Risk Assessment of Aircraft R&D Project

Shouze Li[1], Jianjun Yu[2*]
1 Mechatronic School, Northwestern Polytechnical University, Xi’an
2 Industrial engineering department, South China University of Technology, Guangzhou
[*]EMAIL: yujj@scut.edu.cn

Abstract: The accurate risk analysis and assessment for the aircraft R&D project are prerequisite for scientific decision making, and they are worth researching. Based on the practice investigation and reasoning, the risk hierarchy model of the aircraft R&D project is set up and the risk judgment matrix is constructed. Accordingly combinatorial weight matrix is constructed, and various risk factors are determined. Then the fuzzy risk judgment matrix is constructed after the risk is classified for the aircraft R&D project. Finally the risk value of the aircraft R&D project is obtained by calculating and the risk grade is determined.

Keywords: Arcraft R&D project, risk, judgment matrix, combinatorial weight

I. Introduction

The Aircraft research and development project is the huge and complex system engineering. In the project, the structure is very complex, the scale is very huge, the system steps are many, and the research and development period is very long. These characteristics determine that the project affected area is broad, the fund consumption is huge, the participates are numerous, the system operation is complex, the new technology and the new craft involved are many. If the risk management isn’t paid attention to the project, some little problem from any step may reduce the aircraft performance, prolong the R&D period, increases the investment of the entire project, and also may cause the catastrophic crash, create economic loss which will be unable to recall, so the aircraft R&D project risk management should be deeply research.

2. Risk Model of Aircraft R&D Project

During aircraft research and development, project risk assessment is often faced with the complex system composed of many factors which associate, constraints and conflict each other. According to the restriction degree to the aircraft R&D project, the risk mainly is divided into several sorts: the investment surpasses the budget, the project period prolongs, the anticipated technical performance requirements cannot be met, or the management decision fault. They correspond to the cost risk, schedule risk, technical risk and management risk. If the risk is assessed by single goal (for example technology), then the objectivity can’t be ensured. Analytic Hierarchy Process is a simple method which makes the quantitative analysis to the non-quantitative event, and it is also the measure which makes the objective description to people's subjective judgment. When the analytic hierarchy process is adopted to compute the weight assignment of assessment indicator, the subjective factors can be effectively reduced.

*Corresponding author.

The aircraft R&D project risk is analyzed from the cost, the scheduling, the technology and the management, and the risk hierarchy model of the aircraft R&D project is set up as Fig.1.

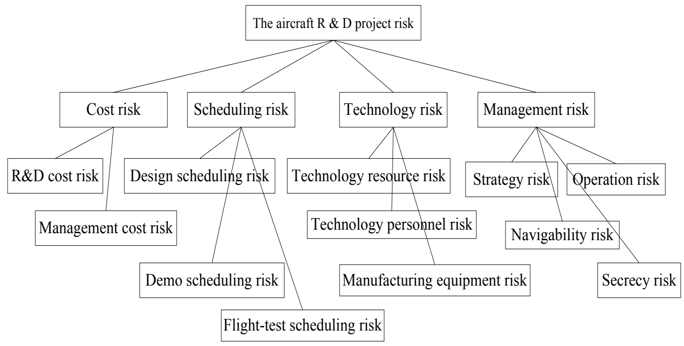

Fig.1 the risk hierarchy model of the aircraft R & D project

3. Upper Layer Judgment Matrix Construction

Based on the aircraft R&D risk hierarchy model, the factors of identical layer that belong to the identical factor of upper layer are contrasted each other to compare their importance degree for the criteria, and then they are quantified according to stipulation scale, and consequently are transferred into matrix notation, namely judgment matrix. The judgment matrix is the basic information of analytic hierarchy process, is also the important basis to compute the relative importance. Each element value in judgment matrix is usually determined with 1-9 scale that is generally obtained by expert assessment or previous (experiential) data.

Tab.1 1-9 scale

scale a_{ij}	meaning
1	The influences of $C_i$and C_j are same
3	The influences of C_i is a little stronger than C_j
5	The influences of C_i is stronger than C_j
7	The influences of C_i is obviously stronger than C_j
9	The influences of C_i is absolutely stronger than C_j
2，4，6，8	Middle between above value
1,1/2,…,1/9	Reverse

According to the above analysis, the judgment matrix A between the first layer and the second layer is constructed.

$$A=\begin{Bmatrix} 1 & 1/2 & 1/5 & 1/6 \\ 2 & 1 & 1/3 & 1/4 \\ 5 & 3 & 1 & 1/2 \\ 6 & 4 & 2 & 1 \end{Bmatrix}$$

After having the judgment matrix, calculates the relative weight in view of its criterion of each various factors in the judgment matrix. Firstly calculate the eigenvector W corresponding eigenvalue λ_{max} of judgment matrix, and then carry on normalization, finally the result is the sorting weight value of the relative importance of the factors in identical layer relative to some factor in previous level.

First calculate the product $\boldsymbol{M_i}$ of elements in each line of the judgment matrix, and then calculate the n root of M_i, $W_i^*=\sqrt[n]{M_i}$.

M_1=1/60	M_2=1/6	M_3=15/2	M_4=48
W_1^* =0.3593	W_2^* =0.6389	W_3^* =1.6549	W_4^* =2.6321

Then, carry on the standardization processes for vector $W^*=[W_1^*,W_2^*,W_3^*,W_4^*]^T$, namely $W_i=\dfrac{W_i^*}{\sum_{i=1}^{n}W_i^*}$,

consequently obtain results as follows:

W_1=0.0680，W_2=0.1209，W_3=0.3131，W_4=0.4980

$$W=[0.0680,0.1209,0.3131,0.4980]^T$$

In order to avoid the disturbance from other factors to the judgment matrix, the estimator can only carry on the cursory judgment in the actual appraisal to the judgment matrix, and sometimes will make the inconsistent mistake. In order to examine the uniformity (compatibility) of the judgment matrix, may use the difference between λ_{max} and the n to examine uniformity.

So, firstly computing the maximum characteristic value of matrix $\lambda_{\max}=\sum_{i=1}^{n}\dfrac{(AW)_i}{nW_i}$:

$$AW=\begin{Bmatrix} 1 & 1/2 & 1/5 & 1/6 \\ 2 & 1 & 1/3 & 1/4 \\ 5 & 3 & 1 & 1/2 \\ 6 & 4 & 2 & 1 \end{Bmatrix}\bullet\begin{Bmatrix} 0.0680 \\ 0.1209 \\ 0.3131 \\ 0.4980 \end{Bmatrix}=\begin{Bmatrix} 0.2741 \\ 0.4858 \\ 1.2648 \\ 2.0158 \end{Bmatrix}$$

$$\lambda_{\max}=\left(\frac{0.2741}{0.0680}+\frac{0.4858}{0.1209}+\frac{1.2648}{0.3131}+\frac{2.0158}{0.4980}\right)/4=4.0341$$

Then calculate consistency index

$$CI=\frac{\lambda_{\max}-n}{n-1}=\frac{4.0341-4}{4-1}=0.0114.$$

Then judge whether the different rank judgment matrix have satisfaction uniformity. Here may introduce the judgment matrix average stochastic consistency index RI . For 1-9 rank judgment matrixes, the RI value is as follows:

Tab. 2 *RI* value

rank	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

From Tab.2. the random index RI can obtained, namely RI=0.90, and then $CR=CI/RI$=0.0114/0.90=0.0127<0.1, therefore, this judgment matrix has satisfactory uniformity, and conforms to the consistency check.

4. Lower Layer Judgment Matrix Construction

4.1 Cost risk

Based on the aircraft R&D risk hierarchy model, the cost factors of identical layer that belong to the identical cost factor of upper layer are contrasted each other to compare their importance degree for the criteria, and then they are quantified according to stipulation scale, and consequently the cost risk judgment matrix A_1 is constructed.

$$A_1=\begin{Bmatrix} 1 & 7 \\ 1/7 & 1 \end{Bmatrix}$$

First calculates the product M_{1i} of elements in each line of the judgment matrix, and calculates the $n_1$root of M_1. $W_{1i}^*=\sqrt[n_1]{M_{1i}}$.

M_{11}=7	M_{12}=1/7
W_{11}^* =2.6458	W_{12}^* =0.3780

Then, carry out the standardization processes for vector $W_1^*=[W_{11}^*,W_{12}^*]^T$,namely $W_{1i}=\dfrac{W_{1i}^*}{\sum_{i=1}^{n_1}W_{1i}^*}$, consequently obtain results as follows:

W_{11}=0.8750，W_{12}=0.1250

$$W_1=[0.8750,0.1250]^T$$

Then calculate the maximum matrix characteristic value $\lambda_{1\max}=\sum_{i=1}^{n_1}\dfrac{(A_1W_1)_i}{n_1W_{1i}}$

$$A_1W_1=\begin{Bmatrix} 1 & 7 \\ 1/7 & 1 \end{Bmatrix}\bullet\begin{Bmatrix} 0.8750 \\ 0.1250 \end{Bmatrix}=\begin{Bmatrix} 1.75 \\ 0.25 \end{Bmatrix}$$

$$\lambda_{1\max}=\left(\frac{1.75}{0.8750}+\frac{0.25}{0.1250}\right)/2=2$$

Then calculate consistency index $CI_1=\dfrac{\lambda_{1\max}-n_1}{n_1-1}=\dfrac{2-2}{2-1}=0$

From Tab.2. the random index RI can obtained, namely RI=0.00, and then CR=CI/RI=0<0.1, therefore, this judgment matrix has satisfactory uniformity, and conforms to the consistency check.

4.2 Schedule risk

Based on the aircraft R&D risk hierarchy model, the schedule factors of identical layer that belong to the identical schedule factor of upper layer are contrasted each other to compare their importance degree for the criteria, and then they are quantified according to stipulation scale, and consequently the schedule risk judgment matrix A_2 is constructed.

$$A_2 = \begin{Bmatrix} 1 & 2 & 4 \\ 1/2 & 1 & 3 \\ 1/4 & 1/3 & 1 \end{Bmatrix}$$

First calculates the product M_{2i} of elements in each line of the judgment matrix, and calculates the $n_2$root of M_2. $W_{2i}^* = \sqrt[n_2]{M_{2i}}$.

M_{21}=8	M_{22}=1.5	M_{23}=1/12
W_{21}^*=2	W_{22}^*=1.1447	W_{23}^*=0.4368

Then, carry out the standardization processes for vector $W_2^* = [W_{21}^*, W_{22}^*, W_{23}^*]^T$,namely $W_{21} = \dfrac{W_{2i}^*}{\sum_{i=1}^{n_2} W_{2i}^*}$,

consequently obtain results as follows

W_{21}=0.5584，W_{22}=0.3196，W_{23}=0.1220

$$W_2 = [0.5584, 0.3196, 0.1220]^T$$

Then calculate the maximum matrix characteristic value $\lambda_{2\max} = \sum_{i=1}^{n_2} \dfrac{(A_2 W_2)_i}{n_2 W_{2i}}$

$$A_2 W_2 = \begin{Bmatrix} 1 & 2 & 4 \\ 1/2 & 1 & 3 \\ 1/4 & 1/3 & 1 \end{Bmatrix} \bullet \begin{Bmatrix} 0.5584 \\ 0.3196 \\ 0.1220 \end{Bmatrix} = \begin{Bmatrix} 1.6856 \\ 0.9648 \\ 0.3672 \end{Bmatrix}$$

$$\lambda_{2\max} = \left(\frac{1.6856}{0.5584} + \frac{0.9648}{0.3196} + \frac{0.3672}{0.1220} \right) / 3 = 3.0158$$

Then calculate consistency index

$$CI_2 = \frac{\lambda_{2\max} - n_2}{n_2 - 1} = \frac{3.0158 - 3}{3 - 1} = 0.0079$$

From Tab.2. the random index RI can obtained, namely RI=0.58, and then CR=CI/RI=0.0079/0.58=0.0136<0.1, therefore, this judgment matrix has satisfactory uniformity, and conforms to the consistency check.

4.3 Technology risk

Based on the aircraft R&D risk hierarchy model, the technology factors of identical layer that belong to the identical technology factor of upper layer are contrasted each other to compare their importance degree for the criteria, and then they are quantified according to stipulation scale, and consequently the technology risk judgment matrix A_3 is constructed.

$$A_3 = \begin{Bmatrix} 1 & 7 & 8 \\ 1/7 & 1 & 2 \\ 1/8 & 1/2 & 1 \end{Bmatrix}$$

First calculates the product M_{3i} of elements in each line of the judgment matrix, and calculates the $n_3$root of M_3. $W_{3i}^* = \sqrt[n_3]{M_{3i}}$.

M_{31}=56	M_{32}=2/7	M_{33}=1/16
W_{31}^*=3.8259	W_{32}^*=0.6586	W_{33}^*=0.3969

Then, carry out the standardization processes for vector $W_3^* = [W_{31}^*, W_{32}^*, W_{33}^*]^T$,namely $W_{31} = \dfrac{W_{3i}^*}{\sum_{i=1}^{n_3} W_{3i}^*}$,

consequently obtain results as follows:

W_{11}=0.8750，W_{12}=0.1250

$$W_1 = [0.8750, 0.1250]^T$$

Then calculate the maximum matrix characteristic value $\lambda_{3\max} = \sum_{i=1}^{n_3} \dfrac{(A_3 W_3)_i}{n_3 W_{3i}}$

$$A_3 W_3 = \begin{Bmatrix} 1 & 7 & 8 \\ 1/7 & 1 & 2 \\ 1/8 & 1/2 & 1 \end{Bmatrix} \bullet \begin{Bmatrix} 0.7838 \\ 0.1349 \\ 0.0813 \end{Bmatrix} = \begin{Bmatrix} 2.3785 \\ 0.4095 \\ 0.2468 \end{Bmatrix}$$

$$\lambda_{3\max} = \left(\frac{2.3785}{0.7838} + \frac{0.4095}{0.1349} + \frac{0.2468}{0.0813} \right) / 3 = 3.0353$$

Then calculate consistency index

$$CI_3 = \frac{\lambda_{3\max} - n_3}{n_3 - 1} = \frac{3.0353 - 3}{3 - 1} = 0.0177$$

From Tab.2. the random index RI can obtained, namely RI=0.58, and then CR=CI/RI=0.0177/0.58=0.031<0.1, therefore, this judgment matrix has satisfactory uniformity, and conforms to the consistency check.

4.4 Management risk

Based on the aircraft R&D risk hierarchy model, the management factors of identical layer that belong to the identical management factor of upper layer are contrasted each other to compare their importance degree for the criteria, and then they are quantified according to stipulation scale, and consequently the management risk judgment matrix A_4 is constructed.

$$A_4 = \begin{Bmatrix} 1 & 5 & 7 & 3 \\ 1/5 & 1 & 2 & 1/2 \\ 1/7 & 1/2 & 1 & 1/4 \\ 1/3 & 2 & 4 & 1 \end{Bmatrix}$$

First calculates the product M_{4i} of elements in each line of the judgment matrix, and calculates the $n_4$root of M_4. $W_{4i}^* = \sqrt[n_4]{M_{4i}}$.

M_{41}=105	M_{42}=0.2	M_{43}=1/56	M_{44}=8/3
W_{41}^*=3.2011	W_{42}^*=0.6687	W_{43}^*=0.3656	W_{44}^*=1.2779

Then, carry out the standardization processes for vector $W_4^* = [W_{41}^*, W_{42}^*, W_{43}^*, W_{44}^*]^T$,namely $W_{41} = \frac{W_{4i}^*}{\sum_{i=1}^{n_4} W_{4i}^*}$,

consequently obtain results as follows:

W_{41}=0.5806，W_{42}=0.1213，W_{43}=0.0663，W_{44}=0.2318

$$W_4 = [0.5806, 0.1213, 0.0663, 0.2318]^T$$

Then calculate the maximum matrix characteristic value $\lambda_{4\max} = \sum_{i=1}^{n_4} \frac{(A_4 W_4)_i}{n_4 W_{4i}}$

$$A_4 W_4 = \begin{Bmatrix} 1 & 5 & 7 & 3 \\ 1/5 & 1 & 2 & 1/2 \\ 1/7 & 1/2 & 1 & 1/4 \\ 1/3 & 2 & 4 & 1 \end{Bmatrix} \bullet \begin{Bmatrix} 0.5806 \\ 0.1213 \\ 0.0663 \\ 0.2318 \end{Bmatrix} = \begin{Bmatrix} 2.3466 \\ 0.4859 \\ 0.2679 \\ 0.9331 \end{Bmatrix}$$

$$\lambda_{4\max} = \left(\frac{2.3466}{0.5806} + \frac{0.4859}{0.1213} + \frac{0.2679}{0.0663} + \frac{0.9331}{0.2318} \right) / 4 = 4.0284$$

Then calculate consistency index $CI_4 = \frac{\lambda_{4\max} - n_4}{n_4 - 1} = \frac{4.0284 - 4}{4 - 1} = 0.009$

From Tab.2. the random index *RI* can obtained, namely *RI*=0.90, and then *CR*=*CI*/*RI*=0.009/0.90=0.01<0.1, therefore, this judgment matrix has satisfactory uniformity, and conforms to the consistency check.

5. Combination Weight Computation

Based on above computation results, the combination weight matrix ***U*** is constructed:

$$U = \begin{Bmatrix} 0.8750 & & & \\ 0.1250 & & & \\ & 0.5584 & & \\ & 0.3196 & & \\ & 0.1220 & & \\ & & 0.7838 & \\ & & 0.1349 & \\ & & 0.0813 & \\ & & & 0.5806 \\ & & & 0.1213 \\ & & & 0.0663 \\ & & & 0.2318 \end{Bmatrix} \bullet \begin{Bmatrix} 0.0680 \\ 0.1209 \\ 0.3131 \\ 0.4980 \end{Bmatrix} = \begin{Bmatrix} 0.0595 \\ 0.0085 \\ 0.0675 \\ 0.0386 \\ 0.0147 \\ 0.2454 \\ 0.0422 \\ 0.0255 \\ 0.2891 \\ 0.0604 \\ 0.0330 \\ 0.1154 \end{Bmatrix}$$

According to the combination weight matrix, the various risk factor weight can obtained as Tab. 3.

Tab.3 the various risk factor weight

criteria			index	
	factor	weight	Risk factor	Combinatorial weight
Project risk	cost factor	0.0680	R&D cost	0.0595
			Management cost	0.0085
	schedule factor	0.1209	Design schedule	0.0675
			Demo schedule	0.0386
			Flight-test schedule	0.0147
	technology factor	0.3131	Technology resource	0.2454
			Technology personal	0.0422
			Manufacturing equipment	0.0255
	manage factor	0.4980	strategy	0.2891
			navigability	0.0604
			secrecy	0.0330
			operation	0.1154

According to computation results, it's appearing that management risk is first important which is worth paying attention to. The management risk weight is 0.4980 which is near to half. Technology risk is second important which is 0.3131. Schedule risk is third important which is 0.1209. Last is cost risk which is 0.0680.

Based on Tab.3, strategy risk is primary and central. Obviously, for the aircraft R&D project, to make the scientific strategy is very important. If strategy decision fault, then it's impossible for the entire R&D project to succeed. In addition, the technological personnel is the second risk factor. Because aircraft R&D is to do new attempt and experiment, and need to break through many key technologies difficulties, it has very strong challenging. Accordingly, whether the project succeed depends on the correlation technique reserve to a great extent.

6. Fuzzy Judgment Matrix Determination

The assessment set is a language description for various layers of assessment index, and it is the set of the comments that are given by appraiser to each assessment index. The goal of the aircraft R & D project's risk investigation is to determine the risk grade. The model's evaluation is divides into five ranks. The comment set is as follows:

V =(V1 ,V 2 ,V 3 ,V 4, V5)= {low， a little lot， moderate， a little high， high}

That's, divides the risk into five ranks, namely low risk, a little low risk, medium risk, a little high risk, high risk. Their risk value scopes are as follows.

[0， 0.2]，[0.2,0.4]，[0.4,0.6]，[0.6,0.8]，[0.8,1]

The table survey method is adopted to collect the data. The expert gives the risk grade value of various factors relative to the assessment set, namely judges each risk factor the risk subordination grade by the surveyor's experience or the data. Some result is obtained after the expert assessment and the normalization.

Tab.4 the expert assessment result

criteria			index		Assessment set				
	factor	weight	Risk factor	weight	V_1	V_2	V_3	V_4	V_5
Project management	Cost factor	0.0680	R&D cost	0.0595	0.1	0.3	0.4	0.1	0.1
			Management cost	0.0085	0.1	0.2	0.3	0.3	0.1
	Schedule factor	0.1209	Design schedule	0.0675	0.1	0.1	0.2	0.3	0.3
			Demo schedule	0.0386	0.1	0.3	0.3	0.2	0.1
			Flight-test schedule	0.0147	0.2	0.4	0.2	0.1	0.1
	Technology factor	0.3131	Technology resource	0.2454	0.1	0.1	0.2	0.5	0.1
			Technology personnel	0.0422	0.1	0.1	0.4	0.3	0.1
			Manufacturing equipment	0.0255	0.2	0.2	0.4	0.1	0.1
	Management factor	0.4980	strategy	0.2891	0.1	0.1	0.3	0.4	0.1
			navigability	0.0604	0.1	0.1	0.3	0.3	0.2
			secrecy	0.0330	0.1	0.3	0.2	0.3	0.1
			operation	0.1154	0.1	0.2	0.3	0.3	0.1

The subjection vector matrix R of the project risk can be obtained from Tab.4. According to the fuzzy synthetic evaluation model's method, calculate the risk degree of membership matrix of this project, namely, $S = U^T R$ =(0.0608, 0.1073, 0.2766， 0.3541, 0.0862). We can see from the result of vector matrix S, 0.3541 is the biggest in 5 numbers, it subordinates in the low risk. Hence, this project risk is in the a little low level.

7. Conclusion

The aircraft R&D project is a systems engineering, whether it will success is affected by many factors and the project is followed by the risks from beginning to end, so to carry on the accurate analysis and assessment to the relative risk is the premise of decision making. In the paper, the aircraft R&D project risk hierarchy model is built, and the aircraft R&D project judgment matrix is constructed. The combinatorial weight matrix is constructed, and each risk factor's weight is determined. The aircraft R&D risk is graded, and the fuzzy judgment matrix is built. The aircraft R&D project risk value is determined through the computation. However, many other uncertainty factors may also affected the aircraft R&D project, only some typical factors are selected to analyze in the paper. What' more, these data in the paper are don't accord to the fact in view of the secrecy. In the practical work, the actual conditions and facts need be considered to analyze and assessment the aircraft R&D project risks and other methods might also be considered to carry on the project decision-making. In order to reflect the real situation of the aircraft R&D project risk as far as possible, thus provided the basis for the macro-scientific decision-making, more researches need to be done.

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Background of Authors

Shouze Li doctor candidate research interest includes project management, advanced manufacturing and supply chain management.

Jianjun Yu Ph.D. research interest includes production scheduling and algorithms.