ATLANTIS PRESS
Advances in Economics, Business and Management Research, volume 85
2nd International Conference on Economy, Management and Entrepreneurship (ICOEME 2019)

Research on Risk Management of Aviation Complex Equipment Collaborative Development Project

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***Abstract*—Firstly, this paper expounds the background of the risk management problem of aviation complex equipment collaborative development project, and points out the significance of studying this problem. Secondly, this paper analyzes the risk occurrence mechanism of aviation complex equipment collaborative development project, and introduces the milestone events and the relationship between events. In addition, based on the system optimal control theory and the risk transfer function, with the goal of minimizing risk loss and risk control cost, this paper constructs a risk optimization model for the aviation complex equipment collaborative development system, and solves the degree of risk optimization of the milestone events. Finally, the model is validated by an example, which proves the validity of the model and provides reference for the collaborative development of aviation complex equipment in the future.**

Keywords—aviation complex equipment; risk management; milestone events

I. Introduction

The risk management of aviation complex equipment development project is a complex project, and it is also the commanding height of competition among countries in the world. As an important means to enhance national scientific and technological competitiveness and comprehensive national strength, the development of large-scale complex equipment has been upgraded to the national strategic level. The new technology developed by complex equipment is of vital importance to the national science and technology competitiveness. It directly determines the improvement of the production efficiency of the entire manufacturing industry and the upgrading of the industrial structure. It has become an important strategic means to improve the national design and manufacturing capabilities. In addition, the development of large-scale complex equipment is also of great significance for transforming the mode of economic growth, promoting the development of science and technology, and accelerating the pace of national modernization.

Due to the dual impact of system complexity and environmental complexity, the risk management is a key issue in the management of large-scale complex equipment development projects. The comprehensiveness, high-tech characteristics, high timeliness, high input and high complexity of complex equipment projects determine the high risk of complex equipment project development. Therefore, the level of risk management of the development and implementation of complex equipment directly affects the success or failure of complex equipment development projects.

The milestone events refer to the important landmark event in the implementation process of project. The project process is carried out with milestone events, and the complex equipment development process can be cascaded into an organic whole with strong logical relationship. In summary, it is necessary to conduct risk management research on complex equipment development projects based on milestone events.

For the risk management problem of complex equipment development projects, domestic and foreign scholars have made the following research. Zhang Xumei [1] discussed the relationship between complex equipment manufacturers and suppliers, and based on the risk-sharing cooperation model, elaborated the collaborative development model between complex equipment manufacturers and suppliers, and discussed the characteristics and key issues of complex equipment development management. Li Xiaosong [2] and so on actualized the mutual mapping of qualitative variables and quantitative variables, and the accurate assessment of weapons' development risks. Yuan Bo [3] improved the traditional risk matrix by considering various technical risk consequences and their influence weights, obtained the risk calculation model for aviation equipment development, and gave the early warning process of aviation equipment development risk. By constructing a cloud inference evaluation model for weapons' development risks, Li Kan [4] proposed that in order to realize the risk warning for the reliability of equipment development projects, the Topsis method, the set pair analysis and evaluation method and the fuzzy evaluation method can be used to realize the analysis of the risk index of the technical indicators, the risk subset of the project management and the conditional risk. Meanwhile, the efficiency coefficient method can be used to determine the comprehensive risk of the project. Based on the "main manufacturer-supplier" synergy model, considering the dominant position of the main manufacturer, and aimed at coordinating the incentive risk control of suppliers, Li Ting [5] established an optimal excitation risk control Stackelberg model in which the main manufacturer shares the risk control input of the supplier. Wang Song [6] pointed out that the development of large-scale complex equipment mostly adopts the project group management mode. Because the risk environment is also opened at the same time, the complex interaction between sub-projects is enhanced, which makes the risk management of the development project group the key factor that restricts the success rate of project development. David B [7] proposed a cost-effective risk control measure selection model and solved the model with a greedy algorithm. Kujawski E [8] used the decision tree method to study the choice of three risk control strategies: “acceptance”, “improvement” and “delay”. SHARIFF AM [9] affirmed the importance of risk management for the success of equipment development, and advocated risk assessment in the equipment design phase to move the risk management port forward to ensure that risk indicators were effectively controlled, thus the risk management costs can be reduced and risk control benefits can be improved.

The scholars have made the following research on the milestone events of complex equipment development projects. Sun Jinyu [10] analyzed the complexity and risk characteristics of large-scale complex equipment development projects, and built a multi-level milestone cooperation developing (MMCD) network system for multi-level milestone collaborative development process, and used this as an analytical framework to explore the risk mechanism of large-scale complex equipment development project. Tao Liangyan [11] put forward the idea of guiding the whole complex equipment development process with milestones. Based on the analysis of the logical relationship among the milestones, and considering the actual process of complex equipment development, he built a complex equipment collaborative development network based on milestones. Ye Wei [12] and others analyzed the collaborative work relationship of the milestone "event tree" subsystem, and designed the corresponding network logic connection nodes to construct a multi-core distributed collaborative GERT network model for civil large aircraft quality control.

Reviewing the research on risk management of complex equipment collaborative development at home and abroad, it has obtained rich research results, which provides the basis and reference for this research, but still has the following defects:

- Most of the existing risk management researches just focus on qualitative descriptions, and only give simple measures and recommendations to reduce risk.
- The existing researches do not conduct a thorough research on the complex collaborative development relationship between the main manufacturers and suppliers, and do not take into account the complex cooperative relationships and conflicts of interest among the participating entities.
- The development of milestone events plays a very important role in the development of complex equipment. Project risk control based on the relationship between milestone events is a key issue to effectively control the overall risk level, and the existing researches aimed at this content are very scarce and need further study.

II. Analysis of Risk Occurrence Mechanism

A. *Risk Classification*

The whole life cycle risk of large complex equipment includes two aspects: one is the possibility of loss; the other is the possibility of development and production interruption. Therefore, the life cycle of large complex equipment faces great risks. According to the source of the risk of large complex equipment projects, the risks can be divided into: First, the internal risks of collaborative development activities, including: technical risks, financial risks, production risks and management risks. On the other hand, it is the external environmental risk of collaborative development activities, including: market demand risk and policy risk. Each risk has its own influencing factors, that is, each risk has its own source of risk.

B. *Stage Division of Aviation Complex Equipment Development Project*

The development process of aviation complex equipment is very complicated. Generally, it is needed to go through the project demonstration stage, feasibility study stage, plan design stage, engineering development stage, module docking test stage and flight test stage. Each stage can be subdivided into many specific tasks. For example, in the engineering development stage, it is necessary to consider the project technology, manufacturing, quality, reliability and other issues comprehensively, and make detailed product design, trial production and testing, and finally pass through the relevant departments’ examination. A schematic diagram of the development process and milestone events of a certain type of aircraft is shown in “Fig. 1”.

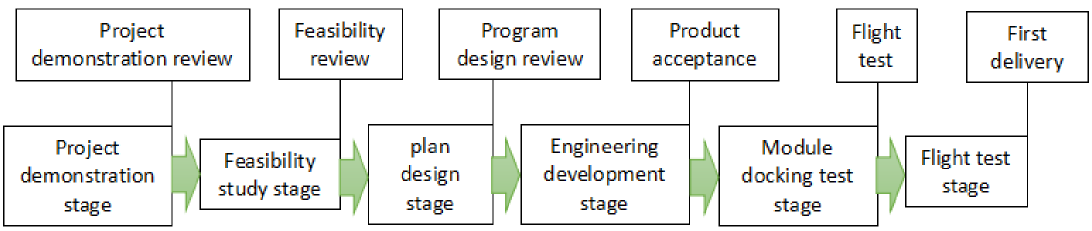

Fig. 1. Milestone events system for aviation complex equipment development process.

C. Classification of the Relationship Among Milestone Events

Due to the existence of competition, cooperation and other relationships among suppliers of complex equipment development activity in reality, there must be a significant logical connection between subsystems, which will lead to a complicated relationship between milestone events. Through our analysis, the collaborative relationships of aviation complex equipment development milestone events mainly include the following:

1) Progressive relationship: In the project, if the milestone event is realized on the basis of the realization of another milestone event, it means that there is a progressive relationship between them in the project process. For example, the first delivery milestone event must happen after the incident of gaining the airworthiness certification event.

2) Coexistence relationship: In the project, any event's completion of subsystems can trigger a milestone event. For example, the main manufacturer assigns one activity to two suppliers. If the two suppliers are treated as two subsystems, then this milestone is completed when either supplier delivers the product, then the main manufacturer can move to the next phase.

3) Complementary relationship: In the project, only after all the sub-milestone events of subsystems are realized, the events of the next stage in the project can be promoted. For example, the main manufacturer assigns two tasks to two different departments. Only when the two departments both complete the development task, the main manufacturer can carry out the next stage of work. This work relationship is called the complementary relationship.

III. Establishing the Risk Control Model

A. Relevant Hypotheses of the Model

Based on the collaborative model risk characteristics of the aviation complex equipment development process, it is need to make the following assumptions.

Hypothesis 1: There is only one main manufacturer M and one supplier S in the collaborative development process. The main manufacturer is responsible for product design, final assembly, sales, after-sales service and production of some parts. The supplier develops and supplies parts and provides related services according to the requirements of the main manufacturer.

Hypothesis 2: The input of the main manufacturer is a key variable in the final benefit function of the development activity. This paper assumes that the main manufacturer's own investment is a fixed value. The effects of other exogenous factors on the benefits are presented in the form of random variables.

Hypothesis 3: The main manufacturer gives certain incentives to the supplier's risk control, such as taking a certain proportion of its cost, and assuming that the risk preferences of the main manufacturer and supplier are neutral.

B. Relevant Parameters of the Model

r: represents the risk level of the strategic supplier, $0 \le r \le 0.3$ is the low risk; $0.3 < r \le 0.6$ is the medium risk and $0.6 < r < 1$ is the high risk.

p: the success rate of collaborative development activities, p=1-r.

x (r): the actual risk control input of the strategic supplier.

y: the resources invested by the main manufacturer on the basis of the success of the supplier's development activities, which will affect the interests of the final development activities. It is necessary to use the Cobb-Douglas production function to reflect output of the collaborative development of complex equipment, assuming: $M(y) = k \times y^{\varepsilon} + \Delta$, where k is the yield coefficient and ε is the return elasticity (assuming ε<1), Δ is another exogenous factor that affects the interests.

x_s: the additional resource inputs for optimal control of supplier's risk levels.

t: the proportional coefficient assumed by the main manufacturer for the supplier's risk control optimization input resources. The incentive degree of the main manufacturer (i.e., the commitment amount) is directly proportional to the investment of the strategic supplier, namely: $t \times x_s$.

β_i: risk sensitivity coefficient, $\frac{1}{\beta_i}$ is risk sensitivity degree. Generally, the more resources invested by suppliers, the lower the risk level, the higher the success rate of innovation, and the increasing marginal cost of suppliers' resource inputs. Therefore, it is assumed that the initial input of risk control, additional investment and risk level satisfy the following relationship: $(1+t) \cdot x_s - x = \beta_i \cdot (r_i - r_i^{'})^2$.

δ_m, δ_s: Revenue impact factors that represent the level of effort of the manufacturer and the supplier, respectively. The value of δ_m is more high, the greater the impact of the efforts of the main manufacturer on the income; similarly, the greater the δ_s, the greater the impact of the supplier's efforts on revenue.

p_m, p_s: the distribution ratio of the final interests of the main manufacturer and the strategic supplier which satisfy the following relationship: $p_m + p_s = 1$.

π_m, π_s: the expected return function of the main manufacturer and supplier before the risk control optimization.

$\pi_m(r^{'}), \pi_s(r^{'})$: the expected return function of the main manufacturer and supplier after the risk control optimization.

C. Synergy Development Risk Transfer Analysis Based on Milestone Events

In the progressive relationship, the risk transfer of the sub-event is similar to the risk transfer of the milestone event. Based on the realization of the previous sub-event, the risk of next sub-event is determined by the risk of the previous sub-event, the initial risk of the sub-event, and the risk optimization. In the coexistence relationship, as long as one or more of the sub-activities are completed, the next milestone event can be triggered, so the completed sub-event risk constitutes the risk of the milestone event and is transmitted to the next event in a progressive way. In the complementary relationship, multiple sub-activities are coordinated to facilitate the next milestone event. Therefore, the accumulated risk of multiple sub-activities constitutes the risk of the milestone event and is passed on to the next milestone in a progressive way. In order to facilitate the quantitative research, it is necessary to propose the following analysis of the model parameters:

s_t: the initial risk level of the milestone event t, t=1, 2,⋯ N.

$s_t(i)$: the initial risk level of the sub-event i of the milestone event t, t=1, 2,⋯ N, i=1,2,⋯n.

r_t: the final risk level of the milestone event t, t=1,2,⋯,N.

r_t (i): the final risk level of the sub-event i of the milestone event t, t=1,2,⋯, N, i=1,2,⋯, n.

Δr_t: optimization degree of risk control of the milestone event t, t=1,2,⋯ N.

$\Delta r_t(i)$: optimization degree of risk control of the sub-event i of the milestone event t, t=1,2,⋯ N, i=1, 2,⋯ n.

p_t: the success rate of the milestone event t, t=1,2,⋯,N.

$p_t(i)$: the success rate of the sub-event i of the milestone event t, t=1,2,⋯,N, i=1,2,⋯,n.

$p_{t/t+1}$: the success rate of the milestone event t+1 based on the success of milestone event t, t=1,2,⋯ N.

$p_{i+1/i}^t$: the success rate of the sub-event i+1 based on the success of sub-event i of the milestone event t, t=1,2,⋯,N, i=1,2,⋯ n.

K: the risk transfer coefficient of milestone events.

K_t: the sub-event's risk transfer coefficient of milestone event t, t=1, 2, ⋯ N.

x (t): the initial risk control investment from supplier of the milestone event t, t=1, 2,⋯N.

x_s (t): the risk control optimization investment form supplier of the milestone event t, t=1, 2,⋯N.

$x_s^i(t)$: the risk control optimization investment form supplier of the sub-event i of the milestone event t, t=1, 2,⋯N, i=1, 2,⋯n.

According to the above analysis, it can be derived that, under the progressive relationship, the risk transfer function of multiple sub-events is as follows:

$$r_t(i+1) = \prod_{i=1}^{n} p_{i+1/i}^t [K_t r_t(i) p_t(i) - a\Delta r_t(i) + b s_t(i)] \quad (3.1)$$

Under the coexistence relationship, the risk transfer function of multiple sub-events is as follows:

$$r_t = \underset{i=1}{\overset{n}{Min}}\{r_t(i)\}[1 - \prod_{i=1}^{n}(1 - p_t(i))] \quad (3.2)$$

Under the complementary relationship, the risk transfer function of multiple sub-events is as follows:

$$r_t = \sum_{i=1}^{n} r_t(i) p_t(i) \quad (3.3)$$

Because there is a progressive relationship between milestone events, the risk transfer function of the milestone events can be expressed as follows:

$$r_{t+1} = p_1 \prod_{i=1}^{n} p_{t+1/t}[K r_t - c\Delta r_t + d s_t] \quad (3.4)$$

D. Model Construction and Solution

In the collaborative development process of aviation complex equipment, the change of supplier's resource input will have a certain impact on the optimization degree of risk control, which will affect the income of both the main manufacturer and the supplier. This paper reflects the impact in the function that the performance of the dominant manufacturer and supplier is influenced by the supplier's resource input and its risk level.

This paper presents the expected benefit function of the main manufacturer's and the supplier's risk control optimization as:

$$\pi_m'(r) = (1 - r) \cdot [p_m \cdot M(y) - y] - t \cdot x_s \quad (3.5)$$

$$\pi_s'(r) = (1 - r) \cdot p_s \cdot M(y) - x - x_s \quad (3.6)$$

It can be seen from the above two equations that the loss of benefits of the main manufacturer and the supplier caused by the risk is:

$$J_L = \sum_{t=1}^{N} r(t)\,[M(y) - y] \quad (3.7)$$

The cost increase brought by risk control is:

$$J_C = \beta \Delta r^2(t) + x \quad (3.8)$$

Therefore, the total risk loss cost is:

$$J_N = J_L + J_C = \sum_{t=1}^{N} r(t)\,[M(y) - y] + \beta \Delta r^2(t) + x \quad (3.9)$$

Substituting equation (3.4) into equation (3.9) gives the following equation (3.10):

$$J_N = \sum_{t=1}^{N-1} r(t+1)\,[M(y) - y] + \beta \Delta r^2(t) + x$$
$$= \sum_{t=1}^{N-1}\{p_1 \prod_{t=1}^{N} p_{t+1/t}\,[K r_t - c\Delta r_t + d s_t][M(y) - y] + \beta \Delta r^2(t) + x\} \quad (3.10)$$

Considering that the initial risk of complex equipment development activities is 0, combined with formula (3.4) and formula (3.10), it can be derived that the state equation and initial conditions of the risk control optimization system of the development activity are as follows:

$$\begin{cases} r(t+1) = p_1 \prod_{t=1}^{N} p_{t+1/t}\,[K r_t - c\Delta r_t + d s_t] \\ r(0) = 0 \end{cases} \quad (3.11)$$

It can be seen that the risk control optimization process of the whole development activity is based on the above state equations. And by solving the Δr (t)=r(t)-r which takes the minimum value of the objective function formula (3.10), the value of r of each milestone can be obtained according to the different values of t, resulting in the risk optimization degree for each milestone event and the risk control input from the main manufacturer and the supplier respectively.

According to the idea of economic cybernetics, considering that the state equation is linear with respect to the state and risk optimization degree and the objective function belongs to the quadratic problem of Δr (t), so the solution of this problem is a problem of the Linear-Quadratic problem. Therefore, the solution process of this problem has a fixed mode, which can be done by software, and will not be described here.

IV. Example Analysis

For a certain type of aircraft, the main manufacturer and the supplier develop the components jointly. Considering that there are several milestone events in the development process. Due to the long period of the collaborative equipment development process and the complex milestone events, the first four milestones are selected to analyze the problem, which means N=4. In the initial state of the development activity, the initial risk level of the first milestone event is 0. According to the plan of the main manufacturer, the risk level at the end of the fourth milestone event needs to be controlled within 0.25. The values of the relevant parameters involved in the first four milestone events are shown in "Table I" below. In the collaborative development process, the relationships between the first four milestones and the sub-events are: the two sub-events of the first milestone event are coexistence relations, and the two sub-events of the second milestone event are complementary relationships, and the rest are progressive relationships.

TABLE I. Relevant Parameter Values

k=4	ε =0.3	Δ =0.8	y=1.6
N=4	r'=0.25	K=0.8	β=3
p_0=0.86	$p_{1/0}$=0.92	$p_{2/1}$=0.96	$p_{3/2}$=0.94
s_1=0.32	s_2=0.39	s_3=0.46	s_4=0.2
x_1=0.17	x_2=0.14	x_3=0.15	x_4=0.18

The objective function can be obtained from the above data:

$$J_4 = x(t) + \sum_{t=1}^{4}[3\Delta r^2(t) + 2.174r(t) - 2.717\Delta r(t) + 2.717s(t)] \quad (4.1)$$

Besides, $\Delta \mathrm{r}(4) = \frac{0.571r(3)-0.107}{0.714} = 0.80r(4) - 0.15$ (4.2)

By substituting (4.2) into (4.1), it can be derived that:

$$J_4 = 0.18 + 3\Delta r^2(4) + 2.174r(4) - 2.717\Delta r(4) + 2.717s(4)$$

$$+x(t) + \sum_{t=1}^{3}[3\Delta r^2(t) + 2.145r(t) - 2.682\Delta r(t) + 2.682s(t)]$$

$$= 1.92r^2(4) - 0.72\mathrm{r}(4) + 1.198 + x(t)$$

$$+\sum_{t=1}^{3}[3\Delta r^2(t) + 2.145r(t) - 2.682\Delta r(t) + 2.682s(t)] \quad (4.3)$$

Through calculation, the optimal risk control level and the risk control optimization degree of the first four milestone events can be obtained as follows:

For the first milestone event, the optimal risk control level r* (1) =0.216 and the risk control optimization degree Δr* (1) =0.037.

For the second milestone event, the optimal risk control level r* (2) =0.302 and the risk control optimization degree Δr* (2) =0.086.

For the third milestone event, the optimal risk control level r* (3) =0.385 and the risk control optimization degree Δr* (3) =0.097.

For the fourth milestone event, the optimal risk control level r* (4) =0.421 and the risk control optimization degree Δr* (4) =0.022.

V. Conclusion

The research and development of aviation complex equipment is a large-scale project with huge investment, long cycle and technical difficulty, and its research and development stage is complex and changeable. Therefore, it is particularly important to control the risk of the project. Through the in-depth analysis of the research and development process of aviation complex equipment, this paper identifies the milestone events that have great impacts on the research and development process, and builds the risk control optimization model based on the relationships between milestone events and its sub-events. Besides, the risk control optimization degree and the optimal risk level of each milestone event are obtained, which provides an important reference for the future research of aviation complex equipment.

Acknowledgment

This paper is financially supported by the National Natural Science Foundation of China (Grant NO. 71573115, 71774072, 71372080) and the Postgraduate Research & Practice Innovation Program of Jiangsu Province, 2018, Project No.: KYCX18_1323.

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