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Modeling of Marine Diesel Engines Collaborative Development Workflow Based on HTCPN

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Abstract: The information exchange, sharing and coordination of development process are required in marine diesel engine collaborative development between multidisciplinary and multi-sector. To solve this problem, many features are required in marine diesel engine collaborative development workflow model, for example, stage, hierarchy, parallelism, coupling, etc. It was modeled in this study by using transformed hierarchical timed colored Petri net (HTCPN). The execution performance of marine diesel engine cooperative development workflow can be simulated by time, the project fine-grained can be enhanced by hierarchy and the task set can be expanded by color. Finally, by using multidisciplinary optimization design business process of marine diesel engine piston part as an example, the workflow model was constructed based on HTCPN.

Key words: Collaborative design, workflow, petri, diesel engines

INTRODUCTION

The marine diesel engine development process is extremely complex engineering project, which contains all the diesel engine production process, such as whole scheme design, preliminary design, detailed design, assembly design, process design and product trial. At the same time, the process involves many internal departments of company, such as information center, finance, design, human resources and production department. Only effective management of product development process can bring about diesel products with high quality and low cost. Therefore, companies need to adopt a new product development model and workflow structure for the model.

As a kind of graphical and mathematical tool for system modeling, Petri net is powerful to describe and analyze complex systems with characteristics of concurrency, asynchronous, distributed and nondeterministic (Yuan, 1998; Van der Aalst, 1998; Zu, 2005). It supports analysis and simulation of model and can realize computer automation for process modeling. Petri net is preferred modeling tools for process because of its powerful functions, many scholars have done some related research and put forward many extended forms such as colored Petri net, hierarchical Petri net, fuzzy Petri net, timed Petri net (Yuan, 1989; Wu, 2006; Huang *et al*., 2003; Wu *et al*., 2007). In the process of Petri net modeling, a librar represents a condition and a change represents an event. One change or event has a certain number of input and output libraries, which respectively represent preconditions and postconditions of the event. The token of library represents resources and data. But for complex workflows, Petri net still exists shortcomings of the following: (1) The hierarchical complex model can not be described; (2) The model is too large and lack of flexibility; (3) Performance analysis of collaborative development process is not qualitative or quantitative. Furthermore, some scholars study a combination of several modeling techniques, such as Tang *et al*. (2002) put forward the modeling methods of Petri net based and IDEF family supplement.

See from the above workflow modeling techniques at home and abroad, every modeling technique has its strengths and weaknesses. Since the modeling problems are only considered from one respect and not synthesized modeling demand, modeling planning, modeling execution and modeling reuse to achieve the goal of playing their respective advantages and making up deficiencies (Jiang, 2007; Zhang and Zhong, 2006; Liu and Zhang, 2006).

In this study, Petri net was expanded to HTCPN for modeling. The execution performance of diesel engine collaborative development workflow can be simulated by time, the project fine-grained can be enhanced by hierarchy and the task set can be expanded by color.Finally, HTCPN workflow of multidisciplinary optimization design for marine diesel engine piston parts was constructed.

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BUSINESS PROCESS OF MARINE DIESEL ENGINE COLLABORATIVE DEVELOPMENT

The research shows that the process of diesel engine product development can be divided into four stages: Analysis of product demand, conceptual design process, overall assembly design process (or called preliminary design/technology design) and detailed design process. At the same time, there are four corresponding stage results: User requirement specification, conceptual product scheme, overall assembly scheme and engineering drawings and technical documentation. Marine diesel engine products are no exception, specific as shown in Fig. 1.

The flow chart shows that user demand is the starting point of diesel engine collaborative development. Key members of the collaborative development team get develop requirements or design code through user demand analysis, which are the key functions and the technical parameters product should achieve. Then product conception design confirms what functional systems should be included and constraint relationship among system components. Based on conceptual product scheme, preliminary design process task is to disassemble user demands further to make sure corresponding relationship between system and user demand. Based on the results of preliminary design, detailed design and optimization should be done for each component, virtual

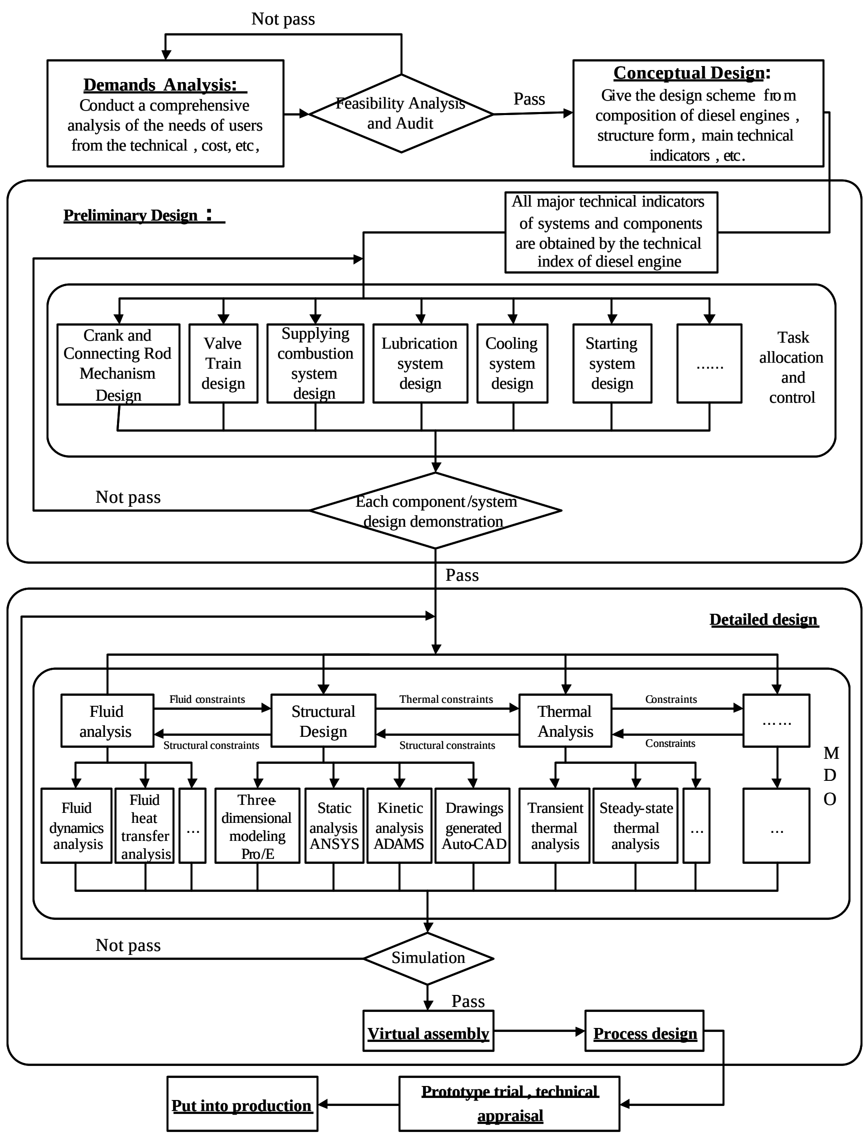


Fig. 1: Design process of diesel engine

assembly and process design should be done on the basis of simulation analysis.

Finally, the prototype is manufactured and identified and the design process of diesel engine product is completed and put it into production.

The diesel engine structure and complexity of the development process shows that diesel engine multidisciplinary collaborative design process is not limited to enterprise development department.

However, it can be cooperated between multidisciplinary and multi-regional members among cross-sectorial, cross-enterprise and cross-industry. Decomposition, allocation and execution make the product development process continuously advance and the entire development process can be maintained and coordinated through the collaborative process control mechanism, such as task flow management, project management, etc.

ANALYSIS OF MARINE DIESEL ENGINE COLLABORATIVE DEVELOPMENT WORKFLOW MOLDING

The requirements of marine diesel engine collaborative development workflow: In the system of marine diesel engine collaborative design, workflow model should be able to meet various requirements for users in the analysis and modeling process. These requirements usually have the following aspects (Zeng and Yan, 2005):

- **Ability of comprehensive description:** Workflow model should be able to describe the marine diesel engine collaborative development process comprehensively and accurately. The main description is as follows: Data flow, such as optimization files, design files, graphics and image files, etc., Control flow, such as design activities route, distribution control and conditions of role. Moreover, it should also be able to describe phenomenon of design task iteration and parallel
- **Hierarchy of model:** Since the complexity of marine diesel engine development and design process, it may consists of hundreds of nodes or tasks. A single model description may cause the model too large and hard to understand, so the model should have the feature of hierarchy to deal with complex process
- **Formal semantics:** The workflow model of marine diesel engine collaborative development is serial, parallel and hierarchical and the business process is also diverse, so modeling method should have comprehensive expression ability to make sure the correctness of data flow and control flow
- **Readable workflow model:** Workflow model should be able to express collaborative development process intuitively. A graphical and readable model is more popular
- **Easy to optimization and analysis:** Workflow model should not only be easy to expression but also can analyze problems qualitatively or quantitatively, which includes analysis of correctness and validity. At the same time, it also can solve the problems of deadlock, redundancy and so on

Mathematical description of HTCPN: Combining the process of marine diesel engine development business and analysis of workflow modeling demand above, this study used transformed Petri net to model for marine diesel engine development business process. Hierarchical timed Petri net is an expansion of Petri net with hierarchy thought and uses hierarchical method to describe complex business process. Its timeliness can be used in simulation analysis and the colourity can be used to distinguish different business process (Zu, 2005). Furthermore, The characteristics of graphical expression (library, change and arc) and concurrency can be used to describe marine diesel engine collaborative development process well.

HTCPN is an expansion of hierarchy, time and color on the basis of Petri net. It has some alternative changes and enables to have some smaller subnets nested in complex Petri net to form a higher level model. Each layer is a subnet of upper layer. Colored Petri net which has no hierarchy is called a page. The input and output library of each page is a port node and it is the token and number of specified pages. The alternative change of each page is called super node, the page including super node is called super page and the library connected to super node is called socket node. The socket node contacts port node through function assigned by port. Specific as follows: Hierarchical timed colored Petri net is a multivariate combination, HTCPN = (S, SN, SA, PN PT, PA, FS, FT, PP), Specific as follows:

- S is a finite set of page and for each page: $SN \subseteq T$ is a non-hierarchical colored Petri net; $\forall s_1, s_2, \in S; s_1 \cap s_2 = \phi$
- $SN \subseteq T$ is a set of alternative change
- SA is a function defined from SN to S and any page is not a subpage itself
- $PN \subseteq P$ is a set of port node and the flow between different pages is accomplished by port node
- PT is a port type function and is defined from PN to {in, out, i/o, genral}
- PA is a function assigned by port and is defined from SN to binary relation as follows:

$$\forall t \in SN: PA(t) \subseteq X(t)\ HPN_{SA(t)} \quad (1)$$

$$\forall t \in SN \forall: (p_1, p_2) \in PA(t): [PT(p_2) \neq general \Rightarrow ST(p_1, t) = PT(p_2)] \quad (2)$$

$$\forall t \in SN \forall: (p_1, p_2) \in PA(t): [C(p_1) = C(p_2) \wedge I(p_1) = I(p_2)] \quad (3)$$

- FS is a finite union set and its elements have the same initial expressions and color:

$$\forall fs \in FS \forall: (p_1, p_2) \in fs: [C(p_1) = S(p_2) \wedge (p_1) = I(p_2)] \quad (3)$$

- FT is a combined type function and is defined from union set to[blobal, page, instance]. Set of local combined nodes and set of page combined nodes belong to the same page:

$$\forall fs \in FS \forall: [FT(fs) \neq global \Rightarrow \exists s \in S: fs \subseteq P_s]$$

- PP is a plural set defined in root page and is usually the highest level of page

MODELING OF MARINE DIESEL ENGINE COLLABORATIVE DEVELOPMENT WORKFLOW BASED ON HTCPN

Workflow modeling steps: Marine diesel engine collaborative development workflow modeling based on HTCPN is a process from the top to the bottom. It can be specifically divided into the following steps:

- **Make sure marine diesel engine collaborative development business process:** Marine diesel engine collaborative development workflow modeling process based on HTCPN should start from the understanding of development process, which including the key element of development process, structure and effect. Key elements mainly refer to the major activities and their targets. Structure refers to the relationships among activities and the flow structure made up by activities and relationships. Effect refers to the overall effect and local effect, such as the total time, the execution time for each activity and resource occupancy rate
- **Modeling initialization:** The main task of modeling initialization is to determine the element types and their properties of development process targets such as token, library and change
- **Establish Petri net top level model of development process:** It is the overall design process of marine diesel engine. According to global optimal strategy, design process should be from the top to the bottom. After a sufficient understanding of the whole process, the key link can be extracted and Petri net top level model can be built to reflect development process situation.
- **Refine Petri net model of sub layer development process:** Based on Petri net top level model, each change is analyzed to make sure it is a basic unit. If not, the corresponding sub model and connection between upper and sub layers are built
- **Determine property value:** According to the properties of every element, the property value is determined for each model element in Petri net

Workflow modeling: Marine diesel engine development process involves multidisciplinary, multilevel analysis, from the view of discipline, product analysis contains static and dynamic analysis, etc. From the view of fine-grained, product analysis contains the whole machine design, part design and component design. There are some coupling relationships in disciplines, through the mission planning of diesel engine product multidisciplinary, the sequence of every discipline can be gotten. The sequence of product layer analysis represents the coupling relationships in the disciplines. Diesel engine product includes a number of parts and between these parts there are some assembly relations. Single disciplinary analysis includes many parts analysis, while part includes many components. Therefore, the part layer analysis should be after the component analysis. Product static analysis is shown in Fig. 2. Product static analysis includes the static analysis of parts 1 and 2 and part 1 static analysis also includes the analysis of component 1 to component 4. So a hierarchical Petri net model is built.

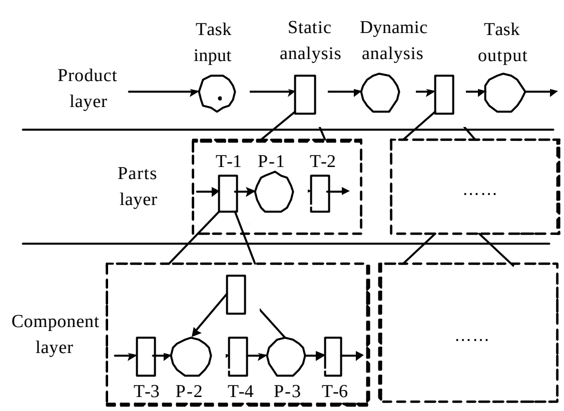
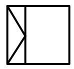
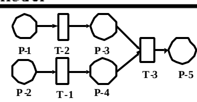
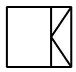
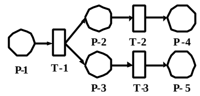
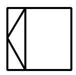
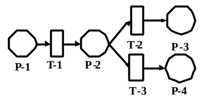
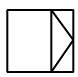
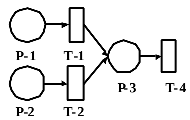
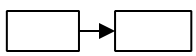
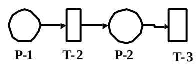
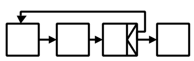
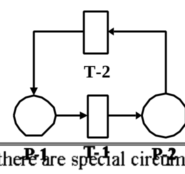


Fig. 2: Hierarchical timed colored Petri net of development process

Table 1: Mapping relationships

Node type	DPCD-WfMS model	HTCPN model	Conversion instructions
And connection			Parallel connection structure transformation
Or branch			Parallel branch structure transformation
Or connection			Selectable branch structure transformation
Or branch			Selectable connection structure transformation
Causality			Sequence structure transformation
Cycle			Cycle structure transformation

Activities transformation above is the most basic transformation. If there are special circumstances, necessary replacement can be exist according to semantic

In this study, serial, parallel, cyclic path and condition selection were defined by DPCD-WfMS modeling tool to support workflow primitives, namely and connection and branch, or branch, cycle and causality. And the expression can be mapped to HTCPN, the specific mapping is shown in Table 1. In modeling process, these components can be directly called by users and used as a module of DPCD-WfMS, it is convenient for users to model.

AN EXAMPLE OF HTCPN WORKFLOW MODELING

In this study, typical piston part was used as the research object and its multidisciplinary design optimization workflow model was built on the basis of Petri net theory, modeling method and modeling steps.

First, according to the needs of customers, designer put forward piston product design scheme and determined parameters and corresponding design goals. Then in order to know feasibility of the design scheme, experts were organized to demonstrate the scheme. If it was feasible, then the implementation stage was went on; if it was not meet the user needs, then the scheme was designed again.

After design scheme was determined, piston product development stage began. This stage mainly included three parts: First, by using three-dimensional modeling software (such as Pro/E, Solidworks, etc.), three-dimensional modeling of piston product was done, it is a shape adjustable and parametric model on the basis of component control and graphics files (format *. x_t) of the piston product can be gotten after modeling. Then, these graphics files were imported in the disciplinary analysis software (such as Ansys, Adams, etc.) to disciplinary analyze. For piston product, this stage need static, dynamic and thermal analysis. Each discipline analysis was an iterative process. According to the analysis goal, the parameters were constantly modified until the design met the design needs and the single discipline was optimal. Finally, corresponding output files were gotten and a single discipline design was completed. Based on the analysis of single discipline, ISIGHT software was used to build multidisciplinary optimization framework. Then the optimization design scheme and optimization algorithm were selected, optimization variables were set, the corresponding input and output files were set. After that the optimization model was run, the output targets were gotten to determine whether the results met the overall optimization and this process was also an iterative and dynamic process. At last, the best

Table 2: Significance of signs in change

Change	Significance	Change	Significance
T-1	Demands analysis	T-2	Propose solutions
T-3	Piston design	T-4	Demonstrate piston project
T-5	SW three dimensional modeling	T-6	Generate graphics files (*.x_t)
T-7	Read graphics conversion files (*.x_t)	T-8	PLOT/volume
T-9	Define element type, real constants and material properties	T-10	Meshing
T-11	Generate finite element model	T-12	Impose constraints and load
T-13	Analysis and result display	T-14	Establish ISIGHT optimization model
T-15	Select optimization program	T-16	Set optimization variables
T-17	Run the optimization model	T-18	Obtain output objective function
T-19	Modify parameters to refine model	T-20	Output the best design solution

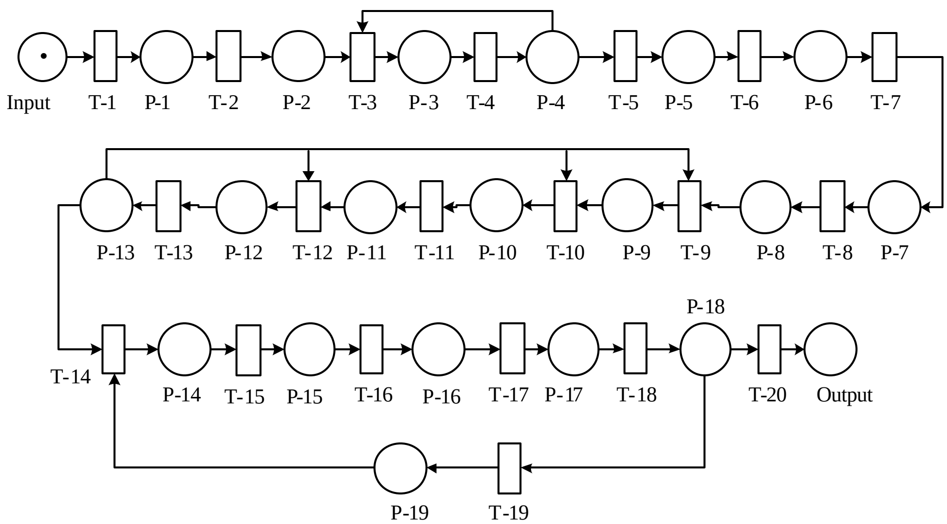


Fig. 3: HTCPN model of the MDO process for piston

design scheme was output and piston product development process was completed.

After the analysis of piston multidisciplinary optimization design, Petri net model was built, as shown in Fig. 3, the significance of each change shown in Table 2.

CONCLUSION

This study analyzed the business characteristic of marine diesel engine design field and gave the flow of marine diesel engine design and development business process. According to the feature of marine diesel engine design and development process, detail analysis was done for demands of marine diesel engine workflow modeling, modeling methods and modeling steps. For complex development process and hierarchical characteristic, Petri net expansion method was used to model. Then workflow modeling method for marine diesel engine collaborative design based on HTCPN was proposed. Finally, the business process of multidisciplinary optimization design for marine diesel engine piston part was taken as an example to build a workflow model based on HTCPN.

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