Technical Risk Evaluation on Equipment Development Based on Risk Conduction

Bo Yuan[1], Ying Wang [1], Xue Yang [2], Yong Si [3]

1.School of Equipment Management and Safety Engineering College,Air Force Engineering University, Xi'an, Shaanxi, 710038;

2. Military Representative Bureau of Air Force in Beijing, Beijing, 100009;

3. Air Force Equipment Academy, Beijng,100076.

Keywords: Risk conduction, combination weighing approach,TOPSIS method, technical risk, risk evaluation.

Abstract. After overall consideration of both the static and dynamic influence factors of technical risk, establish technical risk evaluation metric system for equipment development, then perform quantitative evaluation on various technical risk factors by using combination weighing approach and TOPSIS method, and carry out instance analysis of technical risk evaluation on the development of a certain equipment to verify such method.

1 Introduction

Major equipment development is characterized by large high-tech content, high cost, long development period, high level involved and wide influence area, hence high risk. As the principal risk of major equipment development, technical risk almost exists in the whole process and serves as the key factor of causing cost risk, schedule risk and performance risk. This paper aims to extract the dynamic and static metrics of technical risk evaluation, gain the comprehensive weight of evaluation metric through combination weighing approach and rank the membership of technical risk factors with improved TOPSIS method, so as to find out the risk factors requiring key control.

2 Technical Risk Evaluation on Equipment Development

2.1 Technical risk conduction

Technical factor serves as the motivation of technical risk conduction and directly influences the distance of technical risk transmission and the final loss incurred. Technical risk factor will be propagated via conduction carrier if it cannot be timely and effectively controlled or resolved. In the process of technical risk transimission, particle movement exists in conduction carrier, which can both reduce and enlarge technical risks. Coupling of multiple technical risks during conduction will enhance the capacity of technical risk and cause risk catastrophe just like an amplifier, thus finally leading to technical risk event, as shown below:

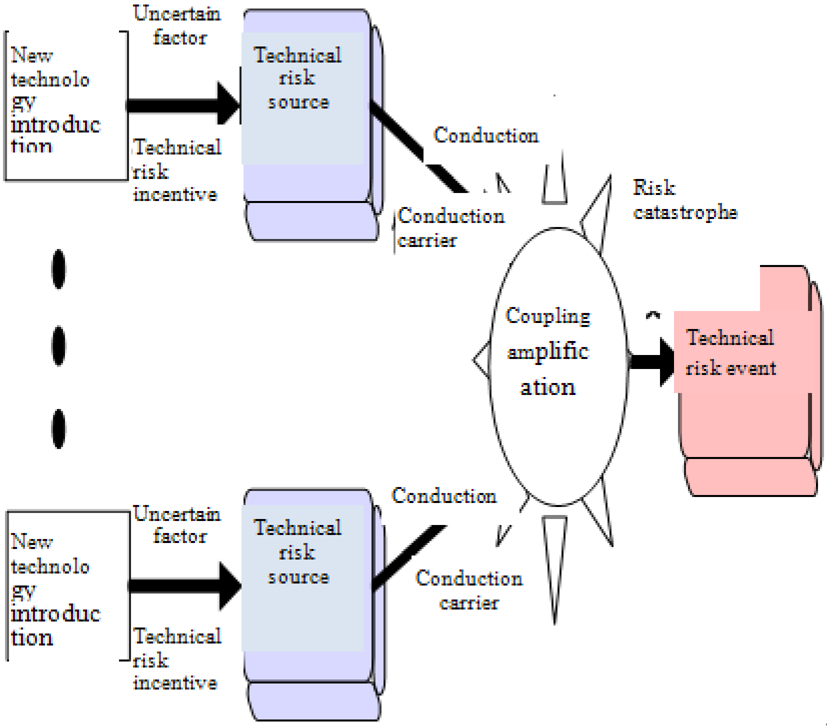

Figure 1 Diagram of Technical Risk Conduction

2.2 Risk evaluation overview

Technical risk evaluation of equipment development refers to the process of comprehensively analyzing technical risk and performing quantization and ranking based on the possibility of technical risk and impact on objectives of development project. Technical risk evaluation is to estimate the risk probability and possible loss based on comprehensive identification and classification of various technical risks to find out the key risk factors and paths and ascertain the overall technical risk level of development project, thus providing scientific basis for technical risk control.

Purposes of technical risk evaluation [1][3]:

1. Perform comparative analysis and comprehensive evaluation on all technical risks of development project to determine their priorities;

2. Find out the association among technical risks of project;

3. Comprehensively consider the conditions for mutual transformation of risk factors of different attributes and ascertain the objective basis of technical risk disposal of the project;

4. Conduct quantitative research on technical risk of the project and further quantize the probability of occurrence and consequence of identified technical risks, to reduce the uncertainty in probability and consequence estimation and offer basis and strategy for subsequent technical risk supervision.

2.3 Evaluation system construction

The Reference [2] provides such metrics as technical maturity, technical complexity, technical advancement and technical standardization, with the metric grade given in Lines 1, 2, 3 and 4 of Table 1. Relatively low technical maturity, great complexity, high advancement and low standardization of the new technology adopted will definitely produce risk factors of different attributes, thus generating risk source.

Once the technology is implanted into equipment, guarantee will be certainly a problem. It requires effective guarantee for whether continuous tactical and technical metric can be maintained for equipment and guarantee needs consideration during equipment development, so technical guarantee metric is introduced. Poor guarantee will indirectly cause equipment risk in service stage.

Technical compatibility and node correlation represents the conduction path length and carrier risk conductivity during technical risk conduction, and favourable technical compatibility can reduce the technical risk in development. However, close node correlation will strengthen and accelerate technical risk conduction, so large supervision weight shall be given during metric weight determination.

Risk tolerance represents the tolerance level of development process towards risk. Risk tolerance is in direct proportion to risk critical value of development link, thus difficult to cause risk accident.

Ten evaluation metrics of technical risk of equipment development project can be obtained by combining related references and technical risk conduction rules, viz.: technical maturity, technical complexity, technical advancement and technical standardization, technical guarantee, technical compatibility, node correlation, risk tolerance, technical economy and technical reliability, as shown in the table below:

Table 1 Grading of Technical Risk Evaluation Metrics

Conduction metric		0.1	0.3	0.5	0.7	0.9
Representing conduction risk source	Technical maturity	Passing industrial production	Passing small batch production	With model machine manufactured	Passing lab stage	In lab stage
	Technical complexity	Presenting slight complexity	Presenting certain complexity	Presenting large complexity	Presenting obvious complexity	Presenting great complexity
	Technical advancement	Advancement within the military	Domestic advancement	Filling up domestic blank	Internationally advanced	International initiative
	Technical standardization	Up to international standards	Up to national standards	Upon to professional standard	Up to military standard	Self-made standard
	Technical guarantee	Completely guaranteed by existing resources	Well guaranteed by existing resources	Guaranteed by existing resources	Generally guaranteed by existing resource	Hardly guaranteed by existing resources
Representing conduction path length and risk conductivity	Technical compatibility	Completely compatible with other subsystems	Well compatible with other subsystems	Compatible with other subsystems	Generally compatible with other subsystems	Poorly compatible with other subsystems
	Node correlation	No node correlation	Little node correlation	Ordinary node correlation	Close node correlation	Extra close node correlation
Risk critical value	Risk tolerance	Extra high node risk tolerance	Relatively high node risk tolerance	Ordinary node risk tolerance	Low node risk tolerance	No node risk tolerance
Incurring cost risk	Technical economy	Favorable economy and within the cost budget	Good economy and not exceeding 5% of estimated cost	Ordinary economy and not exceeding 5%-10% of estimated cost	Poor economy and exceeding 10%-20% of estimated cost	Extremely poor economy and exceeding 20%-40% of estimated cost
Incurring schedule risk	Technical reliability	Favorable reliability and within the estimated budget	Good reliability and not exceeding 5% of estimated cost	Ordinary reliability and not exceeding 5%-10% of estimated cost	Poor reliability and exceeding 10%-20% of estimated cost	Extremely poor reliability and exceeding 20%-40% of estimated cost
Those with qualitative language description between the above two shall have assignment of 0,0.2,0.4,0.6,0.8.						

2.4 Comprehensive weight determination of metrics based on comprehensive weight principle

Weight determination method is mainly classified into subjective weight evaluation and objective evaluation. The former means the expert makes subjective judgment to get metric weight according to experiences; while the latter refers to determining weight for comprehensive evaluation based on correlativity of metrics or variable coefficient of metrics. Integrated weight method can help to obtain more scientific and rational weight calculation result [5] by giving consideration to both subjective and objective influence factors, therefore it is adopted to solve

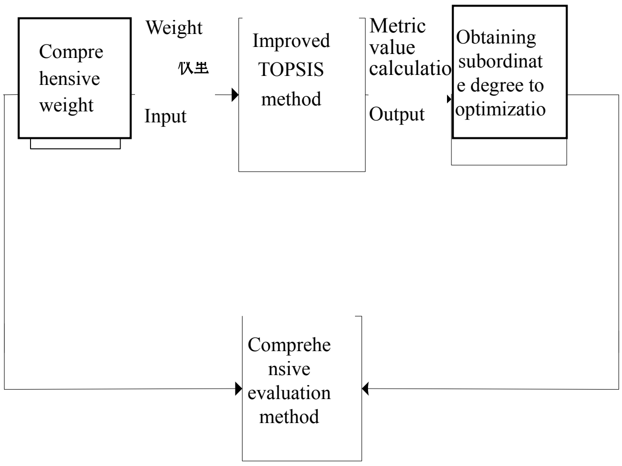

Figure 2 Comprehensive Evaluation Method Based on Comprehensive Weight and Improved TOPSIS Method

Comprehensive weight of metric can be determined by the following steps after the evaluation metric system of technical risk of equipment development project is determined:

Step 1: determine subjective weight via AHP weighting method.

Expert determines the subjective weight $W_j^{'}$ of evaluation metric via AHP weight method by combining equipment development rules and technical risk conduction rules, to obtain $0 \le W_j^{'} \le 1, \sum_{j=1}^{n} W_j^{'} = 1, j = 1, 2, \ldots, n$.

Step 2: determine objective weight via entropy weighting method.

Entropy is a concept of thermodynamics, which is introduced into information theory by C.E.Shannon in 1948, who uses information entropy to measure system state chaos or disorder. Shannon defines a formula to measure the information quantity “generated” by discrete information source [7]:

$$H_j = -K \sum_{i=1}^{m} f_{ij} \ln f_{ij}$$

$$f_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

Where, H_j is the entropy of No. j metric. The greater H_j is, the larger information quantity included in No. j metric of No. m scheme will be, and vice versa. f_{ij} represents the weight of Scheme i under Class j risk degree, K refers to Boltzmann constant, $K > 0$, and there is $K = \frac{1}{\ln m}$ under general conditions.

Entropy weight formula of Class j technical risk is [6]:

$$w_j^{"} = \frac{g_j}{\sum_{j=1}^{n} g_j} = \frac{1-H_j}{n-\sum_{j=1}^{n} H_j}$$

Where: g_j is difference coefficient.

$$\sum_{j=1}^{n} W_j^{"} = 1, 0 \le W_j^{"} \le 1; j = 1,2,...,n$$

Step 3: determine the optimal subjective and objective weights $\overline{\alpha}^*$ and $\overline{\beta}^*$

The optimal value of α and β can be calculated through the formula below: $\overline{\alpha}^*$ and $\overline{\beta}^*$.

$$\overline{\alpha}^* = \sum_{i=1}^{m}\sum_{j=1}^{n} y_{ij} W_j^{'} / \sum_{i=1}^{m}\sum_{j=1}^{n} y_{ij}(W_j^{'} + W_j^{"})$$

$$\overline{\beta}^* = \sum_{i=1}^{m}\sum_{j=1}^{n} y_{ij} W_j^{"} / \sum_{i=1}^{m}\sum_{j=1}^{n} y_{ij}(W_j^{'} + W_j^{"})$$

Step 4**:** calculate comprehensive weight W_j

Substitute the subjective weight $W_j^{'}$ and objective weight $W_j^{"}$ obtained by the above calculation into the formula $W_j = \alpha W_j^{'} + \beta W_j^{"}$ to acquire the comprehensive weight: $W_j = \overline{\alpha}^* W_j^{'} + \overline{\beta}^* W_j^{"}$.

Step 5: calculate normalized matrix

Substitute comprehensive weight W into standard matrix Y to acquire the normalized attribute matrix:

$$B = (b_{ij}), \quad b_{ij} = y_{ij}(\overline{\alpha}^* W_j^{'} + \overline{\beta}^* W_j^{"})$$

TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution), also called double base points method, is a common method of solving multi-attribute decision problem. In multi-objective decision, ideal point refers to the vector composed by maximum assessment value of each metric and negative ideal point refers to the vector composed by minimum assessment value of each metric[8]. As technical risk belongs to cost-type metric, the scheme with low subordinate degree to optimization shall be adopted to ensure the minimum technical risk after the subordinate degree to optimization of all schemes in evaluation is calculated.

Step 6: adopt Euclidean distance to calculate the distance d_i^+ of all risks to ideal point p^+ and the distance d_i^- to negative ideal point p^-.

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(b_{ij} - p_j^+)^2}, i = 1,2,...,m$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(b_{ij} - p_j^-)^2}, i = 1,2,...,m$$

At present, relative Euclidean distance is adopted in most references to calculate the subordinate degree to optimization u_i of various technical risks:

$$u_i = \frac{1}{1 + d_i^+ / d_i^-}, i = 1, 2, ..., m$$

When the scheme close to ideal point is also close to negative ideal point, ranking of schemes according to relative Euclidean distance cannot completely reflect the superiority and inferiority of all schemes. In order to effectively avoid the above problems, the distance from sample point to ideal point and negative ideal point is comprehensively considered and traditional relative Euclidean distance is substituted by the project distance[8] of the connection between the two reference points: ideal point and negative ideal point.

Step 7: calculate the subordinate degree to optimization ρ_i of all technical risk schemes based on projection distance:

$$\rho_i = \frac{\sum_{j=1}^{n} (b_{ij} - p_j^-)(p_j^+ - p_j^-)}{\sqrt{\sum_{i=1}^{m} (d_i^+ - d_i^-)^2}}$$

Rank according to the value of ρ_i. The smaller ρ_i value is, the smaller technical risk will be, thus the optimal scheme.

3 Algorithm Instance

Adopt the above technical risk evaluation system established and evaluation mode based on comprehensive weight and improved TOPSIS method to perform quantitative evaluation on technical risk of a certain equipment project. There are five technical risk schemes presently, i.e. A, B, C, D and E, and the eight technical risk evaluation metrics are evaluated, namely, technical maturity (S_1), technical complexity (S_2), technical advancement (S_3) and technical standardization (S_4), technical guarantee (S_5), node correlation (S_6), risk tolerance (S_7) and technical economy (S_8). The original data sheet as shown in Table 2 is obtained through questionnaire and in combination with grading standard of Table 1 and 0-1 scoring method of expert. The subjective weight of metric is obtained via AHP method, given in Line 7 of Table 3; objective weight is calculated by entropy weighting method, as shown in Line 9 of Table 3. Through calculation, we can acquire $\overline{\alpha}^*$ =0.5352 and $\overline{\beta}^*$ =04648, and further calculate the comprehensive weight of all metrics, as shown in Line 10 of Table 3.

Table 2 Original Data

Evaluation metric / Scheme	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
A	0.53	0.23	0.63	0.61	0.23	0.16	0.26	0.55
B	0.41	0.39	0.59	0.73	0.31	0.20	0.19	0.63
C	0.59	0.42	0.48	0.59	0.25	0.10	0.36	0.51
D	0.32	0.26	0.61	0.65	0.34	0.32	0.23	0.47
E	0.45	0.38	0.52	0.70	0.30	0.26	0.16	0.60

Table 3 Standardized Data and Weight

Evaluation metric / Scheme	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
A	0.2915	0.8660	0.1000	0.1383	0.8660	1.0000	0.8085	0.2532
B	0.6333	0.6666	0.3334	0.1000	0.8000	0.9834	1.0000	0.2667
C	0.1000	0.4122	0.3021	0.1000	0.7245	1.0000	0.5225	0.2470
D	0.8071	0.9357	0.1857	0.1000	0.7643	0.8071	1.0000	0.4857
E	0.5167	0.6333	0.4000	0.1000	0.7666	0.8333	1.0000	0.2667
AHP weight	0.2000	0.1800	0.1600	0.1400	0.1000	0.0800	0.0800	0.0600
Entropy	0.8990	0.9773	0.9430	0.9940	0.9988	0.9972	0.9839	0.9751
Entropy weight	0.4359	0.0980	0.2460	0.0259	0.0052	0.0121	0.0695	0.1075
Comprehensive weight	0.3096	0.1419	0.2000	0.0870	0.0559	0.0484	0.0751	0.0821

Table 4 Normalized Data and Double-base Point

Evaluation metric / Scheme	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
A	0.0902	0.1229	0.0200	0.0120	0.0484	0.0484	0.0607	0.0208
B	0.1961	0.0946	0.0667	0.0087	0.0447	0.0476	0.0751	0.0219
C	0.0310	0.0585	0.0604	0.0087	0.0405	0.0484	0.0392	0.0203
D	0.2499	0.1328	0.0371	0.0087	0.0427	0.0391	0.0751	0.0399
E	0.1600	0.0899	0.0800	0.0087	0.0429	0.0403	0.0751	0.0219
Positive ideal point	0.2499	0.1328	0.0667	0.0120	0.0484	0.0484	0.0751	0.0399
Negative ideal point	0.0301	0.0585	0.0200	0.0087	0.0405	0.0391	0.0392	0.0203

Normalized data and double-base point table as shown in Table 4 can be obtained from calculation of normalized matrix and positive & negative ideal points, with the result of d_i^+, d_i^-, u_i and ρ_i shown in Table 5. It can be learnt from the ranking result that technical risk scheme D has the highest score, 0.7507, and technical risk scheme C has the lowest score, 0.1471, therefore the superiority of the five technical schemes are: C>A>E>B>D.

Table 5 Result of Comprehensive Evaluation on Technical Risk of Five Schemes

Scheme	d_i^+	d_i^-	u_i	ρ_i	Ranking
A	0.1684	0.0916	0.35	0.4353	2
B	0.0686	0.1801	0.72	0.6542	4
C	0.2350	0.0415	0.15	0.1474	1
D	0.0317	0.2362	0.885	0.7507	5

E	0.1026	0.1509	0.59	0.5922	3

Evaluation result in the table indicates obvious comparison and differences between the subordinate degree to optimization ρ_i calculated by improved TOPSIS method and that u_i calculated previously, which is convenient for clearly choosing the best scheme. The instance brings about the conclusion that key control shall be thrown on technical risk scheme D which may have close correlation with other risks and serves as the important risk conduction source of triggering risk conduction and coupling and causing research failure.

4 Summary

This paper is devoted to exploring a quantitative evaluation method of solving technical risk in equipment development based on technical risk conduction. First, define technical risk evaluation of equipment development and ascertain the evaluation purpose. Second, on the basis of considering dynamic features of technical risks triggered by risk conduction, put forward the ten metrics of evaluating technical risks of equipment development, namely, technical maturity, technical complexity, technical advancement and technical standardization, technical guarantee, technical compatibility, node correlation, risk tolerance, technical economy, and technical reliability. Technical maturity, technical complexity, technical advancement and technical standardization are the hazard source of triggering technical risk conduction; technical compatibility and node correlation represent the conduction path length and carrier risk conductivity during technical risk conduction; and risk tolerance represents the tolerance level of development process toward risk. Last, acquire the comprehensive weight of evaluation metrics via comprehensive weight method and rank the subjection degree of technical risk factors by improved TOPSIS method, to find out the risk factors requiring key control.

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