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ONTOLOGICZNE WIELOWIDOKOWE MODELOWANIE USZKODZEŃ WSPIERAJĄCE ZINTEGROWANY ROZWÓJ PRODUKTU I PROCESÓW

ONTOLOGICAL MULTI-VIEW FAILURE MODELING FOR IPPD

Inżynieria niezawodności zajmuje się prowadzeniem licznych działań w zakresie technologii uszkodzeń i zarządzania uszkodzeniami w ciągu całego cyklu rozwoju produktu. Stopniowa identyfikacja uszkodzeń oraz ciągła poprawa niezawodności jest możliwa tylko wtedy, gdy działania te zostaną skutecznie zintegrowane, przy syntetycznym uwzględnieniu szeregu istotnych danych dotyczących uszkodzeń. Obecna praktyka inżynieryjna nie pozwala na efektywną wymianę i ponowne wykorzystanie danych i wiedzy pochodzących z różnych faz rozwoju produktu. Ciągle jeszcze napotyka się trudności dotyczące interoperacyjności różnych działań ukierunkowanych na utrzymanie niezawodności. W artykule opracowano model ontologii uszkodzeń obejmujący modele ontologii uszkodzeń globalnych, funkcjonalnych i sprzętowych. Za sprawą tego modelu ontologicznego, działania niezawodnościowe stają się spójną częścią zintegrowanego rozwoju produktu i procesów (IPPD). Proponowany model uwzględnia ewolucję wiedzy na temat uszkodzenia w ciągu poszczególnych faz rozwoju. Na podstawie prezentowanego modelu ontologicznego stworzono środowisko inżynierii niezawodności oparte na platformie PLM (Zarządzanie Cyklem Życia Produktu) pozwalające zweryfikować poprawność i możliwość zastosowania omawianego modelu.

Słowa kluczowe: O*ntologia uszkodzeń, wiedza, niezawodność, IPPD.*

Reliability engineering includes series of failure focused technology and management activities running throughout the entire product development cycle. Only these activities are effectively integrated and numerous relevant failure data is synthetically applied, the intent for progressively identifying failure and continuously improving reliability can be obtained. In current engineering practice, the reliability data and knowledge produced in different development phases cannot be efficiently shared and reused. There still exist difficulties in interoperating between different reliability activities. This paper establishes the failure ontology models that contain global failure ontology model, functional failure ontology model and hardware failure ontology model. In virtue of this ontology model, the reliability activities are seamlessly integrated into the integrated product and process development (IPPD). In this model, the evolution process of failure cognition during each development phases is considered. Base on this ontology model, a reliability engineering environment is constructed with the support of PLM (Product Lifecycle Management) platform to verify the ontology model's correctness and applicability.

Keywords: *Failure ontology, knowledge, reliability, IPPD.*

1. Introduction

Integrated product and process development (IPPD) is a management technique that integrates all acquisition activities starting with requirements definition through production, fielding/deployment and operational support in order to optimize the design, manufacturing, business and supportability processes [4, 7-10]. IPDD have been viewed by researchers and industry practitioners as the key for reducing cycle times and improving product quality and reliability [19]. In present engineering practice, the implementation of IPPD is usually relying on product life cycle management (PLM) platform. The sharing of product design knowledge and the interoperability of development activities can be realized on the PLM platform.

Reliability engineering includes technologies that fight against failure. Reliability engineering runs through the whole product development cycle and is inseparable from function or performance design [11-13, 17]. Though reliability engineering implementation methodologies have been studied and applied for years, and there are plenty of specified standards and guides for engineering application, most reliability activities still cannot be seamlessly integrated into the IPPD until now. The main cause is the lack of unified understanding on various failure related concept through the whole development cycle, which lead to difficulties in sharing and reusing failure centered reliability data and knowledge, and make it impossible to interoperate between reliability and performance design.

Unified information and knowledge representation is the basis for solving above problems. To this intention, the standard GEIA-STD-0007 gives the data model for reliability requirement and analysis [6]. This type of model is static model designed for related data recording. But during the product development process, the relationship among product, failure and deriving conditions is comprehensive. The failure cognitive process is also difficult to express. Aiming at the disadvantage of static model, this paper describes failure using ontology model.

According to Borst's definition, ontology is a formal specification of a shared conceptualization. This definition emphasizes the fact that there must be agreement on the conceptualization that is specified [3]. In recent years, the ontology model has been widely applied in engineering fields and become the basic method for implementing seamless interoperability in multi-field product design data [1, 15, 16]. Failure related ontology models are also included in those ontology models. Such as the failure process and failure classification ontology presented by Yoshinobu, FMECA knowledge reusing method based on ontology given by V. Ebrahimipour and Lars Dittmann [5, 14, 21]. However, these studies are conducted on simple failure analysis view. These models can only be used in independent reliability analysis method or failure diagnosis. They cannot support the reliability activities in the whole product design processes. The failure ontology models established in this paper cover from the conceptual and preliminary design phase to detail design and development phase. These models enhance the understanding of failure from different view in different design phases. The semantic relation among ontology in different phases is established using ontology mappings.

For validating the applicability of the failure ontology under actual IPPD platform, a typical PLM platform-Teamcenter™ is selected as infrastructure environment. On the basis of failure ontology, the platform object-oriented data model (OODM) is extended for reliability data and knowledge management in the whole product development processes.

2. Ontological multi-view failure modeling

2.1. Product life cycle failure cognitive process

Failure is commonly defined as an event in which an item does not perform one or more of its required functions within the specified limits under specified conditions [18]. Past analysis has shown that there is a quantifiable correlation between the product and failure during the product development phases. But the learned degree and view point for failure cognition are different in different design phase. This paper presents a failure cognitive process model including three levels and three phases as shown in the fig.1. In the conceptual and preliminary design phase, By means of mission requirements，mission environment and operation. are known and we can only understand and describe the failure from top-level function failure view. In detail design and development phase, detailed technical requirement can be acquired and the effect of global loads and stress can be considered. We then can understand and describe the failure from the physical hardware failure view. In this phase, the condition that derives failure and the characteristics of failure are all further understood. The failure mode and loads can directly affect the formulation of design scheme and maintenance supportability scheme. With the design goes deep into more detail, the local loads and stresses are identified more accurately, on another hand, based on the information of particular product physical structure, the methods of physics of failure can be applied to analyze and indentify failure mechanism.

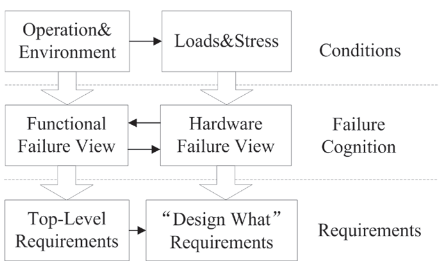

Fig.1. Failure cognitive process in development process

2.2. Global failure ontology model and local failure ontology model

As has mentioned, the cognition of failure in different design phase is distinct, it is no easy to express with the same failure ontology. In this paper, we divide the failure ontology into the global failure ontology and the local failure ontology, such ontology describe the common identities and the different design phase identities of failure. The relationship of failure concept in different design phase is fulfilled by the mapping between ontology.

2.2.1. The Global Failure Ontology

The global failure ontology is the general depiction about the failure and its related concepts; it is independent of the states and the perceived degree of the product. Here, we take the concept failure as one states of a abstract product, which is corresponding to the unexpected function of a product. The key concepts of global failure ontology is defined in formalization, the detail is as follows.

Definition 1: Product element. A physical component of product which is contained in the system without considering of their inside design in product design is called product element. The product is assembled with the set of product element:

$$\boldsymbol{C}=\{(\boldsymbol{c}_1,\boldsymbol{c}_2,\ldots\boldsymbol{c}_n)|\forall \boldsymbol{c}_i\nexists(\boldsymbol{c}_j\subset\boldsymbol{c}_i)\} \tag{1}$$

Definition 2: Product Structural body. ***C*** is a set of product elements, while:

$$\boldsymbol{BC}=\{(\boldsymbol{X},\boldsymbol{Y})|\boldsymbol{X},\boldsymbol{Y}\in\boldsymbol{C}\wedge\boldsymbol{B}(\boldsymbol{X},\boldsymbol{Y})\} \tag{2}$$

where ***B(X, Y)*** shows that product elements ***X*** and ***Y*** are coupled. $\boldsymbol{\sigma}(\boldsymbol{C}, \boldsymbol{BC})$ is a graph, if and only if$\boldsymbol{\sigma}$is connected graph, $\boldsymbol{\sigma}$is structural body. Namely, structural body is a set of product elements interrelated.

Product design is made up of several product items, which are design objects in current view. Product subject contains all functions that current design can reflect in the design field. Function F is universal set of exterior states of product elements, which covers not only required normal function states, but also the illegal function states not required.

Definition 3: Product function theme. Product function theme is expressed by external function view:

$$\boldsymbol{Z_m}=<T,\tilde{\boldsymbol{F}}> \tag{3}$$

Where $\tilde{\boldsymbol{F}}=<F_1,\cdots,F_n>:T\to V_1\otimes\cdots\otimes V_n$. F_i is called the function of the ith possible state of Z, while $\tilde{\boldsymbol{F}}$ is called functions of all states of ***Z***. ***T*** is a set of time, which contains Cartesian products of state variables:

$$\boldsymbol{S}(Z)=\{<z_1,\cdots,z_n>\in V_1\otimes\cdots V_n\mid z_i=\boldsymbol{F}_i(\boldsymbol{T})\} \tag{4}$$

is called possible state space of Z. For product design, only state variables and their combination relations that accord with physical order are considered, so:

$$\breve{S}(Z)=\{S(Z)|<z_1,\cdots,z_n>according\ with\ physical\ order\} \tag{5}$$

is legal state space. Only legal state space is considered in this paper. ***S(Z)*** is used to represent legal state space for convenience.

Product design subject is implemented by design elements, structural bodies and other physical elements.

Definition 4: Failure. If function mode of design subject is $Z_m = < D, \tilde{F} >$, and $fa(z) \in Fa(z)$ is the decision rule of fault, then fault space of product elements is:

$$S_{Fa}(Z) = \{ < z_1, \cdots, z_n > \in V_1 \otimes \cdots \otimes V_n \mid \underline{\tilde{F}} \} \quad (6)$$

where $\underline{F} = \{\tilde{F} \text{ meet each } l(Z) \in L(Z)\}$. $Z_{fm} = < D, \underline{\tilde{F}} >$ is called fault function mode.

Definition 5: Fault event. A sequence pair is called a fault event,

$$Ft = <s', s> \quad (7)$$

where $s \in S_{Fa}(Z)$, $s' \in \overline{S_{Fa}(Z)}$, that is transition from normal state to fault state. If product can transit from fault to normal when the condition triggering fault lost, the fault is called reversible fault event, contrarily irreversible.

There are 4 kinds of relations of ontology, [11] that is part-of, kind-of, instance-of and attribute-of, which are still applicable in depiction of failure ontology.

Part-of expresses relation between part and whole; kind-of expresses relation of inheriting between concepts; instance-of expresses relation between instance and concept; attribute-of expresses that a certain concept is an attribute of another concept. These four relations are still in existence in failure ontology.

The structure of global failure ontologies is shown in fig.2, the dashed line was used to denote the semantic relationship in ontologies.

2.2.2. The Local Failure Ontologies

The local failure ontology model is expressed with the cognition of failure problem, and the failure ontologies have their characteristics in different design phase.

(1) The Functional Failure ontology and the mappings are shown in fig.3. This ontology is for the conceptual and preliminary design phase, the cognition to failure is in the higher level of product, its functional description is also in the higher level, with the higher of product, its types of functions and state are also numerous, and it is more difficult to depict it clearly. The cognition to loads is also in macroscopical style. So in this phase, the multiple and fuzziness of failure is the outstanding point, expert experience and historic information should be used sufficiently to narrow the scope of analysis and to improve the degree of cognition to the failure, it is from the functional level to cognize the failure modes.

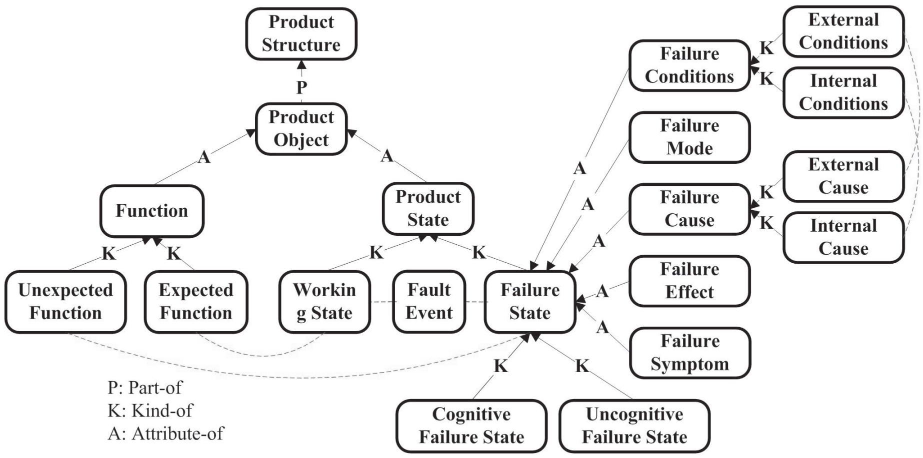

Fig.2. Global Failure Ontology

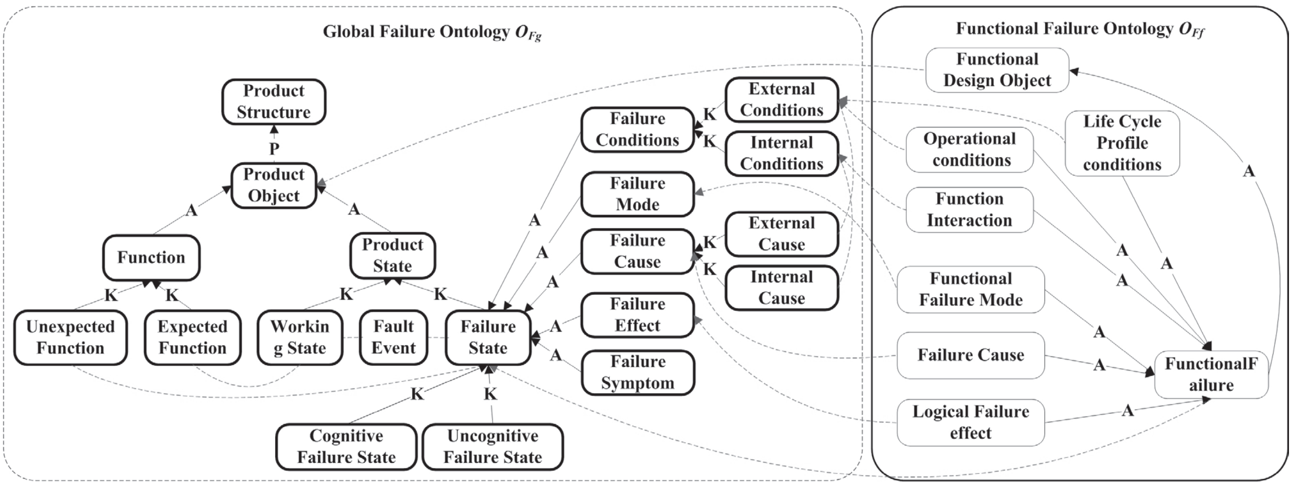

Fig.3. Functional failure ontology model and the mappings

(2) The Hardware failure ontology and the mappings are shown in fig.4. In the detail design and development phase, the functions of product should be fulfilled with hardware units, so the description of failure have been changed from immaterial function to material structure; The cognition of failure has been extended from logical relationship to hardware interaction; and the failure recognition changed from qualitative functional measure to quantitative parametric measure. With the in-depth realization for all system components, the detail parameters of products and applied loads are learned, a more accurate of the failure mechanism and the sites can be obtained.

3. Integrated Framework for reliability engineering based on failure ontology models

Failure ontology models achieves the data interoperability, for the realization of interoperability between reliability design process and the performance design process, The framework interoperability[20] is driven by the identification and mitigation of failure(as shown in fig.5), which focuses on failure ontology. It integrates key factors, such as "process", "method", and "tools" into a uniform environment. These factors are important elements of system engineering process and reliability engineering actives. "Process" is the core element of integrated framework because it defines how to realize the reliability engineering process by identifying and mitigating failure mode during product development process. In Process, the reliability design and re-design actives of all phases of product development are integrated with system engineering process through establishing failure and their mapping relationship. "Method" comprises all methods that support identification and analysis of failure mode, lifecycle load analysis and reliability design, such as FMEA, FTA, ETA, FEM, POF, RBMDO. The technique for implement process tasks are defined though "method", and the interoperability among them can be ensured by strict definition of failure ontology. "Tools" are often software to assist "process" and "method", such as CAE software for temperature analysis and shock/vibration analysis, system reliability design and analysis software, decision making software, multidisciplinary design optimization software, and etc. The integrated application of "process", "method" and "tools" is need to realize reliability system engineering in a uniform environment. The best choice is PLM platform for its function about data integration and flow integration. Realization of "Process" depend the process planning based on PLM system, and failure ontology can be established by the object oriented customization work of PLM. Further the tools integrated into PDM can help implement of method.

A closed-loop process driven by identification and mitigation is shown in fig.6. According to "GEIA-STD-0009"[2], the core actives of these process are composed of identification and confirm of failure mode, analysis of relationship between failure and loads, elimination and mitigation of failure mode, sustained tracking of failure mode, design and re-design, progressive cognition of load, decision making, and etc.

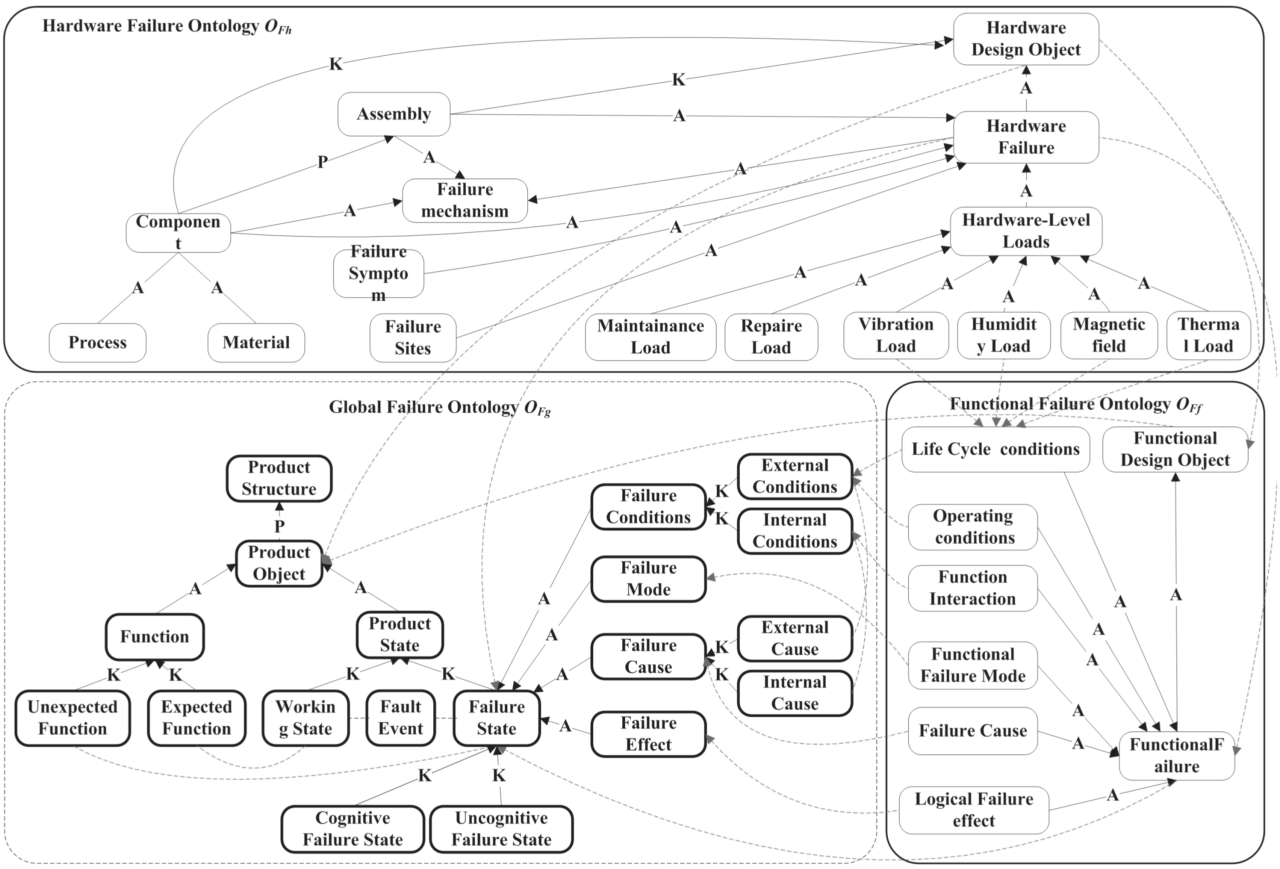

Fig.4. Hardware failure ontology model and the mappings

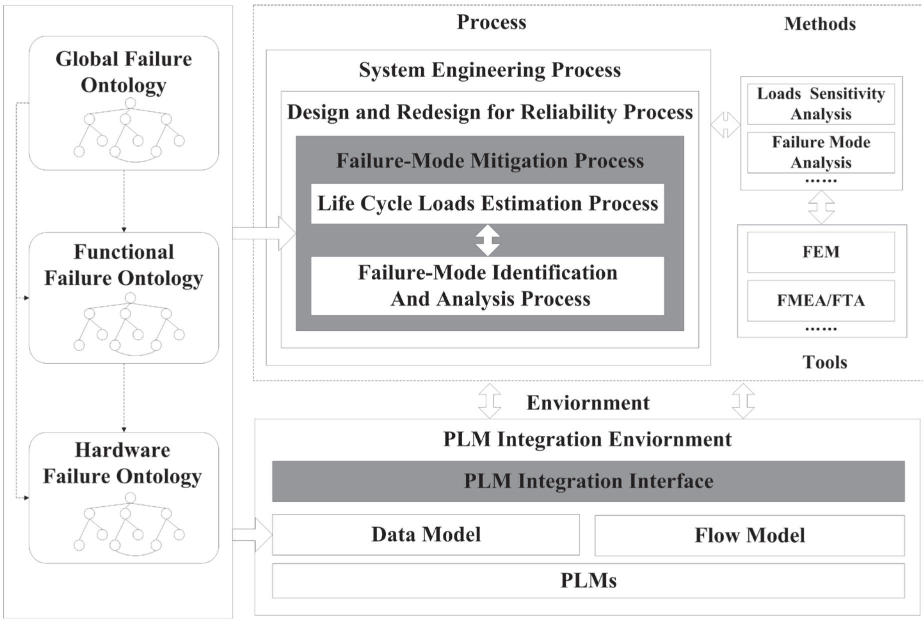

Fig.5. Reliability engineering integrated framework based-on failure ontology

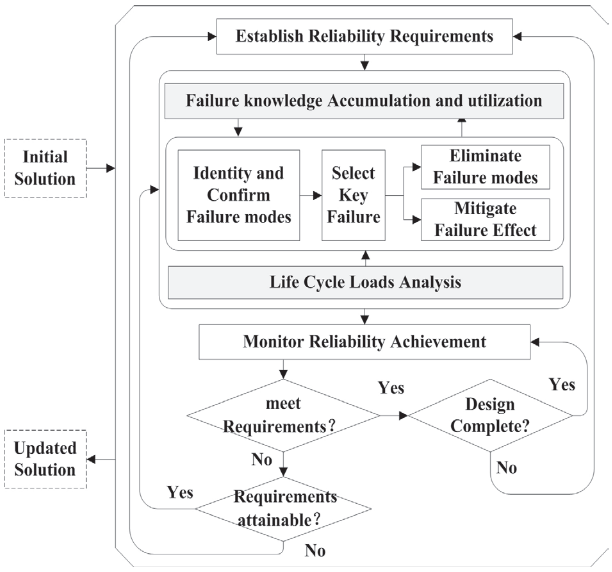

Fig.6. Closed-loop failure control process

4. Realization of reliability engineering process based on PLM platform

This paper discusses the realization of multi-view model of integrated design in PLM by taking Teamcenter PLM product as an example. According to the methodology of customization for Teamcenter，three parts of PLM should be extended which include data service, object management framework (object model and service) and interface. The key of customization is extension of class and relationship.

Step 1: Define class structure. According to the ontology framework, the class structure of concepts such as function or failure should be defined using MODel（Metaphase Object Definition Language）which is the customization of TeamCenter.

Step 2: Define interface. Based on defined class structure, such parts of interface should be defined through MODel, include menu, option, dialog frame, attributes list. Further, the defined interface can be edited by DWE (Dialog Window Editor).

Step 3: Compile Method. The method which is called "Message" in TeamCenter should be realized by calling API function through C language.

Step 4: Compile data dictionary. The object dictionary should be updated according to compiled class structure using MODel compiling order.

Step 5: Extend Database. Last, the Oracle Database should be updated by mapping order "Updatedb".

The object oriented multi-view data model can be found preliminarily when the ontology classes in multi-view model

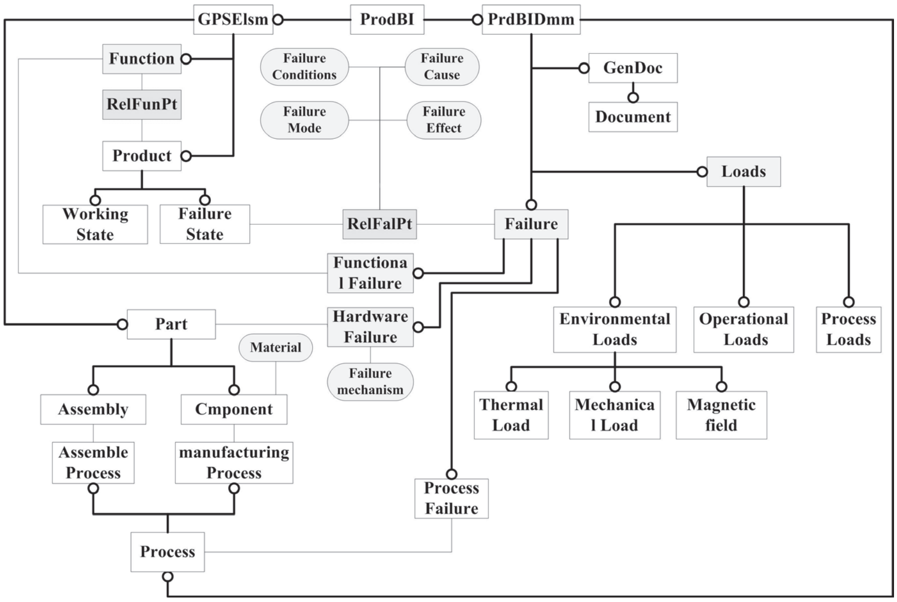

Fig. 7. Class structure of multi-view model ontology in teamcenter

framework were established (as shown in fig. 7) in term of above steps. The "Express-G" expression is adopted to describe the ontology class and relationship among them. Ontology as given here apply mainly to the meta model of field knowledge so that multi-filed tools could call or share knowledge. There are some classes in fig. 7 belonging to the basic class of TeamCener , such as "PSElsm", "ProdBI", "PrdBIDmm", "GenDoc" and "Document". Based on this, the failure ontology and related ontology could be built by class inheritance.

5. Conclusions

A lifecycle data and knowledge modeling methodology for reliability engineering was presented. Focus on the core problem of reliability engineering, 'fight against failure', the multi-view model was constructed with the global and local failure ontology, which can depict the common properties and the different lifecycle phase properties of failure, and handle the complex relationship among product, failure and deriving conditions. To implement this methodology in a real system, an integrated framework for reliability engineering was proposed, which treat the identification and mitigation of failure with failure ontology. This framework can integrate all kinds of reliability activities as an integral process and can share data and knowledge totally.

The concept of ontological multi-view failure model was illustrated for its successful realization on a typical PLM platform. This revealed that the semantic model is suitable for the complicated reliability engineering modeling. Further, this model can be expanded into maintainability engineering, supportability engineering, etc. It is envisaged that future IPPD system will seamlessly integrate with the reliability system engineering process.

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