Hazards Taxonomy and Identification Methods in Civil Aviation Risk Management

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Abstract. The SMS requirements and implementation of ICAO, FAA, Transport Canada, EASA, CAAC, etc. are summarized, and the problems existing in the definition, classification and identification method of hazards put forward by ICAO, SMICG, ECAST, CAAC and FAA are analyzed. Based on the analysis to the definitions of system safety and safety attributes, the definition of system elements is put forward. Then, the hazard taxonomy is set up, which are procedure, responsibility, personnel, and equipment, supervision and inspection, operation environment and effect. Meanwhile, the secondary taxonomy is given. According to the established hazard taxonomy, three hazard identification methods are set up, which are system and job analysis, unsafe events analysis and safety information statistical analysis. For each method, applicable objects, working process and application example are given respectively. The hazard taxonomy and identification methods have been put into practice in a number of service providers in China, the results show that the taxonomy and identification methods have highly practicability.

Keywords: Hazard · Hazard taxonomy · Hazard identification method · Risk management · SMS

1 Introduction

1.1 The Current SMS Implementation

In recent years, with the rapid development of world's air transport industry and aviation industry, the current focus is on improving the level of safety management and preventing serious unsafe events.

Now, service providers from every state are implementing the Safety Management System (SMS). The main elements include safety management policy, safety management organization, safety management responsibility, safety management procedures and standards, etc., and in which the key works are safety risk management, safety information management and safety education. Finally, a positive safety culture is built in the organization, and then reduces the risk of operation.

ICAO. In order to maintain and improve safety in civil aviation, International Civil Aviation Organization (ICAO) developed a new annex to safety management (Annex 19) [1]. Annex 19 requires the implementation of a SMS in civil aviation serves providers and a State Safety Programme (SSP) in Contracting States.

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Annex 19 specifies the framework of a SMS. The framework contains four components and twelve elements as the minimum requirements for SMS implementation, in which the safety risk management is the core component of SMS.

Risk management comprises three elements, which are hazard identification, safety risk assessment and mitigation. Risk management differs from previous methods of safety management and is a proactive safety management method based on the safety data. It is not taking measures after the accident or incident, but identifying hazards and controlling associate risk in advance, so as to prevent the serious unsafe event.

Currently, most contracting states of ICAO have established the SMS requirements to service provider respectively, such as the United States, Canada, European Union, China, Australia, England, etc.

FAA. Federal Aviation Administration (FAA) issued the "Safety Management Systems for Aviation Service Providers" (AC 120-92B) [2]. This advisory circular (AC) provides information that air carriers are required to implement SMS. At same time, FAA issued the "Introduction to Safety Management Systems (SMS) for Airport Operators" (AC 150/5200-37) [3]. This AC introduces the concept of SMS for airport operators.

In order to promote SMS implementation smoothly in airports, from 2006 to 2011 FAA carried out two stage pilot [4] of airport SMS construction. In 2006, FAA selected 26 airports to participate the first stage pilot, and in 2008 the number is 9 in the second stage pilot. Parts of airports participating in the pilot developed their own SMS Manual and implementation plan. Through the pilot FAA gathered information on practice and experience of how to implement SMS in airports.

In 2009, FAA conducted a SMS implementation study for airports. The aim of the study is to gain the procedures and methods of how airports implement the SMS throughout their own operational environment. 14 airports those had participated in the first or second stage pilot were involved in the study. Based on the study, FAA developed the draft of "Safety Management Systems for Airports" (AC 150/5200-37A) [5]. The AC provided detailed guidance to develop and implement SMS on an airport and explained how to develop a proactive way to identify and control potential hazards in a systematically way.

Transport Canada. Canada belongs to the states those implement SMS earlier. Canada has released a large number of rules and guidance aiming at promoting SMS construction. The rules and guidance [6] comprise "Introduction to Safety Management Systems" (TP 13739), "Guidance on safety management systems development" (AC 107-002), "Safety Management Systems for Small Aviation Operations - A Practical Guide to Implementation" (TP 14135), "Implementation procedures for airport operators" (AC 300-002), "Implementation procedures guide for air operators and approved maintenance organizations" (TP 14343) and "Implementation procedures for air traffic services operations" (AC 800-001). At the same time, Canada has taken a lot of measures to SMS construction of service provides.

EASA. European Aviation Safety Agency(EASA)has issued the SMS requirements [7] to flight, cabin crew and air operations in the form of Regulation. The European Commercial Aviation Safety Team (ECAST), the European Helicopter Safety Team

(EHEST) and the International Helicopter Safety Team (IHST) who are the components of the European Strategic Safety Initiative (ESSI), have published some materials and toolkits aiming at promoting the best practices of SMS.

- **Air operators**-Commission Regulation (EU) defined the SMS organization and technical requirements for air operators. The requirements will apply to all operators who are required to hold an AOC/organization certificate under the new EU rules.
- **Airports**-EU has published the “Authority, Organization and Operations Requirements for Aerodromes” with Regulation (EC) No 139/2014. The rules required that airport operators shall implement and maintain a SMS.
- **ATM**-The “Common requirements for the provision of air navigation services” Regulation (EC) No 1035/2011 published by EU mandated Air Traffic Management providers to have a SMS and Quality Management System (QMS). At same time, the management systems of safety, security and quality are required to be integrated.

CAAC. Civil Aviation Administration of China (CAAC) [8] began the SMS construction in 2005. The SMS pilots in Hainan airlines, Hunan airport and Nanjing airport were carried out successively. On the basis of the SMS pilots, the SMS requirements for each type of service provider were issued, which include:

- **Aviation Operators**-“SMS Requirements on Aviation Operators” (AC-121/135-FS-2008-26)
- **Airports**-“Civil Airport Operation Safety Management” (CCAR-140) and “Guidelines for Airport SMS Development” (AC-139/140-CA-2008-1)
- **ATC Providers**-“Guiding Manual for Civil Aviation ATM SMS Development V3” (MD-TM-2011-001) and “Guidance for Civil Aviation ATM SMS Audit” (AP-83-TM-2011-02)
- **Maintenance Organizations**-“SMS of Maintenance Organizations” (AC-145-15)
- **Aviation Security Units**-“Guidelines for Aviation Security Management System (SEMS) Implementation” (AC-SB-2009-1)

CAAC is developing the SMS requirements to Aircraft Manufacturers and General Aviation.

Up to the end of 2016, the SMS of all the Aviation Operators, Airports, ATC Providers, Maintenance Organizations and Aviation Security Units in China have been certificated by CAAC. In order to promote the quality and performance of SMS, CAAC is carrying out the SMS performance oversight to the above service providers through the toolkit of SMS audit. The toolkit is based on a computer server and associate pad clients. The check list contained in this toolkit includes more than 300 check items which covers all the SMS elements from document, responsibility, staff, implement to effect. In the past six years, CAAC has used the toolkit to carry out the SMS audits to more than 30 service providers. At the same time, from 2014 to 2016 CAAC has been carrying out safety performance management pilots in 13 service providers which include aviation operators and airports, which aimed at that SMS can be really in place and play a role.

Others. Meanwhile, Civil Aviation Authority (CAA) [9] and Australian Civil Aviation Safety Authority(CASA) [10] have also done a lot of work to promote service providers to develop SMS. Some Organizations have carried out more research work on SMS, such as EUROCONTROL [11], Flight Safety Foundation (FSF) [12] and Safety Management International Collaboration Group (SMICG) [13], etc.

1.2 The Current Hazards Definition, Classification and Identification

Risk management is the core component of the SMS, which is the key role of transforming safety management from passive to active. As Fig. 1, through the process of hazard identification, risk evaluation and risk control, risk management takes the initiative to find the hazards in operational, and then the risk mitigation measures are taken beforehand. The ultimate goal is to reduce the risk of system operation and prevent the occurrence of accidents or incidents.

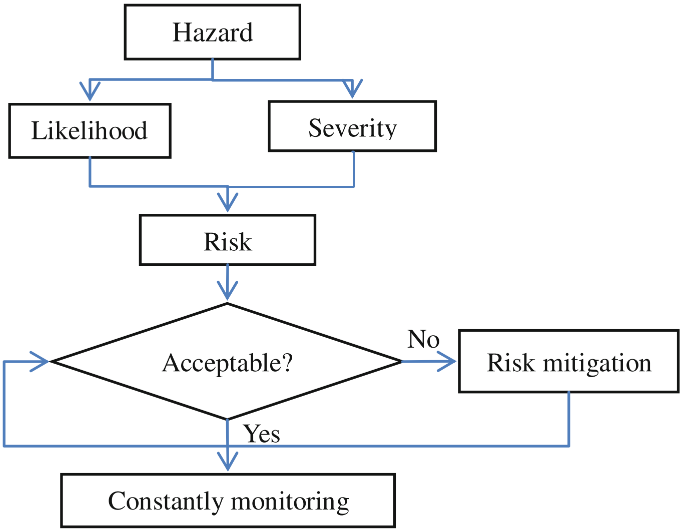

Fig. 1. Risk management process

Hazards identification is first process of risk management. At present, some organizations have carried out some research on the definition and classification of hazards, such as ICAO, SMICG, ESSI, etc.

ICAO. In the second edition of Safety Management Manual (SMM) (Doc 9859) [14], ICAO defined the hazard as a condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function. ICAO also pointed that it is not reasonable to confuse hazards with their consequences. In this situation, the hazard reflects its consequences rather than the hazard itself.

In the Doc 9859 V2, Hazards are divided into three groups, which are natural hazards, technical hazards and economic hazards.

- **Natural hazards** are the consequences of the environment within which operations take place. Examples are adverse weather conditions, geographical conditions, environmental events, public health events, etc.
- **Technical hazards** are the results of energy sources or safety-critical functions. Examples are deficiencies of aircraft, facilities and related equipment, etc.
- **Economic hazards** are the consequences of the socio-political environment within which operations take place. Examples are the growth and recession of economic and the cost of material or equipment.

It also discussed that the scope of hazards in aviation is wide. The factors should be looked into in hazard identification include design, procedures and operating practices, communications, personnel, organizational, work environment, regulatory oversight, defenses, human performance, etc.

There is no further information about the definition and taxonomy of hazard in the third edition of Safety Management Manual (SMM) (Doc 9859) [15]. But it emphasized the importance of distinguish the hazards and their consequences or outcomes.

SMICG. Safety Management International Collaboration Group (SMICG) [16] defined the hazard as a condition that could cause or contribute to an aircraft incident or accident. Based on this definition, the following high level hazard taxonomy was established:

- **Organizational-**Management, documentation, processes and procedures.
- **Environmental-**Weather and wildlife.
- **Human**-Limitation of the human which has the potential for causing harm.
- **Technical-**Aerodrome, Air Navigation, Operator, Maintenance, Design and Manufacturing.

Based on taxonomy, examples of hazards to every category were given.

ECAST. ECAST [17] defined the hazard as a condition, object, activity or event with the potential of causing injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function. ECAST grouped hazards into five families. They are natural, technical, economic, ergonomic and organizational, among which organizational was divided into airport, ground handler, aircraft operator, ANSP, maintenance organization. Examples of hazards were given to every category.

After that, ECAST provided some information about the tools and techniques of hazards identification, such as brainstorm, hazard and operability study (HAZOPS), checklist, failure modes and effects analysis (FMEA), structured what-if (SWIFT), dynamic models, future hazards identification through FAST method, etc. But the introduction is simple and not enough to guide the actual work of hazard identification.

CAAC. In the “SMS Requirements on Aviation Operators” (AC-121/135-FS-2008-26) CAAC given the definition of hazards, that is any existing or potential condition may cause personnel injury, illness or death, or system, equipment or property damage, or environmental damage. But there was no specific and clear category and identification method of hazard.

In terms of hazard classification, service providers in China basically group hazards through the following three ways at present.

- There is no specific hazards category. Hazards are listed one by one, other than in form of category. Only the number statistics can be conducted to hazards, there is no way to carry out the statistics on category, and the common, multiple hazards cannot be identified.
- Hazards are classified in accordance to the business process. First, operation system is divided into subsystems, primary processes and the secondary processes, etc. Then, hazards belong to every processes are identified. The advantage of this method is that it can identify the hazards existing in each business process, but cannot carry out the statistics and management to common hazards in the scope of whole organization.
- Hazards are classified in according to the SHEL model or the man-machine-environmental-management model. Through these models hazards can be classified, but these taxonomies are oversimplified and lack of a more detailed secondary classification standards. For example, the staff is not divided into more detailed classification standard, such as number, qualification, ability and fatigue, etc. It results in more difficult in hazards identification and statistical analysis later.

On the other hand, service providers identify hazards mainly in some subjective ways, such as brainstorm and experience discussion, etc. There is not some clear and scientific methods to insure the comprehensiveness and accuracy of hazard identification.

FAA. In the Safety Assurance System (SAS) [18] FAA defined the hazard as a condition that could foreseeably cause or contribute to an aircraft accident. Meanwhile, FAA Air Traffic Organization [19] defined the hazard as any real or potential condition that can cause injury, illness or death to people; damage or loss to system, equipment, property or environment. FAA ATO given some methods to identify hazard, which are comparative safety assessment, failure model and effect analysis, job task analysis, scenario analysis and what-if analysis, etc. But there is only sample description to these methods, and no detailed implementation procedures.

1.3 The Problems in Hazards Identification

Although there are some hazard definitions and taxonomies, the definitions are not clear enough, the taxonomies are lack of operability and do not cover all types of hazards. And they are lack of adequate guiding significance to the risk management of service providers. In terms of hazards identification, there are some introductions of methods, but they are not detailed and clear enough to guide services providers to identify hazards.

There are also some problems in service provider's daily hazard identification.

- Due to the lack of clear definition and taxonomy of hazard, there is no unified standard for hazards currently. Some service providers take a seriously unsafe event as a hazard, such as runway excursion, etc. Some service providers take a process unsafely event as a hazard, such as human error, equipment failure, etc. Inaccurate hazards identification affects the subsequent hazards assessment and risk control seriously.

- Because of the lack of scientific and feasible methods for hazards identification, many service providers cannot identify all the hazards in civil aviation operation comprehensively, which influence the effect of risk management.

Based on the above problems, in order to improve effectiveness and actual effect of hazards identification, it is necessary to establish a set of comprehensive hazards taxonomy. At the same time, it is needed to establish some scientific and practical methods of hazard identification to ensure the comprehensiveness and effective of hazards identification. This paper focuses on the establishment of the hazards taxonomy and identification methods.

2 Set Up Hazard Taxonomy

2.1 Put Forward the Definition of System Element

In the Safety Assurance System (SAS) [18] FAA defines the system safety as the application of special technical and managerial skills to identify, analyze, assess, and control hazards and risks associated with a complete system.

At same time, FAA put forward the concept of safety attributes, which are the qualities of a system that should be present in a well-designed certificate holder system and process. The safety attributes are:

1. Responsibility—a clearly documented person who is accountable for a process.
2. Authority—a clearly documented person who has the authority to manage a process.
3. Procedures—the methods which are used to accomplish a particular process.
4. Controls—checks and restraints aiming to ensure a desired result.
5. Process Measures—validate a process and identify problems or potential problems, and then correct them.
6. Interfaces—interactions between different processes and units.

Based on the concepts of system safety and safety attributes, the definition of system elements is put forward. System elements are the necessary factors to assure organization function will be achieved. The organization function will be not achieved or achieved partially if all or some system elements are absent. Based on this concept, in the area of civil aviation safety if we want to assure the operation safety, firstly there should be a set of detailed regulations and procedures to tell employees what and how to do. Then, the responsibilities should be allocated to tell employees who to do. At same time, the organization should make sure that there are enough and qualified persons to do the job though recruitment and training. In order to accomplish the organization function, necessary hardware and software should be equipped. After that, what is most important is that employees do the job according to the rules; in order to achieve this supervision is essential. Environment factor should be taken into account in the whole operation process. At last, what we do not want to face is that all the above elements are there but the effect is not accomplished. So, achieve the desired effect is the most impartment.

According to the above ideas, the system elements may contain procedure, responsibility, personnel, implementation, facility, supervision, environment and effect. Only these elements all be there every organization function can be come true.

2.2 Set Up the Hazard Taxonomy

Based on the concept of system safety, safety attributes and system elements above, the hazard taxonomy is put forward, which includes procedure, responsibility, personnel,

Table 1. Hazard taxonomy

First-level taxonomy	Explanation	Secondary taxonomy
1. Procedure	The detailed content, process and standard of operation should be documented.	• Safety policy • Procedure • Standard
2. Responsibility	The safety responsibility should be documented, and the safety personnel should be authorized.	• Responsibility assignment • Rationality of responsibility
3. Personnel.	The abundant, qualified and health personnel should be equipped with, in order to implement system operation.	• Number • Ability • Qualification • Psychological factor • Physical factor • Physical limit • Fatigue • Pressure
4. Implementation	Personnel should implement system operation according to the established procedures and standards.	• Violation • Error • Human-computer interaction • Team cooperation
5. Facility	There should be abundant tools that satisfy the requirement of working and are regular maintained and calibrated.	• Software • Hardware
6. Supervision	The first line operation should be supervised to ensure that all the operations are in accordance with established procedures, responsibilities and standards.	• Mechanism • Inspector • Implement • Effect
7. Environment	The environment factors that influence the safety operation should be considered.	• Working environment • Natural environment • Social environment • Airspace environment
8. Effect	The actual effect of system operation should be considered.	• Lack of effect standard • Not achieves the desired effect

implementation, facility, supervision, environment and effect. At the same time, the secondary taxonomy is put forward (As Table 1).

3 Set Up Methods of Hazard Identification

According to the actual situation of safety and operation of civil aviation, three methods of hazard identification are set up. For each method, the applicable objects and working process are given. Meanwhile, the specific application examples are described in detail respectively.

3.1 System and Job Analysis

Applicable Objects. This method is suitable for the hazard identification of service provider in the following situations:

1. The initial setting up of systems, such as the new company or department. The comprehensive hazard identification is required to search all the hazards existing.
2. The significant changes, such as the adjustment of organization framework, new business, new operation procedure, new equipment, which need hazards identification and management to ensure that there is no safety issues after the change is put into practice.
3. Hazard identification on a regular basis, such as every year or every two years.

Table 2. Decomposition of flight operation system

System	First-level process	Second-level process
Flight operation	Implementation of flight	Preflight preparation
		Flight
		Evaluation after flight
	Pilot scheduling	Airlines analysis
		Pilots qualification analysis
		Develop pilots flight plan
		Adjust pilots flight plan in abnormal situation
	Pilot training	Flight training
		Flight theory training
		Simulator training
	Safety management	Safety information management
		Risk management
		Safety education

Working Process and Application Example.

Decomposition of work process. For a particular operation system, such as flight operation system or maintenance system, etc., the work process is decomposed into some specific work units. It is appropriate that the system is broken down into three levels or four levels process according to the complexity of the system. Take the flight operation system as an example (As Table 2).

Hazard identification. Base on the decomposition of work process, hazards are identified for each minimum level work process in accordance with the above hazard taxonomy.

Take the pilot scheduling as an example to identify hazards for its four second-level processes from the aspects of procedure, responsibility, personnel, implementation, facility, supervision, environment and effect (As Table 3).

Table 3. Hazards identification to pilot scheduling

Work process		Procedure	Responsibility	Personnel	Implementation	Facility	Supervision	Environment	Effect
Pilot scheduling	Airlines analysis	Lack of procedures and standards of airline analysis							
	Pilots qualification analysis		Lack of responsibility of pilot qualification analysis						
	Develop pilots flight plan				There is violation in developing pilots flight plan	The software of developing pilots flight plan is not appropriate			
	Adjust pilots flight plan in abnormal situation			Staff capacity can't meet the requirement of adjusting pilots flight plan in abnormal situation			Lack of supervision to adjusting pilots flight plan in abnormal situation		

So, there are six hazards in the work process of pilot scheduling (As Table 4). The blanks show that there is no hazard.

Table 4. Hazards in pilot scheduling

Hazard taxonomy	Hazards
1. Procedure	• Lack of procedures and standards of airline analysis
2. Responsibility	• Lack of responsibility of pilot qualification analysis
3. Personnel	• Staff capacity can't meet the requirement of adjusting pilots flight plan in abnormal situation
4. Implementation	• There is violation in developing pilots flight plan
5. Facility	• The software of developing pilots flight plan is not appropriate
6. Supervision	• Lack of supervision to adjusting pilots flight plan in abnormal situation

3.2 Unsafe Event Analysis

Applicable Objects. This method is suitable for the hazards identification of service provider in the following situations:

1. For the unsafe event that has happened, the root causes analysis according to the Fault Tree Analysis (FTA) is needed to identify the hazards. The aim is to prevent such event do not happen again.
2. For the unsafe event that has not happened but is unwished and serious, the hazards identification should be carried out to prevent such event do not happen.

Working Process and Application Example.

Construct FTA. For an unsafe event, construct FTA and analysis every causes of the event. Take the vehicle scrape aircraft as an example.

The Fig. 2 shows that the event covers multi-level causes. Vehicle speeding, brake failure, driving not along the route are the direct causes of the event, and the personnel violation, lack of vehicle speed limit, wet ground, vehicle lack of maintenance and the unreasonable route are indirect causes. The cause analysis will find the reasons in the organizational level finally, which includes safety policy, education, resources, etc.

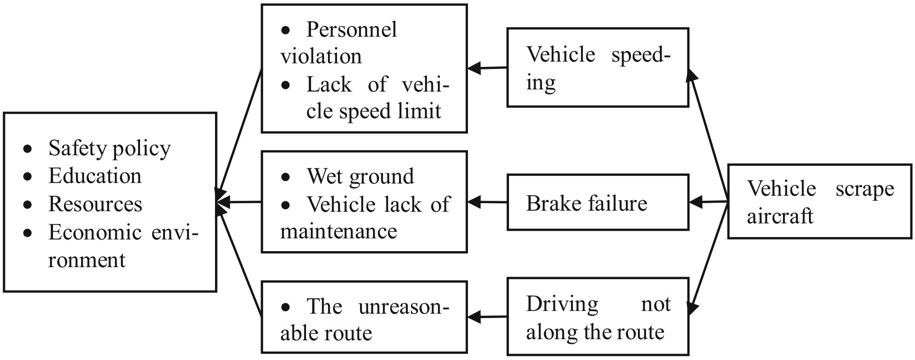

Fig. 2. FTA analysis to vehicle scrape aircraft

Hazard identification. Base on the FTA, the hazards are identified from the aspects of procedure, responsibility, personnel, implementation, facility, supervision, environment and effect, and four hazards are identified (As Fig. 3).

Hazard taxonomy	Hazards
1. Procedure	• Lack of vehicle speed limit
2. Implementation	• Personnel violation
3. Facility	• Vehicle lack of maintenance • The unreasonable route
4. Environment	• Wet ground

Fig. 3. Hazards in vehicle scrape aircraft

3.3 Safety Information Statistical Analysis

Applicable Objects. Service providers collect some kinds of safety information in the daily operation, including:

- Unsafe event;
- Safety check;
- Flight quality monitoring;
- Service difficulty reports (SDR);
- Equipment operation;
- Safety audit;
- Government oversight;
- External safety information; etc.

Statistical analysis is carried out to above information to find common safety issues and tendencies, then the hazards in the daily operation are identified, evaluated and managed.

Working Process and Application Example

Safety information collection and statistics. Collect all kinds of safety information in the daily operation, and carry out statistical analysis regularly. Statistical analysis methods including:

- Quantity statistics;
- Comparison analysis;
- Correlation analysis;
- Trend analysis;
- Principal component analysis; etc.

Through the analysis, some common safety issues existing in the daily operation can be found. Such as:

- The hard landing, in which the vertical overload is form 1.6G to 1.8G, in the fourth quarter is more than that in the third quarter;
- Safety information report delay is more in the second half of the year;
- There are more violations in daily operation; etc.

FTA analysis. For the safety issues got from safety information statistics, the FTA model is used to analysis and identify hazards. Take the safety information submitted not in time as the example to identify hazards.

As shown in Fig. 4, the immediate cause of the event include: lack of information submit standards, inconvenient information submit tools, lack of supervision to information submit and lack of responsibility of information submit. Meanwhile, there are some deeper reasons from the organizational level.

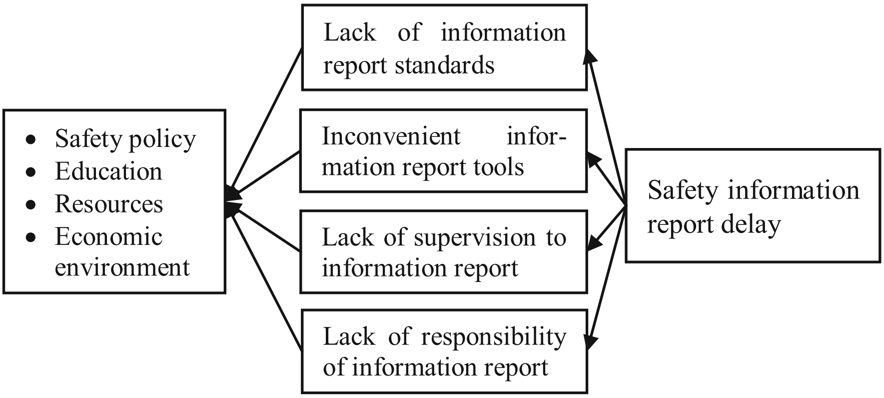

Fig. 4. FTA analysis to safety information report delay

Hazard identification. Base on the above causes analysis, the hazards are identified from the aspects of procedure, responsibility, personnel, implementation, facility, supervision, environment and effect, and four hazards are identified (As Table 5).

Table 5. Hazards in safety information report delay

Hazard taxonomy	Hazards
1. Procedure	• Lack of information report standards
2. Responsibility	• Lack of responsibility of information report
3. Facility	• Inconvenient information report tools
4. Supervision	• Lack of supervision to information report

4 Conclusion

1. The SMS regulations and requirements issued by ICAO, FAA, Canada, EASA, CAAC, etc. and implementation of SMS are summarized. The definition, classification and identification method of hazard put forwarded by ICAO, SMICG, ECAST, CAAC and FAA are summarized, the defects in hazard definition and classification and the problems in the service provider's hazard identification are analyzed.
2. Based on the analysis to the definition of system safety and the safety attributes, the definition of system elements are put forward. Then, the hazard taxonomy is set up, which are the procedures, responsibilities, personnel, and equipment, supervision and inspection, operation environment and effect. Meanwhile, the secondary taxonomy is given.
3. According to the established hazard taxonomy, three hazard identification methods are set up, which are the system and job analysis, unsafe events analysis and safety information statistical analysis. Applicable objects, working process and application example for each method are given respectively.

4. The established hazard taxonomy and identification methods can assist service providers to carry out hazard identification more systematically and comprehensively, which could improve the effectiveness of risk management.
5. The hazard taxonomy and identification methods have been put into practice in a number of service providers in China, the results show that the taxonomy and methods have highly practicability.

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