Risk Assessment of Equipment Repair Cost Based on Multi-Agent Modeling

Xiong Xiao¹, Peng Dong²
¹,²Department of Management Engineering and Equipment Economics, Naval University of Engineering, Wuhan, China, 15071078081@163.com

Abstract. Due to the complicated structure, large equipment is prone to cost risks during the repair process. To assess the cost risk of such equipment, the method of step-by-step decomposition of the repair equipment can be adopted. The repair task is first decomposed into the bottom-level work unit at the system level or equipment level, and the risk factors are identified by the WBS-RBS method, and the risk is calculated by the FAHP method. The factors are combined with the probability values, and the comprehensive probability values of these risk factors are input into the cost risk assessment model based on Anylogic software. In the equipment repair task of a diesel engine, the model realizes the cost risk assessment of the underlying work unit through single agent, and builds the multi-agent to summarize the evaluation results to obtain the repair task cost risk assessment value.

1. Introduction
In recent years, the research on equipment repair in the fields of natural resource exploitation, aviation, power station and other fields has attracted the attention of scholars at home and abroad, and has completed the following types of work:
- The use of fault trees and graphical tools such as Bayes network [1-4];
- The statistical classification of the risk of repair accidents [5-6];
- The assessment of the overall risk situation of the maintenance system [7-8].

These studies addressed some of the risk issues in the repair process from different dimensions, but did not address specific cost risk assessments.

For equipment repairs, the risks are mainly from maintenance personnel, equipment itself, materials, maintenance processes, external environment, and management of the repair company. Therefore, in order to avoid cost overruns, managers must analyze these risk sources in advance, take control, and focus on the overall risk situation of the project while focusing on potential risk events in the repair process. Based on WBS-RBS (work-risk structure decomposition), this paper decomposes the repair task into the underlying work unit, and uses FAHP (fuzzy analytic hierarchy process) to calculate the comprehensive probability of risk factors. Finally, the Anylogic software is used to construct the intelligent body group. Simulation of the risk assessment of diesel engine repair costs.

2. Repair task decomposition
2.1. Work Breakdown Structure
WBS (Working Breakdown Structure) is a relatively mature work breakdown structure in project management. It will decompose the repair tasks into the underlying work units according to a certain structural relationship, such as the repair equipment system configuration and the repair equipment
repair process. In the specific application, the work structure is often decomposed into the underlying work unit through 2~3 layers. Figure 1 is a block diagram of the bottom working unit obtained by decomposing the working structure of the ship repair according to its system configuration.

![Figure 1 Ship repair WBS decomposition](image)

### 2.2. Risk Breakdown Structure

RBS (Risk Breakdown Structure) is a category-oriented risk decomposition structure constructed after reference to the WBS principle. In the specific application, the source of risk factors can be divided into the following parts: repair personnel, repair equipment, materials, repair process, repair environment and management of the repair enterprise.

- **Sources of personnel risks:** low skill of repair personnel, insufficient communication of personnel, irregular operation of personnel, insufficient effective labor rate, and lack of labor.
- **Sources of technical risks:** improper selection of engineering schemes, defects in design content, backward repair processes, low repair quality, insufficient technical documentation, low technical maturity, and excessive site survey errors.
- **Sources of environmental risks:** poor climatic conditions, chaotic work sites, rising prices, and changes in staff wages.
- **Management risk sources:** management of weak construction period lag, improper planning of repair schedule, unreasonable resource organization, organizational structure risk.
- **Equipment risk source:** super-strength use of repaired equipment, advanced technology of repaired equipment, and weak construction of maintenance facilities.
- **Material risk sources:** too much new materials and untimely supply of materials.

The risk structure decomposition is shown in Figure 2:
2.3. **WBS-RBS decomposition**

The WBS-RBS risk matrix is constructed by combining the work structure and the risk structure decomposition. This matrix is used to identify the risk factors of the underlying work unit of the level repair as shown in Figure 3:

![Figure 2 Repair risk RBS decomposition](image)

![Figure 3 WBS-RBS decomposition of the repair task](image)

3. **Risk assessment simulation**

3.1. **Risk assessment method**

In the 1970s, Professor T.L. Satty proposed the Analytic Hierarchy Process (AHP) and successfully applied it to US defense projects. Sorting is the basic principle of AHP. Decompose complex problems into a multi-level ladder structure model, and then ask experts, authorities and first-line production
workers to objectively judge the work task units at each level, and give quantitative descriptions of their importance; finally, use mathematical methods to calculate and test . In 1965, L.A.Zadeh published an article "Fuzzy Sets" in "Information and Control", marking the birth of fuzzy mathematics [9]. Based on fuzzy mathematics and analytic hierarchy process, the fuzzy analytic hierarchy process (FAHP) stratifies the cost risk factors of the underlying work units, and uses the risk fuzzy judgment matrix to calculate the probability of the cost risk factors. The specific calculation steps are as follows:

• Determine the relative probability between risk factors
• Construct risk fuzzy judgment matrix
• Test the consistency of fuzzy judgment matrix
• Calculate the comprehensive probability of each risk factor

After calculating the risk factor synthetic probability of the underlying work unit by the above method, the probability values are taken as the input of the multi-agent model to participate in the equipment repair cost risk assessment.

3.2 Model ideas
Through the WBS-RBS decomposition, the repair task is broken down into the underlying work units. The underlying work unit is the basis for the risk assessment of equipment repair tasks, and is the unit of work that is independent of each other in the equipment repair process. The independence of the largest feature of the underlying work unit, the repair content of each underlying work unit is fixed, and the boundaries of other underlying work units are clear, such as the removal of the cylinder liner and the assembly of the cylinder head. The affordability of risk is the basis for the risk assessment of the underlying work unit costs. Based on expert experience or historical data, the initial probability value \( p \) of each underlying work unit cost risk is given, and the comprehensive probability of each risk factor is calculated by the fuzzy analytic hierarchy process (FAHP) as the input value of the simulation.

The simulation principle is as follows: firstly, the simulation judgment criterion for the occurrence of the risk event is set. For the ongoing underlying work unit, if the risk event occurs, the cost loss is recorded; if the risk event does not occur, the next underlying work unit is executed, until the end of the repair mission. Finally, the simulated output data is collated and the risk level of the repair task is determined. The judgment basis of the repair cost risk level is shown in Table 1.

| Table 1. Cost Risk Classification |
|-----------------------------------|
| Excessive cost | 0 | 0~10% | 10%~30% | >30% |
| Risk level      | no risk | Minor risk | Moderate risk | Severe risk |
| Acceptable level| Acceptable | Acceptable | Tolerable | Not accepted |

3.3 Simulation algorithm
The steps to simulate the repair cost of the repair task using Anylogic software are as follows:

Step 1: Establish a repair task multi-agent group. The agent inside the agent group is the underlying work unit, that is, the specific device or subsystem, as shown in Figure 4:
Step 2: The agent determines whether the risk event of the repair occurs. If the risk event occurs, the cost of repairing the underlying work unit is calculated, and the overrun fee is recorded and accumulated into the data set. If the risk event does not occur, the next underlying work unit is executed. The judgment process of whether the risk event occurs is shown in Figure 5:

Step 3: Run to the last underlying work unit, output the simulation results, and judge the repair project cost risk level.

4. case study
The simulation operation of a diesel engine repair model has been broken down into 16 underlying work units. The evaluation of each underlying work unit is shown in Table 2.

Table 2. Host Maintenance Process Risk Assessment Results

| Repair content | Underlying work unit | Risk consequences | Risk comprehensive probability |
|----------------|-----------------------|-------------------|--------------------------------|
| Cylinder head removal | ① Decompose the cylinder head ② Cleaning and descaling, replacing zinc blocks ③ Grinding valve ④ Measure the bushing clearance to determine if it is repaired | Insufficient clearance between stem and conduit seal bushing | \( p_1 \) \( p_2 \) \( p_3 \) \( p_4 \) |
Piston rod repair
⑤ Remove carbon deposits from pistons, connecting rod bearings, piston pins, etc. ⑥ Detecting connecting devices such as pistons, piston rings, and piston pins ⑦ Flush the connecting rod oil passage and the piston oil chamber ⑧ Replace the piston gas ring as appropriate ⑨ Check the appearance of the piston pin and connecting rod bolts and replace them as appropriate

Piston pin and connecting rod spiral crack damage or wear tolerance is not found

Cylinder liner overhaul
⑩ Check the wear and corrosion of the cylinder liner ⑪ Detect the inner diameter of each cylinder liner

Cylinder liner repair is not in place

Gearbox overhaul
⑫ Replace the zinc block ⑬ Check bolt fastening ⑭ Check if the safety valve can be opened flexibly ⑮ Clean the blown oil separator and drain pipe

Through the spiral

The simulation model is constructed as shown in Figure 6:

The simulation operation time is set to 1000 times, and the cost risk simulation result in the diesel engine is obtained. The risk distribution of the diesel engine repair cost is as shown in Table 3:

| Overage ratio | 0 | 0~10% | 10%~20% | 20%~30% | >30% |
|---------------|---|--------|---------|---------|------|
| Proportion    | 0.418 | 0.421 | 0.081 | 0.064 | 0.016 |

Based on the above results, the distribution of the cost risk of the diesel engine repair can be known. In this repair, the cost risk within the acceptable range is 83.9%, of which the risk is completely within the tolerance of 41.8%; The risk outside the acceptable range is 16.1%, of which moderate risk is 14.5%; heavy risk is 1.6%. The simulation of diesel engine repair cost risk by simulation can provide a basis for
the development of repair risk control measures. The accuracy of the simulation model is related to the following factors.

- Whether the decomposition of the underlying work unit is reasonable during the repair process
- Whether the data on the cost is accurate
- Whether the risk threshold setting is reasonable
- Whether the quantitative treatment of risk consequences is reasonable
- Whether the generation mechanism of each random number in the simulation is reasonable

5. Conclusion

Risk management is an important part of equipment repair project management. Based on the underlying work unit cost risk assessment, this paper uses the cost risk probability value of the bottom work unit as the basic input, and realizes the risk simulation evaluation through the Anylogic model. The risk assessment simulation of a diesel engine repair proves the scientificity and practicability of this method, but the model is only practiced in equipment repair projects that are easy to decompose and have fewer underlying work units. Subsequent research will further increase the number of working units at the bottom and be tested on a complex structural repair.

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