Identifying Safety Performance Indicators for Risk Assessment in Civil Aviation

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Abstract. Safety is particularly important for civil aviation because civil aviation accident will result in serious casualties and property losses. As a core element of safety management system, safety performance management plays a more and more important role in improving safety management efficiency of service providers. A systematic establishment process of safety performance indicator system is presented. A novel risk assessment model of a department is proposed based on four types of safety performance indicators identified by system and job analysis, event tree analysis, fault tree analysis, bow-tie, and so on. A case study of risk assessment using the proposed model is presented for two departments in an airport which implements safety performance management. The results illustrate the operation risk of different departments can be assessed based on safety performance indicator system.

1. Introduction
Safety is particularly important for civil aviation because civil aviation accident will result in serious casualties and property losses. According to data from the Aviation Safety Network, Figure 1 presents the statistics of fatal commercial aircraft accidents from 2010-2019 [1].

Figure 1. The statistics of fatal commercial aircraft accidents from 2010-2019
In order to reduce the number of incidents and accidents, direct and indirect costs, and improve staff productivity, the International Civil Aviation Organization (ICAO) required each ICAO Member State to implement a Safety Management System (SMS). SMS contains four components and twelve elements: safety policy and objectives which contain 5 elements, safety risk management which contains 2 elements, safety assurance which contains 3 elements, and safety promotion which contains 2 elements. Although many service providers have established their safety management system from company level to department level, the implementation effect of SMS should be further improved [2]. In recent years, with more and more researches on safety performance management, a large number of research papers have been published in different databases. Papers published from 2008 to 2019 have been filtered with “safety performance” in the title and keywords in China National Knowledge Infrastructure (CNKI) database and Elsevier ScienceDirect database. The statistics of papers filtered from the above two databases is presented in Figure 2.

![Figure 2. The statistics of papers filtered from the CNKI database and Elsevier ScienceDirect database.](image)

In order to establish safety performance indicators, Enoma, Reiman, and Sultana et al. used a variety of approaches to establish safety performance indicators for different organizations [3-5]. Safety performance indicators of different organizations can be classified as a number of types from various perspectives, a lot of researchers classified safety performance indicators as high-consequence or low-consequence safety performance indicators, proactive or reactive safety performance indicators, outcome or process safety performance indicators, lagging or leading safety performance indicators [6-11]. To evaluate the safety management effectiveness of different service providers, some researchers proposed many approaches which considering different dimensions and aspects of safety performance management of a certain organization [12-22]. In the area of risk assessment, some risk assessment models of organizations or departments have been established based on safety performance for airlines, airports, and so on [10-11, 23-24].

The establishment process of safety performance indicator system is presented in Section II. Section III introduces the novel risk assessment model proposed based on four types of safety performance indicators identified by system and job analysis, event tree analysis, fault tree analysis, bow-tie, and so on. In Section IV, a case study of two departments of an airport is provided. Finally, some conclusions are given in the last section.
2. Safety performance indicator system

As a core element of safety management system, safety performance management plays a more and more important role in improving safety management efficiency of service providers in civil aviation. On the basis of ICAO Doc 9859 Safety Management Manual (SMM), a recommended process of designing safety performance indicator system is proposed. The recommended process is presented in figure 3.

![Diagram](image)

**Figure 3. The recommended process of designing safety performance indicator.**

In this process, four main establishment steps are given: design safety performance indicator, make safety action plan, monitor actual safety performance, and improve safety performance system. In order to design safety performance indicator, some management objectives should be defined, such as reduction of incidents and accidents, improving safety management capacity, etc. According to these management objectives, safety performance indicators should be established by using different methods, such as system and job analysis, event tree analysis, fault tree analysis, bow-tie, and so on. Once safety performance indicators are established, then corresponding metrics should be determined. These metrics can be classified as: value type, ratio type, etc. Then, the target value and warning value for a certain safety performance indicator need to be determined. Safety action plans should be made to achieve safety objectives. Safety action plan contains many elements, such as safety action measures, responsible person, implementation period, resource requirements, status of safety action plan, effect of safety action plan, etc. For the third step, data of each safety performance indicator should be collected month by month to monitor the actual safety performance. In order to improve safety performance of civil aviation organization, there are three aspects: improving safety performance level based on established safety performance indicator system, optimizing safety performance indicator system by adjusting safety performance indicator, and promoting safety performance management by adjusting safety performance team, procedures, technical methods, etc. Many researchers proposed a variety of classifications of safety performance indicators from different dimensions. According to practical experience, safety performance indicators are classified as occurrence, foundation, management, and operation indicators. Meanwhile, occurrence indicators can be further classified into three types: accident/serious incident indicator, general incident indicator, and other events indicator.
Some safety performance indicators belong to different classifications are given as shown in Table 1.

**Table 1. Examples of occurrence, foundation, management, and operation indicator.**

| Type            | Example                             |
|-----------------|-------------------------------------|
| Occurrence indicator | Accident/Serious incident Number of serious incidents |
|                 | General incident Event rate of runway incursions |
|                 | Other events Number of bird strikes   |
| Foundation indicator | Proportion of new employees         |
| Management indicator | Implementation rate of supervision |
| Operation indicator | Completion rate of runway incursions training |

In order to explain how to determine the metric, target and warning value for each indicator, the indicator ‘Proportion of new employees’ is used as an example. The metric can be determined as the ratio of new employees to total employees. The target can be determined based on statistics value of last year, such as 20%. Then the warning value can be set as 20%. If the proportion of new employees is more than 20%, then the warning is triggered.

3. **A novel risk assessment model**

In order to assess operation risk of organizations and departments, the severity of different safety performance indicators should be determined. Safety performance indicators can be classified as occurrence indicator, foundation indicator, management indicator, and operation indicator. For the occurrence indicators, it can be further classified as accidents, serious incidents, general incidents and other events. ‘Civil Aircraft Incidents Standards’ and ‘Event Samples’ can be used to differentiate serious incident, general incident, and other events. The severity of a certain safety performance indicator can be determined based on the consequence if the occurrence does occur. According to the statistics of civil aviation occurrence event of China, the 300-29-1 ratio is still work. Heinrich’s Law is used as baseline by considering experts’ evaluation. Severity for occurrence, foundation, management, and operation indicators are presented in Table 2.

**Table 2. Severity of occurrence, foundation, management, and operation indicator.**

| Type            | Severity |
|-----------------|----------|
| Occurrence indicator | Accident/Serious incident 1000 |
|                 | General incident 35         |
|                 | Other events 3              |
| Foundation indicator | 3                       |
| Management indicator | 3                        |
| Operation indicator | 1                        |

At the department level of an organization in civil aviation, there are all types of safety performance indicators. Based on the severities assigned for occurrence, foundation, management, and operation indicator presented in Table 2, the risk of a department based on safety performance indicator system can be calculated as:
\begin{equation}
R_d = \frac{\sum_{i=1}^{n} s_i \times f_{pi}}{\sum_{i=1}^{n} s_i \times 100} \times 100
\end{equation}

where, \( n \) is the number of safety performance indicators of this department, \( s_i \) is the severity of the \( i \)th safety performance indicator, \( f_{pi} \) is the value in the hundred-mark system of \( i \)th safety performance indicator based on the statistics data month by month. For some of safety performance indicators, the higher the statistics value collected month by month, the better (Type I). But for other safety performance indicators, the lower the statistics value, the better (Type II). For safety performance indicators belong to Type I,

\begin{equation}
f_{pi} = \begin{cases} 
\frac{s_n - s_{pi}}{s_n} \times 100, & s_n > s_{pi} \\
0, & 0 \leq s_n \leq s_{pi}
\end{cases}
\end{equation}

where, \( s_{ni} \) is the warning value of \( i \)th safety performance indicator, \( s_{pi} \) is the statistics value of \( i \)th safety performance indicator month by month.

For safety performance indicators belong to Type II,

\begin{equation}
f_{pi} = \begin{cases} 
\frac{1 - \frac{s_n - s_{pi}}{s_n}}{s_n} \times 100, & s_n > s_{pi} \\
100, & 0 \leq s_n \leq s_{pi}
\end{cases}
\end{equation}

4. Case study

Airport is the key component of air transport system and the important node of civil aviation transport production. There are many departments to provide different function in an airport. An airport which implements safety performance management is used as a case to verify the proposed novel risk assessment model. Among all departments of an airport, ground service department and terminal management department are very two very important departments. Safety performance indicator system of ground service department and terminal management department are established. The numbers of occurrence, foundation, management, and operation indicators of ground service department and terminal management department are listed in Table 3.

| Safety performance indicator | Ground service department | Terminal management department |
|-----------------------------|---------------------------|-------------------------------|
| Occurrence indicator        | 6                         | 3                             |
| Foundation indicator        | 1                         | 2                             |
| Management indicator        | 13                        | 20                            |
| Operation indicator         | 44                        | 22                            |

Operation data of all these occurrence, foundation, management, and operation indicators from Jan. 2019 to Oct. 2019 is collected and used to calculate the operation risk of ground service department and terminal management department. The risk assessment results of ground service department and terminal management department are presented in figure 4 and figure 5, respectively.
According to Fig. 4 and Fig. 5, for the ground service department, there are six months which the operation risk is located in the blue area. For the terminal management department, only one month’s operation risk is located in the blue area. It is clear that the operation risk of the ground service department is higher than the terminal management department. Further, if the risk trend of the ground service department or terminal management department rises, it will be reflected in specific safety performance indicators. Then specific control measures can be developed to reduce operation risk.

5. Conclusions
As a core element of SMS, safety performance management plays a more and more important role in improving safety management efficiency of service providers. A recommended process of designing safety performance indicator is presented. All identified safety performance indicators for a civil aviation organization have been classified as occurrence indicators, operation indicators, management indicators, and foundation indicators. The severities have been assigned for all these four types of safety performance indicators. A novel operation risk assessment model based on safety performance is proposed. A case study of risk assessment using the proposed model is presented for the ground
service department and the terminal management department in an airport which implements safety performance management. The risk for the ground service department and the terminal management department are calculated based on ten months’ data from Jan. 2019 to Oct. 2019. We can find that the risk of the ground service department is higher than the terminal management department according to the calculated operation risk values.

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