# Spacecraft Information Flow Collaborative Design Model and Application

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**Abstract.** To depict information flow structure of spacecraft system, the paper introduced information flow analysis method and defined tow information flow factors, the entity and the relationship. The relationships among entities were analyzed and the information mapping rules of activities and roles were given with information flow as main line. Based on these information mapping rules which were adapted to the spacecraft development process and engineering practice, models of collaborative design activity, role and information alternation were built. Finally, the application of the Electronic Data Sheet Manage System (EDS) showed. The results show that the method and models proposed in the paper are feasible and effective, which satisfy the collaborative design requirements of the spacecraft information flow.

**Keywords:** Information flow · Collaborative design · Mapping rule · Model

## 1 Introduction

The information flow design of spacecraft system is a part of the overall design of spacecraft. With the continuous development of spacecraft technology and the accumulation of experience, the means of spacecraft development are constantly enriched, and the functions, logic, information flow, software protocol and interface of spacecraft system are becoming more and more complex. Traditional mode of implementation can't meet the needs of complex system design, development and integration testing.

In view of the fact that spacecraft development is a system engineering involving multi-disciplinary integration, and its development process has high requirements for the control of the overall state of the product, in order to solve the above problems, all parties propose to adopt the information flow collaborative design method to improve the efficiency of satellite product design and reduce the cost of product development. At present, information transmission has become a key research field in information management, as research showing in [2–4]. However, these studies are from the perspective of macro and management, and stay at the conceptual level, lack of theoretical and practical. As a result, they can't support real system design. Based on the information flow analysis method, combined with the development process of spacecraft in China and its application in engineering practice, this paper defines the information flow elements, studies the information mapping rules, establishes the collaborative design model, role model and information interaction model of spacecraft information flow, and describes the complex and diverse information processing and interaction relationship in spacecraft information flow design. Thus, it provides a new idea and


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method for spacecraft information flow collaborative design modeling and information demand analysis. Finally, this paper gives the operation effect of the information flow collaborative design platform based on the model.

## 2 Information Flow Elements

According to the basic principle of information flow analysis method, the characteristics and change rules of information in the whole interaction process are the key and difficult points of the research [5]. Therefore, the primary task is to clarify the information flow elements of spacecraft development and their relationships. According to the general method of architecture design theory, spacecraft information flow development elements can be divided into entity and relationship.

### 2.1 Entity

Definition 1: Entity is all the objects related to the design of information flow system under the traction of specific task requirements, including collaborative design information, collaborative design role and collaborative design activities. It is represented as:

$$CE = \{CE_i \mid i \in [1, m]\} \tag{1}$$

In formula (1), m is the entity category [6]. The level and quantity of similar entities are determined by the form and view granularity of the collaborative design system of information flow.

Collaborative design information is a general term for all data generated and processed in the process of spacecraft development. It is a direct or indirect expression of the existing mode, operation state, change situation, load execution task and the result of the mission, etc., and it is expressed as:

$$CE_{info} = \left\{ I_{i,j}^{\omega} / i \in [1, X_0], j \in [1, I_0], \right\} \tag{2}$$

In formula (2), ω is the system structure granularity, $I_0$ is the information type, and x0 is the form type divided by granularity.

Collaborative design role refers to the collaborative design entity with the functions of model creation, personnel allocation, form initiation, filling in, submission, approval, consulting, calling back, simulation verification and auxiliary design [7], and it is represented as:

$$CE_{Role} = \left\{ R_{i,j}^{r} / i \in [1, J_0], j \in [1, R_0], \right\} \tag{3}$$

In formula (3), r is the system structure granularity, $R_0$ is the total number of collaborative design roles, and $J_0$ is the form type divided by granularity.

Collaborative design activities are a collection of ordered behaviors that can accomplish certain research tasks for the purpose of collaborative design of spacecraft information flow, and it is expressed as:

$$CE_{action} = \left\{ A_{i,j}^{a} / i \in [1, H_0], j \in [1, A_0], \right\} \tag{4}$$

In formula (4), a is the system structure granularity, $A_0$ is the total number of collaborative design activities, and $H_0$ is the form type divided by granularity.

Collaborative design task is an ordered set of activities organized to achieve specific collaborative design intent, and it can be expressed as:

$$CE_{task} = \{ T_i / i \in [1, T_0], j \in [1, A_0], \} \tag{5}$$

In formula (5), $T_0$ is the total number of tasks, and task $T_i$ is expressed as:

$$T_i = A_{k+1} \cup A_{k+2} \cup \ldots \cup A_{k+j} \tag{6}$$

In formula (6), $k \in [1, H_0]$, $j \in [1, A_0]$.

## 2.2 Relationship

Definition 2: Relationship refers to the information flow between different entities, which is identified by the directed information demand line, expressed as:

$$CR = \{ CR_i / i \in [1, n] \} \tag{7}$$

In formula (7), n is the number of association relationships. According to the function, the relationship can be divided into task allocation relationship, approval relationship and task dependency relationship.

The above two information flow elements are the necessary conditions for modeling the spacecraft information flow collaborative design architecture, and also the basis for ensuring that the architecture meets the modeling syntax normalization and information completeness. The internal relationship is shown in Fig. 1.

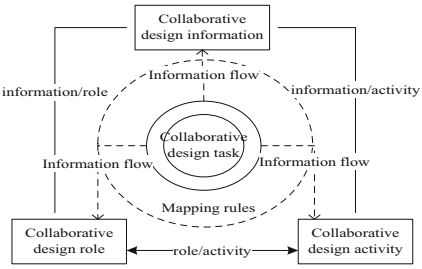


**Fig. 1.** Relationship between entities

A ternary relationship is formed around collaborative design tasks, collaborative design activities, collaborative design roles and information, which is recorded as formula (8), and this is the key of information flow collaborative design system modeling.

$$CR = \gamma\left(CE_{action}, CE_{node}, CE_{info}\right) \tag{8}$$

## 3 Information Mapping Rules

Definition 3: Information mapping rules refer to the basic rules followed by the association information relationship between different entities, including activity → activity information mapping, activity → role information mapping, role → activity information mapping and role → role information mapping [5], and it can be expressed as:

$$CF = \{CF_i / i \in [1, p]\} \tag{9}$$

In formula (5), p is the number of rules. According to the basic modeling principle of IDEF0 diagram [6], the specific process of information mapping is as follows.

Rule 1: Activity - activity information mapping

Activity - activity information mapping is a way of association between collaborative design activities, which defines the information interaction between activities and reflects the input, output and control information of collaborative design activities, as shown in Fig. 2.

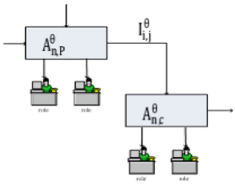


**Fig. 2.** Activity - activity information mapping

The structure granularity θ of the information flow collaborative design system should be firstly determined; And then for any collaborative design information $I^{\theta}_{i,j}$, we can determine its producing collaborative design activities and ending collaborative design activities; Information $I^{\theta}_{i,j}$ is treated as activity $A^{\theta}_{n,P}$ output data constraints, and as activity $A^{\theta}_{n,c}$ input (or control) data constraints; So we can build activities-activity information mapping between $A^{\theta}_{n,P}$ and $A^{\theta}_{n,c}$ as formula below:

$$CF_1 = A_{n,P}^{\theta} \xrightarrow{I_{i,j}^{\theta}} A_{n,c}^{\theta} \tag{10}$$

Rule 2: Activity - role information mapping

Activity-role information mapping is the way to associate collaborative design activities with collaborative design roles, indicating all roles involved in collaborative design activities, and defining the information interaction between activities and roles, as shown in Fig. 3 below:

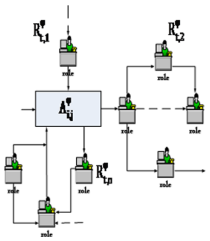

**Fig. 3.** Activity - role information mapping

The structure granularity φ of the information flow collaborative design system should be firstly determined; Based on the development process of various activities in spacecraft information flow collaborative design practice, for any the collaborative design activity $A_{i,j}^{\varphi}$, the collaborative design role that triggers the activity is determined as $R_{t,1}^{\varphi}$, $R_{t,2}^{\varphi}$,…, $R_{t,n}^{\varphi}$, and it can be expressed as set $R_{t,r}^{\varphi}$:

$$R_{t,r}^{\varphi} = R_{t,1}^{\varphi} \cup R_{t,2}^{\varphi} \cup \ldots \cup R_{t,n}^{\varphi} \tag{11}$$

Similarly, we can determine control roles set of $A_{i,j}^{\varphi}$ as $R_{t,z}^{\varphi}$, and output roles set as $R_{t,c}^{\varphi}$. So we can build activity - role information mapping of activity $A_{i,j}^{\varphi}$ as:

$$CF_2 = A_{i,j}^{\varphi} \rightarrow R_{t,r}^{\varphi} \cup R_{t,z}^{\varphi} \cup R_{t,c}^{\varphi} \tag{12}$$

Rule 3: Role > activity information mapping

The role-activity information mapping indicates all the activities the role participates in, and defines the information interaction between roles and activities, as shown in Fig. 4.

The structure granularity ϑ of the information flow collaborative design system should be firstly determined; According to the assignment of responsibilities, rights and responsibilities of each participant in the collaborative design of spacecraft information flow, for any the collaborative design role R, we can determine its participating activities $A_{h,1}^{\vartheta}$, $A_{h,2}^{\vartheta}$, …, $A_{h,n}^{\vartheta}$, and these can be expressed as set $A_{h}^{\vartheta}$:

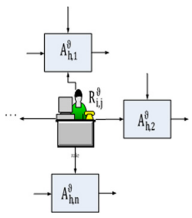

**Fig. 4.** Role activity information mapping

$$A_h^{\vartheta} = A_{h,1}^{\vartheta} \cup A_{h,2}^{\vartheta} \cup \ldots \cup A_{h,n}^{\vartheta} \tag{13}$$

By establishing connections from $R_{i,j}^{\vartheta}$ to all elements of activity set $A_h^{\vartheta}$, we can build role-activity information mapping of $R_{i,j}^{\vartheta}$ as:

$$CF_3 = R_{i,j}^{\vartheta} \rightarrow A_{h,1}^{\vartheta} \cup A_{h,2}^{\vartheta} \cup \ldots \cup A_{h,n}^{\vartheta} \tag{14}$$

Rule 4: Role-role information mapping.

Role-role information mapping is a way to associate roles in collaborative design, which clarifies the association relationship and interaction information between roles, as shown in Fig. 5.

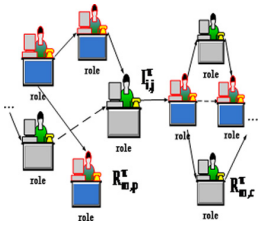


**Fig. 5.** Role-role information mapping

The structure granularity π of the information flow collaborative design system should be firstly determined; And then for any collaborative design information $I_{i,j}^{\pi}$, we can determine its producing role $R_{m,p}^{\pi}$ and its ending role $R_{m,c}^{\pi}$. By establishing connection from role $R_{m,p}^{\pi}$ to role $R_{m,c}^{\pi}$, we can build role-role information mapping of information $I_{i,j}^{\pi}$ as:

$$CF_4 = R_{m,p}^{\pi} \xrightarrow{I_{i,j}^{\pi}} R_{m,c}^{\pi} \tag{15}$$

# 4 Modeling of Spacecraft Collaborative Design System Based on Information Flow

## 4.1 Spacecraft Collaborative Design Process

Firstly, the collaborative design activities and roles are decomposed hierarchically, according to the structure granularity of spacecraft information flow collaborative design system. And then based on the requirements of spacecraft development process and information mapping rules, the activity model, role model and information interaction model are established respectively. The specific steps are shown in Fig. 6.

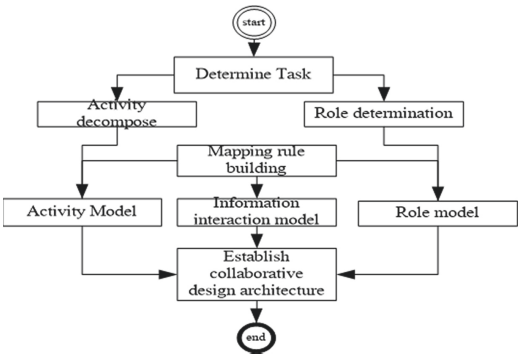


**Fig. 6.** Process of spacecraft collaborative design system based on information flow

(1) According to the characteristics of the spacecraft model, collaborative design activities, roles and collaborative design hierarchy are determined;
(2) According to the information mapping rules 1–3, the interaction information among activities is determined, all the roles involved in the activities are clarified, and the activities involved in each role are defined, and the collaborative design activity model is constructed;
(3) According to information mapping rule 4, the interaction information between roles is defined, and the role model of collaborative design is constructed;
(4) According to the activity and role model of collaborative design, the information relationship between different collaborative design or top nodes is determined, and the information interaction model is constructed;
(5) The collaborative design architecture based on information flow is designed by collaborative design activities, roles and information interaction model.

## 4.2 Activity Model of Spacecraft Collaborative Design

The activity model of spacecraft collaborative design reflects the hierarchical information flow interaction among collaborative design activities, which can be expressed by special ternary functions among activities, roles and information:

$$OAM = \{CEaction, CEinfo, CERole\} \tag{16}$$

The collaborative design of spacecraft information flow is divided into two levels: subsystem and single machine; At the same time, collaborative design activities are divided into nine categories: project creation, personnel allocation, form initiation, form design, form submission, form approval, form consulting, form rollback, simulation verification and aided design, and the corresponding activity set is:

$$CE_{action} = \{A^2_{n,t} | n\epsilon[1,6], t\epsilon[1,A_0]\} \tag{17}$$

The information set between activities is:

$$CE_{info} = \{I^2_{p,q} | p\epsilon[1,X_0], q\epsilon[1,I_0]\} \tag{18}$$

And the role set participating in the activity is:

$$CE_{Role} = \{R^2_{f,t} | f\epsilon[1,H_0], l\epsilon[1,R_0]\} \tag{19}$$

### 4.3 Role Model of Spacecraft Collaborative Design

The role model of spacecraft collaborative design reflects the complex and diverse information interaction relationship and hierarchical information requirements among collaborative design roles, which can be expressed by special functions between roles and information:

$$ONM = \{CERole, CEinfo\} \tag{20}$$

The roles of cooperative design for spacecraft information flow are divided into six categories: project manager, project administrator, information master, subsystem master, device manager and software manager. Then the corresponding role set is:

$$CE_{Role} = \{R^2_{m,k} | m\epsilon[1,6], k\epsilon[1,R_0]\} \tag{21}$$

And the information set between roles is:

$$CE_{info} = \{I^2_{i,j} | i\epsilon[1,X_0], j\epsilon[1,I_0]\} \tag{22}$$

### 4.4 Information Interaction Model of Spacecraft Collaborative Design

The information interaction model of spacecraft collaborative design reflects the diversified information interaction relationship among the nodes in the collaborative design activities in the process of collaborative design implementation. It can be expressed by the special ternary function of collaborative design information, roles and activities, which is recorded as:

$$OIM = \{CEinfo, CERole, CEaction\} \tag{23}$$

The collaborative design of spacecraft information flow is divided into two levels: subsystem and device; And then for any collaborative design information $I^2_{\mathrm{i,j}}$, we can determine its producing role $R^2_{m,\mathrm{p}}$ and its ending role $R^2_{m,\mathrm{c}}$. Thus, the corresponding information interaction model can be expressed as:

$$\{R^2_{m,p}|A^2_{m,p}\} \xrightarrow{I^2_{i,j}} \{R^2_{m,c}|A^2_{m,c}\} \tag{24}$$

# 5 Practice of Spacecraft Information Flow Collaborative Design

As mentioned above, based on the general principles of collaborative design, combined with the development process of spacecraft in China and its application scenarios in engineering practice, a set of spacecraft information flow collaborative design system model is given, and the model is applied to the implementation of EDS (electronic data sheet) integrated management system.

## 5.1 Division of Information Flow Elements

In the design practice of spacecraft information flow system, we should not only avoid the long coordination chain and heavy management workload, but also facilitate the full communication and cooperation among the system, subsystem and device (software). The structure granularity of collaborative design system is defined as two-level working mechanism. On this basis, the information flow elements are determined as follows: the collaborative design information is determined as telemetry parameters, remote control instructions, data protocols (intra satellite bus protocol, inter satellite link protocol, satellite ground telemetry, remote control protocol, etc.) and application data expression (instruction group, instruction sequence, thermal control table, etc.); The collaborative design roles are determined as project administrator, information master, subsystem master, device manager and software manager; Collaborative design activities include form initiation, form design, form submission, form approval, form rollback, simulation verification, aided design, etc.; The relationship between entities can be divided into three types: task allocation relationship, approval relationship and task dependency relationship.

## 5.2 Collaborative Design Activity Model

According to the rule of activity information mapping, the internal information mapping of spacecraft information flow collaborative design activity is established, as shown in Table 1.

The activity diagram of establishing the collaborative design model of information flow is shown in Fig. 7.

**Table 1.** Mapping relationship between information flow collaborative design activities

| Source activity | Destination activity | Information type |
|---|---|---|
| Project creation | Personnel allocation | $I_{CC}$ |
| Personnel allocation | Form initiation | $I_{CC}$ |
| Form initiation | Form design | $I_{IS}$ |
| Form design | Form submission | $I_{IS}$ |
| Form submission | Form approval | $I_{CC}$ |
| Form consulting | Form rollback | $I_{CC}$ |
| Form rollback | Form design | $I_{CC}$ |
| Form consulting | Form approval | $I_{CC}$ |
| Aided design | Simulation verification | $I_{IS}$ |
| Simulation verification | Form design | $I_{IS}$ |

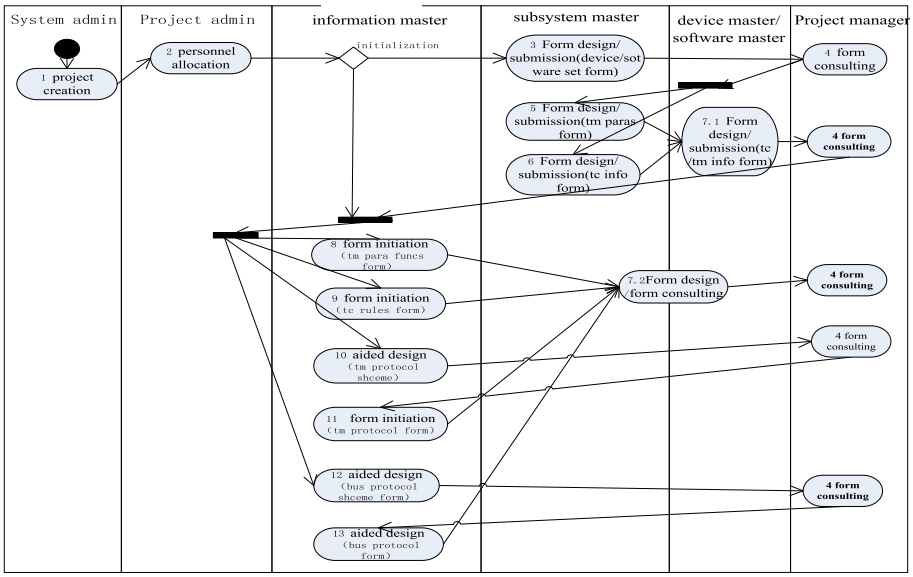


**Fig. 7.** Activity diagram of information flow collaborative design model

According to the mapping rules of activity-role and role-activity information, 9 activity-role information mappings and 24 role-activity information mappings are established, as shown in Table 2.

### 5.3 Role Model of Collaborative Design

According to the rules of role-role information mapping, the following 11 role-role information mappings are established, as shown in Table 3.

**Table 2.** Activity-role mapping information flow collaborative design model

| Activity | Participate role |
|---|---|
| Project creation | System administrator |
| Personnel allocation | Project administrator |
| Form initiation | Information master/subsystem master |
| Form design | Information master/subsystem master/device master/software master |
| Form submission | Information master/subsystem master/device master/software master |
| Form consulting | Information master/subsystem master/device master/software master |
| Form rollback | Information master/subsystem master/device master/software master |
| Aided design | Information master/subsystem master |
| Simulation verification | Information master/subsystem master |

**Table 3.** Mapping relationship between information flow collaborative design activities

| Source role | Destination role | Information type |
|---|---|---|
| System administrator | Project administrator | $I_{CC}$ |
| Project administrator | Information master/subsystem master/device master/software master | $I_{CC}$ |
| Information master | Subsystem master/device master/software master | $I_{IS}/I_{CC}/I_{wc}$ |
| Subsystem master | Device master/software master | $I_{IS}/I_{CC}/I_{wc}$ |
| Device master | Device master | $I_{IS}$ |
| Software master | Software master | $I_{IS}$ |

### 5.4 Information Interaction Model

According to the given four types of information mapping rules, based on the collaborative design activity model and collaborative design role model, combined with the current spacecraft verification process and engineering practice experience, this paper analyzes the relationship between the source point, destination point, production activity and consumption activity of different types of information flow layer by layer, and clarifies the information transfer process and interaction between collaborative design activities and roles, The model of spacecraft collaborative design system based on information flow is established, as shown in Fig. 8 below.

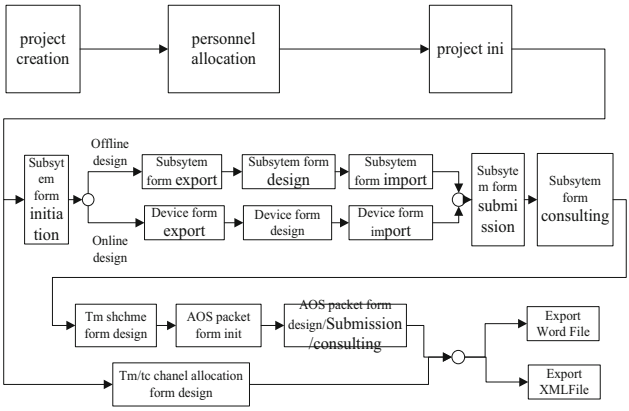


**Fig. 8.** Model of spacecraft information flow collaborative design system

Based on this model, the EDS integrated management system platform is established. Up to now, EDS has been involved more than fifty projects, and has been put into trial in several research models. The experimental results show that, compared with the traditional spacecraft development model, the information flow collaborative design model can more clearly describe the complex information interaction between the spacecraft generation and development parties, more intuitively display the dynamic whole process of the whole spacecraft development activities, and more systematically assist the development parties to coordinate and agree The design and implementation of complex large system are realized efficiently.

Through the analysis of the trial situation of the model in progress, it can be seen that the use process of EDS integrated management system conforms to the actual situation and habits of each model development, the modeling method meets the requirements of the information circulation and utilization design of spacecraft, and the collaborative design modeling elements can cover all links of the whole life cycle of satellite development, the baseline release, technical status change, greatly reduce the cost of point-to-point manual communication, significantly improve the error risk caused by single point design and implementation, greatly improve the production and development efficiency of spacecraft, with an increase rate of more than 40%.

## 6 Conclusion

Based on the contents of digital development of spacecraft information flow and the new requirements and problems faced by traditional development mode, combined with the general theory of collaborative design, this paper presents a collaborative design mode of information flow suitable for the development of spacecraft in China, and applies it to the construction of EDS integrated management system of our Institute. Through the statistical analysis of the practical application results, it is proved that the information flow collaborative design model proposed in this paper comprehensively considers the responsibilities, rights and responsibilities of all parties in the

collaborative design, takes the information flow as the main line, comprehensively considers the factors such as roles, activities and information, realizes the architecture modeling, refines the process analysis of collaborative design activities, and highlights the design characteristics of different types of information. The rules of collaborative design [9] are standardized, and the general idea, objectives and implementation means are feasible, which are in line with the actual operation scenarios and requirements. The related information flow protocol modeling method and parameter format model are universal and flexible, which can cover most of the daily production needs, and provide rich theoretical support and a large number of practical verification data for spacecraft development and design and management mode transformation.

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