solve these problems: imprecise environment information obtained from the entirely unknown environment and inaccurate, uncertain and even highly contradicted data acquired by single sensor.

The rest part of the paper is organized as follows:the next section gives a simple review of DSmT. In section Ⅲ,a condition evaluation model is established based on DSmT. Section Ⅳ realizes the condition evaluation of diesel engine based on DSmT. The conclusion of the research is given in section Ⅴ.

## II. A SIMPLE REVIEW OF DSMT

### A. *Notion of Hyper-power Set* $D^\Theta$

The notion of hyper-power set is one of the cornerstones of the DSmT.Let $\Theta = \{\theta_1, \theta_2, \cdots \theta_n\}$ be a finite set (called frame) of $n$ exhaustive elements.The hyper-power set $D^\Theta$ is defined as the set of all composite propositions built from elements of $\Theta$ with $\cup$ and $\cap$ operators in the following way:

1) $\phi, \theta_1, \theta_2, ...., \theta_n \in D^\Theta$

2) If $A, B \in D^\Theta$, then $A \cap B \in D^\Theta$ and $A \cup B \in D^\Theta$

3)No other elements belong to $D^\Theta$ , except those obtained by using rules 1 or 2.

### B. *Generalized belief function*

From the frame of discernment $\Theta$ ,a map $m(.): D^\Theta \to [0,1]$ is defined as:

$$m(\phi) = 0 \text{ and } \sum_{A \in D^\Theta} m(A) = 1$$

The quantity $m(A)$ is called the generalized basic belief assignment/mass (gbba) of A. The generalized belief and plausibility functions are defined respectively in almost the same manner as within the DST, i.e.

$$Bel(A) = \sum_{\substack{B \subseteq A \\ B \in D^\Theta}} m(B)$$

$$Pl(A) = \sum_{\substack{B \cap A \neq \phi \\ B \in D^\Theta}} m(B)$$

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## C. Classic DSm rule of combination

Let $M^f(\Theta)$ is a free model of DSmT ,the classic DSm rule of combination $m_{M^f(\Theta)} \equiv m(.) \overset{\Delta}{=} [m_1 \oplus \cdots m_k](.)$ of independent sources of evidences is given as:

$$\forall A \neq \phi \in D^\Theta, m_{M^f(\Theta)}(A) = \sum_{\substack{X_1,\cdots X_k \in D^\Theta \\ (X_1 \cap \cdots X_k) = A}} \prod_{i=1}^{k} m_i(X_i)$$

# III. MODEL OF CONDITION EVALUATION BASED ON DSMT

## A. Deterioration grade of Condition Character Parameter

By using monitoring sensor,condition monitoring data relevant to system health can be obtained.Condition monitoring data are very versatile,which include vibration data,temperature,pressure and oil analysis data,etc.In order to evaluate the effect of each parameter consistently, deterioration grade $l$ is presented in this paper.

$$l = \left| \frac{C-A}{B-A} \right| \quad (1)$$

In formula (1), $l$ is the deterioration grade of condition character parameter, $A$ is the normal value of condition character parameter, $B$ is the threshold value of condition character parameter, $C$ is the practical measure value of condition character parameter.It's seen from formula (1) that $l$ reflects the deterioration degree of condition character parameter.When $l = 1$ ,it shows that the system is in abnormal condition.And when $l = 0$ ,it shows that the system is in normal condition.

## B. Modeling Based on DSmT

### 1) constructing the body of evidence $E$

The condition evaluation must be made based on system current monitoring data,so the system condition character parameter can be taken as the body of evidence of condition evaluation $E = \{E_1, E_2, \cdots, E_n\}$.

### 2) defining the frame of discernment $\Theta$

Considering the condition character of system,this paper suppose there are two focal elements in system,and the frame of discernment is defined as:

$$\Theta = \{\theta_1, \theta_2\}$$

Here $\theta_1$ means the system is in a abnormal condition, $\theta_2$ means the system is in a normal condion.So we can get its hyper-power set as:

$$D^\Theta = \{\phi, \theta_1 \cap \theta_2, \theta_1, \theta_2, \theta_1 \cup \theta_2\}$$

Then the generalized basic belief assignment/mass (gbba) is constructed as follows: $m(\theta_1)$ is defined as the gbba for abnormal condition; $m(\theta_2)$ is defined as the gbba for normal condition; $m(\theta_1 \cap \theta_2)$ is defined as the gbba for conflicting mass ; $m(\theta_1 \cup \theta_2)$ is defined as the gbba for unknown mass due to the restriction of knowledge and technology.When there exists belief assigned to abnormal condition,and also exists an object on normal condition ,unknown condition or conflict condition.

### 3) constructing the generalized basic belief assignment/mass (gbba)

According to the physical characteristics of condition monitoring data,the gbba of a set of mapping $m(.)$ is constructed as follows:

$$m(\theta_1) = \begin{cases} \frac{1-l^2}{\lambda} & A \leq C \leq B \\ 0 & otherwise \end{cases} \quad (2)$$

$$m(\theta_2) = \begin{cases} \frac{l^2}{\lambda} & A \leq C \leq B \\ 0 & otherwise \end{cases} \quad (3)$$

$$m(\theta_1 \cap \theta_2) = \begin{cases} \frac{1}{2}(1 - \tanh \lambda)l & A \leq C \leq B \\ 0 & otherwise \end{cases} \quad (4)$$

$$m(\theta_1 \cup \theta_2) = \begin{cases} l \tanh \lambda & A \leq C \leq B \\ 0 & otherwise \end{cases} \quad (5)$$

Where $\lambda = A - B$ .

### 4) generating the classic DSm rule of combination $m_{M^f(\Theta)}$

Considering the free model of DSmT,the classic DSm rule of combination $m_{M^f(\Theta)}$ of the independent sources of evidence body $E$ is given as follows:

$$m_{M^f(\Theta)} \equiv m(.) \overset{\Delta}{=} [m_1 \oplus m_2 \oplus m_3](.)$$

When the free model does not depend on the intrinsic nature of elements of the fusion problem,some constraints are introduced explicitly and formally in $M^f(\Theta)$ to adapt to reality as close as possible.In such case,the hybrid DSm rule of combination for three or more independent sources of information for all $A \in D^\Theta$ is defined with these functions:

$$m_{M(\Theta)}(A) = \psi(A)\left[S_1(A) + S_2(A) + S_3(A)\right] \quad (6)$$

$$S_1(A) = \sum_{\substack{X_1, X_2, \cdots, X_k \in D^\Theta \\ (X_1 \cap X_2 \cap \cdots \cap X_{,K}) = A}} \prod_{i=1}^{K} m_i(X_i) \quad (7)$$

$$S_2(A) = \sum_{\substack{X_1, X_2, \cdots, X_k \in \phi \\ [u=A] \vee [(u \in \phi) \wedge (A = I_t)]}} \prod_{i=1}^{K} m_i(X_i) \quad (8)$$

$$S_3(A) = \sum_{\substack{X_1, X_2, \cdots, X_k \in D^\Theta \\ (X_1 \cap X_2 \cap \cdots \cap X_{,K}) \in \phi \\ (X_1 \cup X_2 \cup \cdots \cup X_K) = A}} \prod_{i=1}^{K} m_i(X_i) \quad (9)$$

Where $\psi(A)$ is the characteristic non-emptiness function of a set A, $\psi(A)$ is defined as

$$\psi(A)=\begin{cases}1 & if \quad A\in\phi \\ 0 & otherwise\end{cases} \tag{10}$$

5) *making decision*

The final verification result is obtained as

$$result=\begin{cases}accept & if \quad BelP(m_{M(\Theta)})\geq t \\ reject & otherwise\end{cases} \tag{11}$$

Where t is the threshold t to pignistic probability.The decision process is presented in Fig. 2.

Therefore,the evaluation steps of condition based on DSmT are list in Fig. 1.

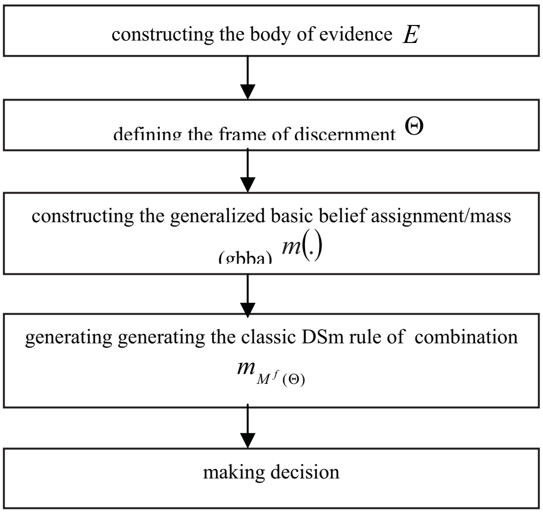


Figure 1. The evaluation steps of condition based on DSmT

## IV. EXPERIMENTAL RESULTS AND ANALYSIS

In this paper,diesel engine is taken as a example.The transient speed, lubricant pressure and temperature are the three main monitoring parameters on diesel engine. So the body of evidence is defined as $E=\{E_1,E_2,E_3\}=\{E_{transientspeed},E_{lubricantpressure},E_{temperature}\}$. Here two examples are presented to comparing the fusion quality of DSmT and DST.

$T_{threshold}$ and $T'_{threshold}$ are the two threshold of decision.In this paper, $T_{threshold}$ and $T'_{threshold}$ are given as:

$$T_{threshold}=0.4$$

$$T'_{threshold}=0.1$$

### A. Example Ⅰ

The current condition character parameters are given in TABLE Ⅰ.Based on the fusion step described in Fig. 2,the result is shown in TABLE Ⅱ and TABLEⅢ.

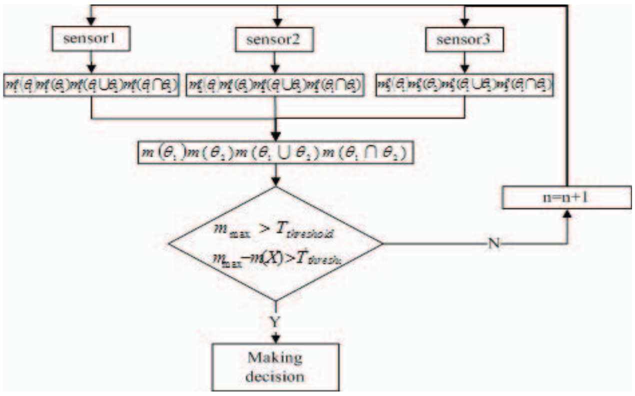


Figure 2. The fusion processing based on DSmT

TABLE I. THE CURRENT CONDITION CHARACTER PARAMETERS OF DIESEL ENGINE

| Parameter | Value | Unit |
|---|---|---|
| ***the transient speed*** | 800 | Rpm/min |
| ***lubricant pressure*** | 1.8 | Kg/mm2 |
| ***temperature*** | 63 | ℃ |

TABLE II. THE RESULTS OF GENERALIZED BASIC BELIEF ASSIGNMENT/MASS (GBBA) $m(.)$

| **gbba** $m(.)$ | $\theta_1$ | $\theta_2$ | $\theta_1\cup\theta_2$ | $\theta_1\cap\theta_2$ |
|---|---|---|---|---|
| $E_1$ | 0.69 | 0.18 | 0.06 | 0.07 |
| $E_2$ | 0.73 | 0.16 | 0.04 | 0.07 |
| $E_3$ | 0.80 | 0.10 | 0.05 | 0.05 |

TABLE III. COMPARISON FROM CONDITION EVALUATIONG BETWEEN DSMT AND DST

| **Combination rules** | **DSmT** | | | | **DST** | |
|---|---|---|---|---|---|---|
| $m_{M(\Theta)}$ | $m(\theta_1)$ | $m(\theta_2)$ | $m(\theta_1\cup\theta_2)$ | $m(\theta_1\cap\theta_2)$ | $m(\theta_1)$ | $m(\theta_2)$ |
| $m_1$ | 0551 | 0.268 | 0.104 | 0.077 | 0.537 | 0.463 |
| $m_2$ | 0.566 | 0.234 | 0.101 | 0.099 | 0.681 | 0.319 |
| $m_3$ | 0.657 | 0.163 | 0.088 | 0.092 | 0.709 | 0.291 |
| $m_1m_2$ | 0.562 | 0.217 | 0.126 | 0.095 | 0.665 | 0.335 |
| $m_1m_3$ | 0.573 | 0.208 | 0.095 | 0.124 | 0.672 | 0.328 |
| $m_2m_3$ | 0.638 | 0.172 | 0.131 | 0.059 | 0.684 | 0.316 |
| $m_1m_2m_3$ | 0.614 | 0.175 | 0.099 | 0.112 | 0.668 | 0.332 |
| ***result*** | $\theta_1$ | | | | $\theta_1$ | |

Seen from TABLE Ⅱ and TABLEⅢ,the belief assign on the final result $\theta_1$ increased with the increasing evidence of fusion.Considering given threshold $T_{threshold}$ and $T'_{threshold}$,the fusion result is $\theta_1$ that means the system in an abnormal condition. By using DSmT and DST, the same confusion conclusion reached easily and obviously.Thus both DSmT and DST can be applied to evaluating the system condition.

### B. *Example Ⅱ*

In this example,the current condition character parameters are given in TABLEⅣ and the confusion result is shown in TABLEⅤand TABLEⅥ.

TABLE IV. THE CURRENT CONDITION CHARACTER PARAMETERS OF DIESEL ENGINE

| Parameter | Value | Unit |
|---|---|---|
| ***the transient speed*** | 1200 | Rpm/min |
| ***lubricant pressure*** | 1.6 | Kg/mm2 |
| ***temperature*** | 63 | ℃ |

TABLE V. THE RESULTS OF GENERALIZED BASIC BELIEF ASSIGNMENT/MASS (GBBA) $m(.)$

| **gbba** $m(.)$ | $\theta_1$ | $\theta_2$ | $\theta_1 \cup \theta_2$ | $\theta_1 \cap \theta_2$ |
|---|---|---|---|---|
| $E_1$ | 0 | 0.7 | 0.2 | 0.1 |
| $E_2$ | 0.5 | 0.2 | 0.1 | 0.1 |
| $E_3$ | 0.8 | 0.1 | 0.05 | 0.05 |

TABLE VI. COMPARISON FROM CONDITION EVALUATIONG BETWEEN DSMT AND DST

| **Combination rules** | **DSmT** | | | | **DST** | |
|---|---|---|---|---|---|---|
| $m_{M^f(\Theta)}$ | $m(\theta_1)$ | $m(\theta_2)$ | $m(\theta_1\cup\theta_2)$ | $m(\theta_1\cap\theta_2)$ | $m(\theta_1)$ | $m(\theta_2)$ |
| $m_1$ | 0 | 0.653 | 0.186 | 0.161 | 0.113 | 0.887 |
| $m_2$ | 0.388 | 0.196 | 0.181 | 0.235 | 0.090 | 0.91 |
| $m_3$ | 0.457 | 0.245 | 0.119 | 0.179 | 0.007 | 0.993 |
| $m_1m_2$ | 0.487 | 0.263 | 0.148 | 0.102 | 0.120 | 0.880 |
| $m_1m_3$ | 0.552 | 0.209 | 0.197 | 0.042 | 0.004 | 0.996 |
| $m_2m_3$ | 0.593 | 0.147 | 0.077 | 0.183 | 0.137 | 0.863 |
| $m_1m_2m_3$ | 0.645 | 0.095 | 0.169 | 0.091 | 0.106 | 0.894 |
| ***result*** | $\theta_1$ | | | | $\theta_2$ | |

In TABLEⅤ, there is a conflicting condition:evidence $E_1$ gives objective assign on $\theta_1$ ,while evidence $E_2$ and $E_3$ give belief assign on $\theta_1$.

The fusion results summarized in TABLEⅥ. There exists conflicting results in DSmT and DST:the final result is $\theta_1$ in DSmT while in DST the final result is $\theta_2$. Even though evidence $E_1$ gives objective assign on $\theta_1$, evidence $E_2$ and $E_3$ give definite belief assign on $\theta_1$.So $\theta_1$ should be the real fusion result. Seen from TABLEⅥ, with the increasing evidence of fusion,the belief assign on $\theta_1$ increased from 0 to 0.645 in DSmT while in DST the belief assign on $\theta_1$ is still in the range of 0.004-0.137.The different belief assign leads to extremely different fusion result. Despite the belief assign on $\theta_1$ ,DST gives the result $\theta_2$ since there exist an object on $\theta_1$.This is unreasonable obviously.

This example showed that DST is difficult to deal with highly conflicting information.Though both DSmT and DST can be applied to information fusion,DSmT is more effective and successful than DST,which can be seen easily from comparison in TABLEⅥ. Thus,DSmT is proved to be more valid than DST.

TABLE VII. COMPARISON FROM FUSION QUALITY BETWEEN DSMT AND DST

| examples | Combination rules | Time(S) | Quality of fusion |
|---|---|---|---|
| ***Example Ⅰ*** | DSmT | 248 | high |
| | DST | 251 | high |
| ***Example Ⅱ*** | DSmT | 287 | high |
| | DST | 342 | general |

TABLEⅦ gives a simple comparison from the time of computing and the quality of fusion.In Example Ⅰ,both DSmT and DST perform well in dealing with information fusion. While in Example Ⅱ,DSmT waste less time than DST with giving fusion results with higher quality.So DSmT is more superior to DST.It must take a lot of time to deal with conflicting evidence.Seen from TABLEⅧ,DSmT is more superior to DST in the worse case when the evidence are conflicting.

## V. CONCLUSION

Using condition monitoring in CBM allows to apply information fusion method such as DSmT and DST to combine condition monitoring data. This paper introduced DSmT to condition evaluation of system.Unlike statistical techniques,the proposed mehod for condition evaluation mitigates effectively conflicting decisions when the evidences are imprecise and conflicting due to poor monitoring on system. Through the comparison given in this paper,DSmT showed higher quality than DST.

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