Knowledge Modeling of Airborne Missile Management System Based on Multi-dimensional Fuzzy Ontology

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Abstract. Health management system of airborne missiles has a large amount and variety of knowledge, but such technical documents are lack of effective management in the knowledge level. According to the technical characteristics of knowledge in the field of airborne missile health management, a HTA analysis model (Hierarchy, time, and activity analysis model) based on multi-dimensional fuzzy ontology in the health management field of airborne missiles is constructed, and ontology description language OWL is introduced to express knowledge. It provides a theoretical and methodological basis for the dynamic management of health knowledge in the field of condition monitoring, prediction and evaluation, fault diagnosis, technical service.

1. Introduction
In the process of globalization, high and new technologies continue to emerge, and equipment and products show a development trend of intelligence and automation [1-2]. In the field of airborne missile health management, knowledge sharing and reuse are very important to improve the operation and maintenance ability of missiles [3-5]. Nevertheless, the rapid growth of information and data makes it more and more difficult to seek knowledge in massive data. Therefore, how to effectively manage the knowledge in the field of complex equipment health management, so that users can quickly and conveniently acquire knowledge and even find solutions to some technical problems is an urgent problem.

In this paper, a HTA analysis model (Hierarchy, time, and activity analysis model) based on multi-dimensional fuzzy ontology in the health management field of airborne missiles is proposed. Ontology description language OWL is introduced as the carrier to express knowledge. This model constructs the knowledge of airborne missiles in the health management field from four dimensions: hierarchy, time and activity, which can provide decision support for support personnel of airborne missiles to carry out reasonable maintenance and support work.

2. HTA Analysis Model
The health management of airborne missile is a process of fault diagnosis, state evaluation, potential fault discovery, remaining useful life estimation, optimize resource allocation, and knowledge update. The knowledge involved in this process is complex in structure, diverse in type and variety. Therefore,
it is necessary to build a multi-dimensional knowledge model of airborne missile health management and create a clear semantic environment for knowledge information, and establish an organizational network with clear concept hierarchy, reasonable structure and definite attribute relations among concepts [6-7].

To build the HTA model, we define the concept of health management task as follows:

**Definition 1** Health management task (HMT): Complete an activity for fault diagnosis, condition monitoring, health assessment, fault prediction, maintenance planning, and logistic support.

The HTA model can be described as

$$HMT_{HTA} = \{H, T, A\}$$  \hspace{1cm} (1)

H represents hierarchy dimension. It is mainly used to describe the structural relations of missile subsystems and components. Since the hierarchy of missile system is relatively stable, H can be considered as a fixed dimension for a particular health management task.

T is the time dimension, which describes the life-cycle period of a health management task, T can be considered as a fixed dimension for a particular health management task.

A represents activity dimension. This dimension includes fault diagnosis, state evaluation, potential fault discovery, remaining useful life estimation, optimize resource allocation, and knowledge update.

### 2.1. Hierarchy dimension model

According to GJB 431-88, a complexed system can be divided into eight levels: system, subsystem, device, module, unit, assembly, component, part. To describe the hierarchical relationship of different elements, we define the following properties:

**Definition 2** subClassOf: Describe that an element is a child of another element. For example, the relationship that E1 is the sub-element of E2 can be expressed as SubClassOf (E1, E2).

**Definition 3** sameLevelAs: Describe that two elements are in the same level. For instance, the relationship that E1 and E2 are in the same level can be represented as sameLevelAs (E1, E2).

**Definition 4** hasLevelNumber: Describe the level number of an element. For example, the relationship that the level number of element E1 is 2 can be expressed as hasLevelNumber (E1, 2).

**Definition 5** ConnectsWith: Describe that an element connects with another element directly. For instance, the relationship that element E1 connects with element E2 can be represented as ConnectsWith (E1, E2).

Based on above definition of properties, the hierarchy dimension model can be described in Figure 1.

![Figure 1. Hierarchy dimension model](image)
According to the structural characteristics of airborne missiles, we define the hierarchy of an air-to-air missile into five levels: system, subsystem, assembly, component, part, which is shown in Figure 2.

![Hierarchy dimension model of XX missile](image)

**Figure 2.** Hierarchy dimension model of XX missile

### 2.2. Time dimension model

Health management activities extend throughout the life cycle of airborne missiles.

As the basic dimension of missile health management, time records and expresses various activities and the change of missile status. Therefore, it is necessary to construct the time dimension model.

Time ontology is an ontology that describes time entities and their relations, and represents hours, minutes, seconds and other contents [8]. It provides a description of the measurement, calculation and representation methods of time [9]. To construct a time ontology, distinguishing the top-level concepts is essential. In the time ontology model, class TemporalEntity is used to represent the time element in health management of missiles. TemporalEntity has only two subclasses: Instant and Interval, which represent time point and time period respectively. The formal expression of time entity can be expressed as follows:

\[
(\forall T, T_{\text{int}}, T_{\text{int}}) \quad [\text{TemporalEntity} \equiv \text{Instant}(T_{\text{int}}) \lor \text{Interval}(T_{\text{int}})]
\]  

(2)

Instant, also known as a moment when an activity occurs, can be considered with the same start and end. The formal expression of Instant can be expressed as follows:

\[
(\forall T_{\text{int}}) \quad [\text{Instant}(T_{\text{int}}) \supset [\text{timeStart}(t, T_{\text{int}}) = \text{timeEnd}(t, T_{\text{int}})]]
\]  

(3)

Interval represents the time period from occurrence to extinction of a phenomenon or process, which is composed of two time points that have a sequential relationship, namely the beginning time and the end time, and the continuous time period between them. The formal definition of interval is as follows:

\[
(\forall T_{\text{int}}, t_1, t_2) \quad [\text{Interval}(T_{\text{int}}) \supset [\text{timeStart}(t_1, T_{\text{int}}) \land \text{timeEnd}(t_2, T_{\text{int}}) \land (t_1 < t_2)]]
\]  

(4)

In health management activities, in order to carry on the quantitative description to the time information, time relation and data time correlation degree, building a time coordinate system is essential. We define C represents the time coordinate system, O, U and D represent the time reference datum, scale datum and positive direction of time respectively, then the time coordinate system can be expressed as follows:

\[
C = \{O, U, D\}
\]  

(5)
2.3. Activity dimension model

Activity dimension model contains fault prediction model, FMECA (Failure Mode, Effects and Criticality Analysis) model, and maintenance decision model. Limited to space, here we only introduce the FMECA model. The FMECA model of airborne missiles can be describes by several classes: failure mode, failure cause, failure effect, and criticality. The FMECA model of the XX missile is shown in Figure 3.

Figure 3. FMECA model of XX missile

3. Conclusion

This paper proposed a HTA analysis model (Hierarchy, time, and activity analysis model) based on multi-dimensional fuzzy ontology in the health management field of airborne missiles, and ontology description language OWL is introduced to express knowledge. The construction of the HTA model provides a reference for the dynamic management of health knowledge in the field of condition monitoring, prediction and evaluation, fault diagnosis, technical service.

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