Preliminary Study on Risk Assessment Method of Spacecraft Reverse Process Assembly

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Abstract. According to the technical characteristics and risk distribution of spacecraft inverse process assembly, the risk analysis method is proposed based on multi-level comprehensive evaluation. Combined with the specific risk factors, the indicators and guidelines of risk assessment are designed for spacecraft inverse process assembly, and through an inverse process assembly risk analysis of a satellites instance, the inverse process of the satellite and the results of the risk assessment process are given to verify the reliability and validity of the method.

1. Introduction
Due to the occurrence of technical coordination, schedule adjustment and quality problems, reverse assembly process often occurs in the process of spacecraft assembly. The reverse process of spacecraft assembly refers to the temporary deviation from the original planning technical status requirements caused by the implementation of the scheduled assembly work by the partial reverse technology process, which often causes the hazards of the overlapping of various unidentified risk factors, the difficulty of assembly implementation and the sharp increase of risk. [1]. In order to effectively control the risk of reverse process assembly, it is necessary to carry out risk assessment of reverse process operation and optimize the technical process of reverse process operation.

2. Characteristics of Reverse Process Implementation of Spacecraft Assembly

2.1. The timing of reverse flow is unpredictable.
Reverse process assembly is usually triggered by some unexpected events, which directly depends on whether the components of the whole system engineering are normal or not. The technical status of reverse process assembly depends on the state of the whole system engineering and the degree of development. Therefore, the timing of the reverse process is uncertain and irregular, and the technical status of spacecraft varies, which can’t be prevented and avoided in the early stage of the project.

2.2. The technical state of reverse process is complex.
Reverse process operation is caused by unexpected events and can quickly become a model development board. It must solve the problem in the shortest time. The time is tight and the task is heavy, which is one of its typical characteristics. In order to complete the technical analysis and operation implementation of the reverse process in a short time, it is necessary to consider many factors, such as product status, technical requirements, process plan, operation steps, implementation environment, auxiliary tooling, personnel ability, etc. These factors often produce new risk factors. It is very important...
to eliminate the interference of various factors as far as possible, identify risks in advance and take control measures.

2.3. Potential risk of reverse operation
Spacecraft cabins are equipped with different system components, instruments, equipment, cables, conduits and so on. They have high density of loading, poor openness and visibility, and some even blind areas. The operating conditions are very bad. In addition, there are many explosive devices, such as high-pressure gas devices, engines, fuel and other dangerous goods, which have a high degree of operational risk and many unmeasurable items. Forward process usually considers various boundary conditions of assembly operation, and considers practicability as an important factor. By arranging a more reasonable process route, it avoids technical risks and improves operation conditions as far as possible, thus reducing the assembly risk. However, in reverse assembly process, there are few alternative process routes. The focus of the work has become to formulate risk plans under the existing conditions. Any minor mistake in operation may cause major quality and safety accidents, and may also lead to secondary disasters. Potential risk is the most important feature of reverse assembly process.

3. The evaluation principle of total risk of reverse process
This article combined with the comprehensive analysis and analytic hierarchy process (AHP), forming a spacecraft inverse process risk evaluation model of assembly work, strive to satisfy the risk analysis of spacecraft assembly engineering constraints, simple and effective, which adapt to vessel developed toward the direction of large-scale, integrated, high-performance, satisfy the spacecraft's index of long life, high reliability requirements.

3.1. Process of total risk assessment of reverse process
Faced with a reverse process assembly, we need to work out a reasonable process route to reduce the risk of implementation, and then carry out risk assessment from three levels: project risk, key process risk and residual risk assessment of emergency plan, that is, to identify key projects of reverse process assembly, and formulate detailed risk plan, and finally to evaluate residual risk comprehensively. The detailed analysis and evaluation process is presented in Fig. 1.

![Flow chart of risk evaluation of the reverse process](image-url)
3.2. Evaluation principle of risk comprehensive evaluation model

Because of the characteristics of sudden and technical state, the composition of the subprocess can only be divided according to the actual technical state. Combining the actual boundary condition of assembly and inverse process operation, operating mode and the element of risk involved, the risk $Q$ can be with technical scheme $Q_c$ and operation risk $Q_w$ two quantitative parameters for evaluation of the failure mode.

Among them, the technical solution risk value $Q_c$ is the four quantitative indexes, including the technology scheme maturity, the control degree of risk, the coupling degree of the forward process and the complexity of the technical solution. The operation risk value $Q_w$ is composed of four quantitative indexes, namely, the destruction degree of the product, the severity of the environment, the complexity of operation and the maturity of the operation project.

If the total assembly of an inverse process is divided into $N$ sub-processes, the risk value of the $k$ sub-procedure is $Q_k (1 \leq k \leq N)$, and the weight of the $k$ sub-procedure is $E_k$, and the risk value of the general assembly risk $Q$ is:

$$Q = \sum_{k=1}^{N} E_k Q_k$$

(1)

Type, $E_1 + E_2 + \ldots + E_N = 1$, and $0 \leq Q \leq 1$, the general assembly risk value $Q_k$ of the $k$ sub-procedure can be evaluated by several quantitative risk factor parameters on the failure mode analysis, and the risk factors are determined through expert evaluation. Considering the engineering experience of the general assembly of the reverse process, $Q_k$ takes the product of the two quantified parameters of the technical scheme of the sub-process $Q_{kc}$ and operation risk $Q_{kw}$.

$$Q_k = \sqrt{Q_{kc} \cdot Q_{kw}}$$

(2)

Taking the risk $Q_{kc}$ of technical solution as an example, this paper introduces the calculation process of technical solution risk $Q_{kc}$. Known from the analysis of the front of the first k is the process of technical solution risk $Q_{kc}$ risk factors for a total of four (technical scheme, control of the risk degree of maturity, and the positive flow coupling and the technical scheme of complexity), the weight of risk factors for the first $j$ and (0$\leq j \leq 4$, and $b_1^j + b_2^j + \cdots + b_4^j = 1$ ), is the process of assembly and set for the first $k$ experts to evaluate risk factors scoring a total of $s(k)$, including the $i$ expert scoring weight of (0$\leq i \leq s(k)$, and $a_1^k + a_2^k + \cdots + a_4^k = 1$ ), the $s(k)$ is a specialist to evaluate four risk factors to constitute the first $k$ is the process of assembly technology risk matrix $C_k$:

$$C_k = \begin{bmatrix} C_{41} & C_{42} & \cdots & C_{44} \\ C_{21} & C_{22} & \cdots & C_{24} \\ \vdots & \vdots & \ddots & \vdots \\ C_{4(k-1)} & C_{4(k-1)2} & \cdots & C_{4(k-1)4} \end{bmatrix}$$

(3)

Among them, $c_{ij}$ represents the result of the $i$ expert's evaluation of the $j$ risk factor of the $k$ sub-procedure. Then, the corresponding technical risk value $Q_{kc}$ can be calculated according to the risk factor weight vector of the $k$ sub-procedure, namely:

$$G_k = A_k \times C_k = \begin{bmatrix} a_1^k \\ a_2^k \\ \vdots \\ a_{4(k-1)}^k \end{bmatrix}^T \begin{bmatrix} c_{411} & c_{412} & \cdots & c_{414} \\ c_{421} & c_{422} & \cdots & c_{424} \\ \vdots & \vdots & \ddots & \vdots \\ c_{4(k-1)1} & c_{4(k-1)2} & \cdots & c_{4(k-1)4} \end{bmatrix} = [G_{k1}, G_{k2}, \ldots, G_{k4}]$$

In the formula: $G_{kj}$ represents the comprehensive evaluation result of the $j$ risk factor in the k sub-procedure. Then, the corresponding technical risk value $Q_{kc}$ can be calculated according to the risk factor weight vector of the $k$ sub-procedure, namely:
In the same way, the operation risk of the $k$ sub-procedure can be obtained by $Q_{kw}$, except that the risk factors and weights are different.

After calculating the technical risk value $Q_{kc}$ and operation risk $Q_{kw}$ of each sub-procedure of the total assembly reverse process, the subwork can be obtained according to formula (2). The overall risk value $Q_k$ is calculated according to formula (1), and the total risk value $Q$ is calculated, and then the risk level of the reverse process assembly in the process scheme is evaluated [4].

### 3.3. Risk factors and evaluation description

Calculate the inverse process of value at risk is the key to reasonably determine the risk factors for each working procedure and criteria of evaluation factors and quantitative, the technical scheme risk value of $Q_k$ is technology scheme, control of the risk degree of maturity, and the positive flow coupling, the technical scheme of complexity of four quantitative indicators, the evaluation standard are shown in table 1; The operating risk value $Q_{w}$ is composed of four quantitative indicators, such as the destruction degree of the product, the severity of the environment, the complexity of operation and the maturity of the operation project. The evaluation criteria are shown in table 2.

**Table 1. Standard sub-standard of risk parameters for reverse process operation project technical scheme.**

| Technical solution maturity | Control of risk | Forward process coupling | Technical solution complexity |
|---------------------------|----------------|-------------------------|-----------------------------|
| 0.1~0.2                   | Extremely low  | High                    | Simple                      |
| 0.3~0.4                   | Low            | Probability             | General                     |
| 0.6~0.7                   | General        | general                 | Larger                      |
| 0.9~1                     | High           | low                     | Large                       |

**Table 2. Standard score of operating risk parameters for reverse process project.**

| The rework of the spacecraft | The rigor of the operating environment | The complexity of the operation | Operational project maturity |
|-----------------------------|----------------------------------------|--------------------------------|------------------------------|
| 0.1~0.2                     | Extremely low                          | Extremely low                  | Extremely High               |
| 0.3~0.4                     | Low                                    | Low                            | High                         |
| 0.6~0.7                     | certain                                | General                        | General                      |
| 0.9~1                       | High                                   | High                           | Low                          |

### 3.4. Risk assessment rules

The comprehensive evaluation method to determine the weights can be divided into three grades, respectively is the child process risk weighting vector of the weight vector of $E_k$, risk factors $B_k = [b_1, b_2, \ldots, b_k]$, and expert scoring weight vector $A_k = [a_1, a_2, \ldots, a^{(k)}]$, which the child process risk weighting by the project director (process director) according to the size of important degree and the workload of each working procedure to determine; The weight of risk factors is determined by the two-and-two comparison method, each time taking two factors (defined as $y_i$ and $y_j$), and using the ratio of $y_i$ and $y_j$ to the safety management level [5]; However, the determination of each expert's evaluation of scoring weight needs to take into account the experts' professional direction, professional title, position, engineering experience and other factors, and can be determined by means of average value, namely:

$$a^i_1 = a^i_2 = \ldots = a^{(k)}_i = 1/q(k)$$

The total risk of the reverse process is random, fuzzy, relativity and multiplicity. The numerical value on the available interval $[0,1]$ is used to measure the total risk of the inverse process, and the degree of
risk is graded according to the magnitude of risk value $Q$ which is lower risk ($Q \in [0, 0.3)$), moderate risk ($Q \in (0.3, 0.6]$) and high risk ($Q \in (0.6, 1]$). Through the analysis of the actual situation and experience of the inverse process, it is necessary to analyze the operation items and take precautions and remedial measures when the risk value is less than 0.3. When the risk value reaches $0.3 \sim 0.6$, it is necessary to focus on the analysis of operational projects and prepare detailed risk plans. When the risk value of more than 0.6, the project many requirements greatly from the reality, the inverse process is extremely dangerous operation, should avoid as far as possible, otherwise, must be the expert review the feasibility of the appraisal process.

4. Conclusion
This paper analyses and discusses the characteristics of reverse process assembly. On the basis of analytic hierarchy process and fuzzy comprehensive evaluation method, a risk analysis method of reverse process assembly based on multi-level comprehensive evaluation model is proposed. This method can evaluate and calculate the risk of reverse process assembly conveniently, and provide quantitative evaluation for the improvement effect. It can also be used to determine the process plan of reverse process assembly.

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