Space safety emergency prevention research

Chen Wang[a], Yongping Wang[b*], Yanhe Wen[c]

Space engineering university, Beijing, 101400, China

[a]502457296@qq.com, [b*]980463501@qq.com, [c]807769385@qq.com

Abstract. With the development and utilization of space, the probability of space safety emergencies is increasing, and the study of the prevention of space security emergencies is needed to safeguard space security and prevent the occurrence of various space security emergencies. This paper introduces the analysis model of the space safety emergency mechanism, designs an evaluation indicator system, builds a weighting calculation model of the "Starlink" based on the mechanism of space safety emergency, and analyzes the risk assessment method of a space safety emergency. The cross-analysis of different risks was used to divide the accidents, and the main work of prevention of space safety emergencies was carried out.

Keywords: Space safety; emergency prevention; risk assessment

1 Introduction

Space security emergencies are sudden events that require space access and personnel, space access and use activities, space development rights, other countries that are affected by space, and the ability to ensure space's sustainable security, or may cause threats and damage, and need to take emergency measures to respond to emergencies. As the world's development and utilization activities of space continue to extend, the natural and human factors of space security are increasing, and the probability of a space security emergency is getting higher and higher. At present, the research on emergency prevention is gradually further, but the space safety emergencies and their prevention research are still blank, and the lack of scientific methods is a way to guide the prevention of space security emergencies. This leads to effective prevention and prevention in the face of various kinds of space security emergencies.

At present, there are many research methods for sudden events. Cui et al. [1] put forward that the calculation method of aviation safety and the numerical value is proposed to reflect the safety level of aviation. Chen et al. [2] build the fault tree model of fire accidents, and the structural importance of the basic events in the fault tree is analyzed by the Boolean rule, and the prevention of fire accidents in the subway is provided with new ideas and theories. Based on the real demand for space security, this paper studies the prevention of space safety emergencies by using the risk assessment method and the cross-analysis method.

X. Ding et al. (eds.), *Proceedings of the 2023 4th International Conference on Big Data and Social Sciences (ICBDSS 2023)*, Atlantis Highlights in Social Sciences, Education and Humanities 12,
https://doi.org/10.2991/978-94-6463-276-7_46

2 Analysis model of space safety emergency mechanism

The production and development of space safety emergencies are the results of multiple internal and external factors, and in the research of existing disaster theory, disasters are the result of the combination of the disaster environment, the disaster factor, and the disaster body[3-4]. In the course of the development of disasters, the participation of human emergency management can lead to changes in the state of the emergency, which may prevent the occurrence of emergencies or make emergencies in a more serious direction. Therefore, in the analysis of the mechanism of space safety emergency, the "control factor" representative should be introduced as the intervention factor. A space safety emergency was described in the case of the disaster environment, the disaster factor, the disaster body, and the control factor [5].

The disaster factor is the main body of the space security emergency. For example, solar activities, physical environments in space, various cosmic rays, meteorites, comets, space debris, atmospheric environment, geographical environment, geographical location, and human space competition and technical management.

The disaster body is the object of the space safety emergency. For example, space assets such as spacecraft systems, ground infrastructure, space information links, space resources such as space orbit resources, space-frequency resources, and space resources, as well as astronauts, technicians, and relevant people affected by space activities.

The disaster environment is the external environment of the disaster factor and the disaster body, and the different environments of the same disaster factor and body cause completely different consequences. The condition of the pregnancy disaster is mainly manifested in the land environment, marine environment, air environment, atmospheric environment, and space environment.

The control factor is a measure to reduce the loss of events. All measures taken by people in the process of space safety emergency management will affect the final direction of the event.

The emergence and development of space safety emergencies is the process of the effect of the disaster factors in a given one in a single pregnancy environment, which is used in the process of the interaction of the disaster body, as shown in Figure 1.

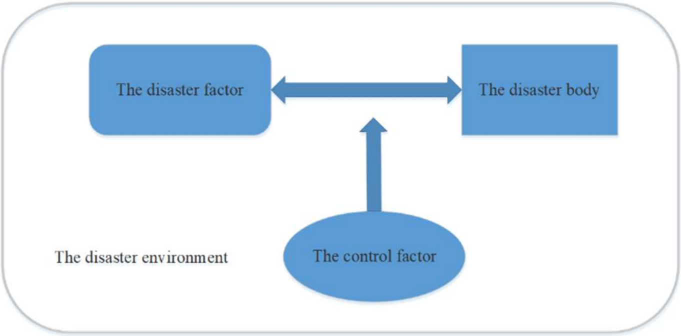

Fig. 1. Mechanism description of space safety emergency

3 Method of risk assessment

Comprehensive use of risk assessment method to study the risk of space safety emergencies needs to design the evaluation indicator system and construct the weighted calculation model. This helps to quantify the possibility and severity of risk, providing more reliable support for the prevention of space security emergency managers in space security emergencies.

3.1 Design evaluation indicator system

According to the mechanism of space safety emergency and the evolution process, the evaluation indicator system of the disaster factor, the control factor, the disaster environment, and the disaster body is transformed into the actual risk assessment process. The indicator system mainly sets the possibility(p) and severity(c) as primary indicators, and according to the characteristics of different emergency risks, the two primary indicators are detailed and classified, the secondary and tertiary indicators are set, and the complete evaluation indicator system is established.

There is an example of the indicators of the US Space X company's "Starlink" satellite security emergency risk. On February 3, 2022, 49 "Starlink" satellites took off in the "falcon-9" rocket. According to the launch program, all satellites first entered the 210-kilometer book of the lowland sphere, waiting for "initial system inspection" to restart the electric propeller movement to rise to 540 kilometers. On February 4, however, a small magnetic storm at the G1 level had been launched, and air resistance increased by 50% compared with previous launches. For this, SpaceX has set the satellite as a "safety model", turning the satellite into fly edge-on mode to minimize air resistance and effectively avoid the magnetic storm. But the strategy did not work, and the increased resistance makes the satellite leave the safety model, leading to the inability of multiple satellites to rise. According to subsequent data, this group of 49 "Starlink" satellites eventually had 38 falling atmospheres burning the body [6].

In the aspect of the disaster factor, the sun activity indicator is set up; in the aspect of the disaster environment, the space environment and atmospheric environment indicators are set up; in the aspect of the control factor, pre-preparation, process disposal, and post-disaster management indicators are set up; in the aspect of the disaster body, the result indicator is set up. The seven secondary indicators were classified by two levels of probability and severity, and there were several three levels of indicators under each secondary indicator. These seven secondary indicators include the necessary factors in the "Starlink" satellite security emergency, as shown in Figure 2.

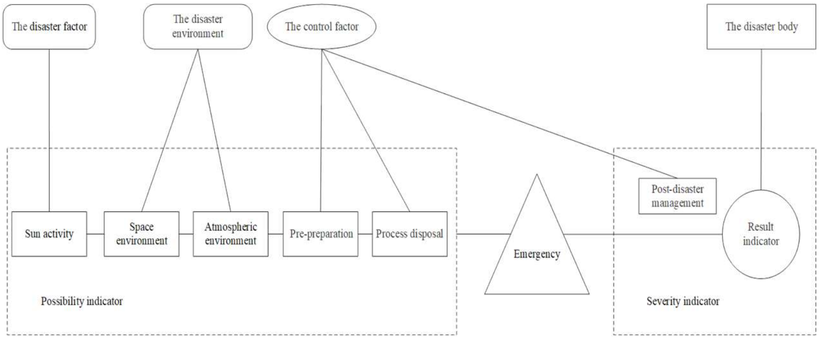

Fig. 2. A schematic diagram of the "Starlink" event based on the mechanism of space safety emergency

Under each secondary indicator, the actual situation of the case of a satellite safety emergency event is set up, and several three levels are set, and the target settings are shown in Table 1.

Table 1. Indicators of satellite safety emergency risk of Starlink

Primary indicator	Secondary indicator	Tertiary indicator
Possibility indicator	1. Sun activity	1.1. Variation of geomagnetic perturbation indicator
		1.2. Changes in the solar radiation indicator
	2. Space environment	2.1. The effect of the vacuum environment
		2.2. The effect of a neutral atmosphere
		2.3. The effect of plasma
		2.4. The effect of the radiation environment
		2.5. The effect of meteorites and space debris
	3. Atmospheric environment	3.1. Changes in atmospheric density
		3.2. Atmospheric temperature changes
		3.3. Is there extreme weather
	4. Pre-preparation	4.1. Whether the weather status forecast is accurate
		4.2. Whether the spatial disaster level forecast is accurate
		4.3. The "Starlink" satellite's hall effect is sufficient
		4.4. Is the satellite itself a technical flaw
	5. Process disposal	5.1. The spatial environment model is accurate
		5.2. The station's atmospheric density test is accurate
		5.3. Whether the atmospheric density inversion is accurate

		5.4. The reliability of the satellite safety model
		5.5. SpaceX company's technology
Severity indicator	6. Post-disaster management	6.1. Whether to set up contingency plans
		6.2. Do emergency exercises
		6.3. Management and technical personnel's emergency handling ability
	7. Result indicator	7.1. Will there be a derivative accident
		7.2. The amount of property loss caused
		7.3. Will there be casualties
		7.4. Will it cause space pollution

3.2 Build the weighting model

This paper uses the analytic hierarchy method to determine the weights of each secondary indicator and the tertiary indicator [7].

$$\mathrm{P} = \sum_{i=1}^{n} T_i W_i = \sum_{i=1}^{n} (\sum_{j=1}^{m_i} Y_{ij}\, W_{ij})\, W_i \tag{1}$$

In the formula:

P-evaluate the calculated value of the object risk probability;

n- the secondary indicator number;

T_i-the secondary indicator scores of items i;

W_i-the secondary indicator weight of item i;

m_i-the tertiary indicator number under the secondary indicator of item i;

Y_{ij}-the tertiary indicator scores of item j under the secondary indicator of item i;

W_{ij}-the tertiary indicator weight of item j under the secondary indicator of item i.

And the same thing, we're going to compute the c. After calculating the weight, the risk level is evaluated by building the risk judgment matrix. The risk judgment matrix is a qualitative risk assessment analysis method that can comprehensively evaluate the possibility and severity of danger[8], as shown in Table 2.

Table 2. Risk decision matrix

Possibility	Severity			
	Level I	Level II	Level III	Level IV
A	I A (Major risk)	II A (Major risk)	III A (Greater risk)	IV A (General risk)
B	I B (Major risk)	II B (Major risk)	III B (Greater risk)	IV B (General risk)
C	I C (Major risk)	II C (Greater risk)	III C (General risk)	IV C (Low risk)
D	I D (Greater risk)	II D (General risk)	III D (General risk)	IV D (Low risk)
E	I E (General risk)	II E (General risk)	III E (General risk)	IV E (Low risk)

3.3 Application of risk assessment method

Since human space activities, all kinds of space safety emergencies have been common. In combination with the actual analysis of space activities, space security emergencies can be divided into eight categories, which are security emergencies, ground infrastructure security emergencies, space information link security emergencies, space orbit safety emergencies, space-frequency safety emergencies, space mining safety emergencies, training test safety emergencies, and space access and safety emergencies. In response to the risk of these emergencies, the chain of the mechanism of each risk and the corresponding secondary and tertiary indicators are established. The risk assessment method can be applied to all kinds of space safety emergencies.

The specific method of assessment is by establishing the system of risk assessment indicators of various events and according to the case, characteristics, and expert experience, the indicator weight and scoring are determined by the weight calculation model. Refer to the risk probability and severity classification standard comparison table, and determine the corresponding relationship between the grade and the two values, as shown in Table 3. The risk level of the event is obtained by the risk decision matrix in Table 3, which is shown in Figure 3.

Table 3. Classification criteria for risk probability and severity

Probability level	A	B	C	D	E
P value	(8,10]	(6,8]	(4,6]	(2,4]	[0,2]
Severity level	Level I	Level II		Level III	Level IV
C value	(9,12]	(6,9]		(3,6]	[0,3]

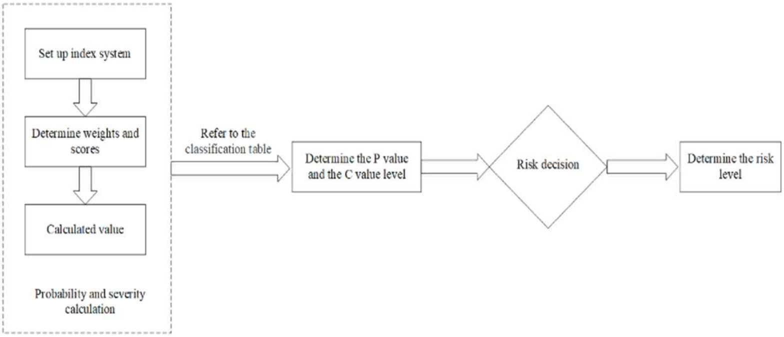

Fig. 3. Risk assessment method application flow chart

The following is an assessment of the risks that the "Starlink" satellite may face during orbit operation. The possibility indicators it faces are mainly divided into three categories, namely the changes in the space environment caused by solar activity, the accuracy of predicting atmospheric density changes, and the potential problems of satellite propulsion systems themselves. The secondary indicators "space environment" in Table 1 all have long-term impacts and can be overcome through the surface materials of the stars, so the weight factor is small. The atmospheric environment is directly related to solar activity, so the weight of the "atmospheric environment" item and the "solar activity" item should be equal. However, currently, humans cannot accurately predict solar activity, so items related to forecasting should be given higher scores. When a satellite is in a harsh space environment, it can only rely on its own propulsion system to overcome adverse effects, and the reliability of the satellite should be strictly tested before launch. Therefore, in the indicators for the problem of the satellite itself, high scores and low weights should be considered. In the calculation of C-value, the possibility of major accidents is relatively low, but the harm is relatively serious, which should be a high score and low weight item. The emergency plan and emergency response capability determine whether accidents can be avoided, which is a high score and high weight item.

Explanation is given for the 1.1 and 1.2 indicators in the third level, as shown in Figure 4, which shows the solar index (F10.7 and F10.7a), geomagnetic index (Ap), and GRACE-A satellite orbital atmospheric density values for the years 2003 and 2007. From the graph, it can be seen that there is an approximate positive correlation between solar activity and geomagnetic activity, and the atmospheric density undergoes a lagged change under its influence. In addition, the variation range of the solar index is 0-250, meaning that the score for item 1.1 is 0-250 points, while the variation range of the geomagnetic index is 0-200, meaning that the score for item 1.2 is 0-200 points. But before calculating the weights, it is necessary to normalize them so that their P-values are all within the range of 0-10.

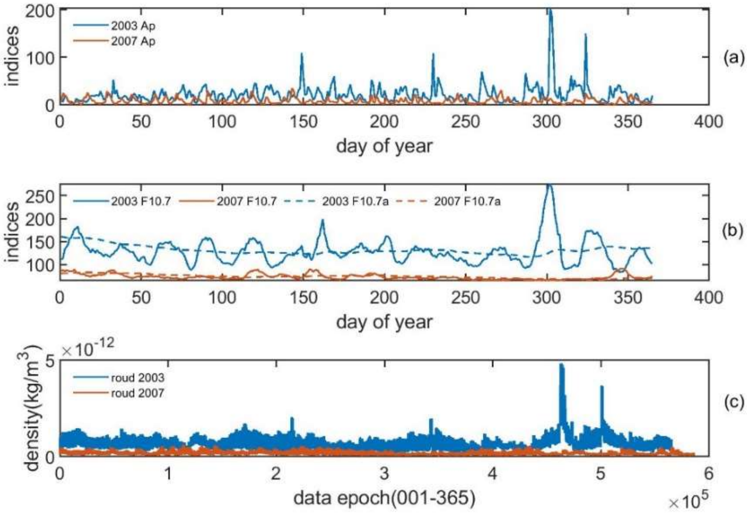

Fig. 4. Space Environment Index and Atmospheric Density Along the Orbit of GRACE-A Satellite

Table 4. Risk indicator weight score setting during the geomagnetic storm period of the "Starlink" satellite

Tertiary indicator	Y_{ij}	W_{ij}
1.1. Variation of geomagnetic perturbation indicator	9.95	0.1
1.2. Changes in the solar radiation indicator	10	0.1
2.1. The effect of the vacuum environment	1	0.03
2.2. The effect of a neutral atmosphere	1	0.03
2.3. The effect of plasma	1	0.03
2.4. The effect of the radiation environment	1	0.03
2.5. The effect of meteorites and space debris	1	0.03
3.1. Changes in atmospheric density	9.95	0.1
3.2. Atmospheric temperature changes	10	0.1
3.3. Is there extreme weather	10	0.1
4.1. Whether the weather status forecast is accurate	4	0.05
4.2. Whether the spatial disaster level forecast is accurate	4	0.05
4.3. The "Starlink" satellite's hall effect is sufficient	5	0.025
4.4. Is the satellite itself a technical flaw	5	0.025
5.1. The spatial environment model is accurate	5	0.05
5.2. The station's atmospheric density test is accurate	5	0.05
5.3. Whether the atmospheric density inversion is accurate	5	0.05
5.4. The reliability of the satellite safety model	8	0.025
5.5. SpaceX company's technology	2	0.025
6.1. Whether to set up contingency plans	8	0.2
6.2. Do emergency exercises	8	0.2
6.3. Management and technical personnel's emergency handling ability	8	0.2
7.1. Will there be a derivative accident	5	0.1
7.2. The amount of property loss caused	8	0.1
7.3. Will there be casualties	0	0.1
7.4. Will it cause space pollution	5	0.1

In summary, using the same analysis method for other three level indicators, the corresponding scores and weights for each sub indicator can be obtained. After weighted calculation, the corresponding risk judgment matrix can be obtained. For simplicity, the weights of each three-level indicator are shown in Table 4, and due to the lack of specific technical details of satellite links, the reliability indicators of the satellite are assumed values. In addition, according to the normalized scores during the 2003 Halloween geomagnetic storm given in Table 4, due to accurate environmental index predictions and normal satellite propulsion systems, the final P-value is 6.79. Due to the absence of derivative accidents and casualties, the final C-value is 6.6. During geomagnetic storms, the "Starlink" satellite faces a significant II B level risk, and it is necessary to improve space weather forecasting capabilities and establish emergency plans and conduct emergency drills to reduce the risk level.

4 The space safety emergency prevention

Good precautions can prevent the disease from being in the bud, and nip the space security emergency in the bud. In all kinds of space activities, we should establish and improve the risk assessment method, by using the cross-analysis method, the prevention measures of the different risk levels are formulated, and the prevention of space safety emergencies is emphasized, to coordinate the prevention of space safety emergency management forces.

4.1 Develop emergency prevention measures

For all kinds of space security emergencies, we need to organize experts in space and develop practical precautions. Combined with the risk assessment results, the use of space safety emergency cross-analysis method is used to partition the possible region according to different risk levels [9], as shown in Figure 5.

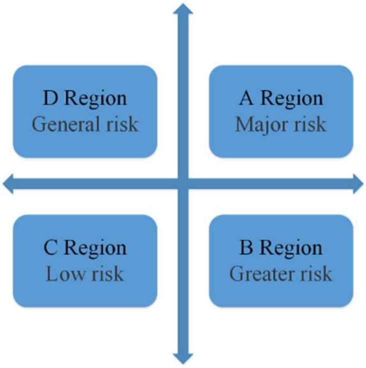

Fig. 5. The cross-analysis of space safety emergency

The A region represents space safety emergencies with significant risks, indicating a high probability and severity. This requires the great attention of space safety emergency management departments, and timely measures must be taken to control and mitigate the threat caused by emergencies.

The B region represents a large risk of space safety emergencies, which indicates that the occurrence of the possibility and severity is low. This requires constant readiness for disposal through enhanced daily training and exercise.

The C region represents a low-risk space safety emergency, which indicates that the occurrence of the occurrence is small and the severity is low. This only needs to be disposed of as it occurs, and no targeted measures are taken on a day-to-day basis.

The D region represents a space safety emergency that has general risks, which are small and serious. This requires strengthening space safety emergency management preparedness activities at the overall level, doing a good job in planning, exercise, training and team building, and striving to prevent and properly deal with it in advance.

4.2 Improve the emergency prevention procedures

In the course of the prevention of space security emergencies, the paper analyzes the common characteristics of space security emergencies, combined with the analysis model of the space safety emergency mechanism, and combines the risk assessment method and the cross-analysis method to improve the emergency prevention procedure.

General procedure for the prevention of space security emergencies: first, the evaluation indicator system is established for all kinds of single events; then, according to the risk assessment method introduced in the previous article, the risk assessment of the event is made scientifically, and the risk level of the event is determined according to the risk assessment results; then, the cross analysis determines the division of the event; according to different event region, corresponding preventive measures are taken; finally, the problems in the prevention work are summarized, and the system of the indicator is improved and improved, the specific process is shown in Figure 6.

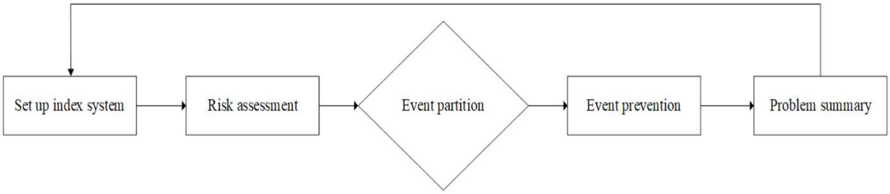

Fig. 6. General procedure for emergency prevention

4.3 Improve the ability of emergency prevention

Space safety emergency prevention is an important aspect of the prevention of space security emergencies. The prevention of emergencies requires the following: First, we will develop an emergency prevention plan to strengthen emergency prevention drills for prevention measures. Second, we will establish a system, mechanism, and legal system for the prevention of emergency events, and ensure that emergencies are clear, and the process is smooth and legal. Third, we will improve the system of risk assessment and the comprehensive risk assessment indicator system in combination with emergencies. Fourth, we will strengthen the personnel team and establish a professional space safety emergency prevention team. Fifth, we will accelerate the development of the prevention and management information platform, assist in the prevention of command work, assist in the dispatch of the command, and the recovery of the evaluation.

5 Conclusion

In this paper, the model of the analysis mechanism, the design risk assessment indicator system, and the establishment of the weight calculation model is established, and the setting of the risk secondary indicator and the three-level indicators of the event risk is introduced, and the application of the risk assessment method is introduced, and the method of the risk assessment of space security emergency is described. In this paper, the main work of prevention of space security emergencies is proposed by using the cross-analysis method.

This paper establishes a risk matrix by studying the possibility and severity of space security emergencies, which can reflect the comprehensive and special characteristics of different events. However, there are several limitations in the study: one is that the target setting is based on the analysis of the case analysis, whether it fully contains the factors of the various aspects of the incident, and the further study; Second, there is a lack of authoritative data support, and the risk of risk and severity classification may have a certain deviation. Third, there is a lot of work on space safety emergencies, which only deals with major work.

Therefore, in future research, we need to improve the following aspects: one is the systematic and detailed research on the various factors of the production and development of space security emergencies, and set more reasonable secondary and tertiary indicators, making the process of risk assessment more accurate. Second, we will collect authoritative data, give the weights and points of the weight analysis model more scientific and reasonable, and be more accurate and accurate in the probability and severity of the risk. Third, we will improve the prevention of space security emergencies and improve the prevention of space security emergencies in more ways.

References

1. Cui Lijie, Chen Haoran, Ren Bo, Zhang Jiakui. The method of quantitative analysis of aviation insecurity in the mixture of uncertainty conditions[J]. Journal of national science and technology university,2022,42(02):92-97.
2. Chen Huiyang, Mou Ruifang, Sha Minghua. Research on the safety hazard of subway operation based on major emergencies[J]. Transportation Engineering and information journal,2017,15(04):120-126.
3. Shi Peijun. On the theory and practice of disaster research[J]. Natural disaster journal,1996,11(4):6-17.
4. Li Baojun, Yuan Yi, Zou Ming, et al. Progress and countermeasures of China natural disaster emergency management research[J]. Natural disaster journal, 2004, (3):18-23.
5. Wang Yao, Li Jimei. Research and application of risk assessment method based on sudden event mechanism analysis[J]. Safety, 2019, 40(07):24-28.
6. Luo Bingxian, Wang Ronglan, Liu Wei, Yan Ruidong, Ren Tingling, Ren Shuyi, Liu Siqing, Lei Jiuhou. The “Starlink” satellite is destroyed in the spatial environment analysis of geomagnetic storm events[J]. International Space, 2022(05):35-39.
7. Zhuang Suofa. A comprehensive evaluation model based on hierarchical analysis[J]. Journal of Hefei Industrial University (Natural Science), 2000, 23(4):582-585.
8. Xu Xin, Hua Weijin, Wu Huiqing, et al. Comprehensive risk assessment technology research based on HAZOP and QRA[C]. Beijing: Chemical industry risk analysis and risk control exchange seminar, 2015.
9. Xiong Kanghao. Research on the basic problems of civil aviation emergencies[J]. Traffic management, 2018, 33(01):88-91.