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Relevance research of threat/ error and undesired states in air traffic management based on Bayesian Network Model

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ABSTRACT

We have realized that the quantitative analysis of safety data is an advanced technology of unsafely events research. Based on the analysis and statistical research on Air Traffic Control irregular events of 2011 using The Threat and Error Management (TEM) model, we have established the Bayesian network model to perform a precise quantitative analysis on the relevance between the threat, error and undesired states in Air Traffic Control operation. This analysis, based on the prior probability, obtained the relevance of the three kinds of safety information above through studying the respective posterior probabilities of threats or errors under undesired states. The result showed that the relevance of controller communication error and undesired states was 75%, and the relevance of Air Traffic Control threats as well as communication error with undesired states in Air Traffic Control was 13.3% and 25%, respectively. Therefore, this research method is of great significance for improving the mechanism of the Air Traffic Control operation risk management.

1. Introduction

The first advisory notice of threat and error management in air traffic control, referred to as TEM (International Civil Aviation Organization, 2008), was presented by International Civil Aviation Organization (ICAO). The Threat and Error Management (TEM) framework was established in the analysis of crew resource management (CRM) with the study of human factors as its basis. It shows analyzable and available diagnostic feature upon the performance of human and machine, taking both human and environment into consideration, and has been widely used in audit, supervise, and safety training in crew resource management (CRM) and Air Traffic Control(ATC) team resource management (TRM).

Great deals of researches have been done on quantifying unsafely events. Dodd (Dodd, 2007) has introduced data processing using Bayesian Assessment method and how to apply these data with risk management. In document (Pape et al., 2001), PAPE A uses ASRS data to study the relationship between ground operation, airspace operation and ATC based potentials, respectively. Lux$^{\varphi}$j (Luxhφj, & Coit, 2006) has established a risk management model for human errors of low probability but with severe consequences, and then a medium risk management aggregate model for human-machine-environment system in maintenance. In document (Janic, 2000), Poisson Process has been engaged by Janice to build a risk assessment model. Discussions on civilian air safety information and its quantitative analyzing have been hold by domestic researchers. However, these discussions rely too much on statistical and Probability assessment, which cannot give a clear view on the relationships between different elements and thus are unable to extract the key factors from large amount of safety data or to find and improve the weakness point.

Based on the analysis of irregular events database of ATC, with the application of TEM architecture, we aim to have a quantitative analysis of air traffic management operational risk factors, to find out the closest kinds of threats or errors to each given undesired situation types. Furthermore, we aim to provide a quantitative risk management system method for air traffic management operation. The Bayesian network is helpful to achieve this quantitative algorithm. Its most recognizable characteristic is that it calculates the posterior probability with prior one. It is closer to reality using

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posterior probability to express the probability of occurred events under certain circumstances, using arcs to express dependency relationships between variables, and using probability distributions to express the strength of such dependency. Pearl (Cao, & Li, 2011) established a practical model, called the Bayesian Network, for quantitative analysis of human factors. It uses graphic methods to depict the relationship between data, which is clear and easy to understand. Recently, Bayesian Network is greatly applied in Chinese Medicine study (Xiaoyan, 2014; Jiang & Hu, 2014). In this article, a Bayesian Network model will be established based on TEM statistical analysis of factors in threat, error and undesired states to study the relevance in between.

2. Relevance research of threat/error and undesired states in ATC

2.1. Statistics of ATC abnormal events based on TEM model

The Threat and Error Management (TEM) framework is a conceptual model that assists in understanding, from an operational perspective, the interrelationship between safety and human performance in dynamic and challenging operational contexts. There are three basic components in the TEM framework, from the perspective of air traffic controllers: threats, errors and undesired states. Threats are defined as events or errors that occur beyond the influence of the air traffic controller, increase operational complexity, and which must be managed to maintain the margins of safety. Errors are defined as actions or inactions by the air traffic controller that led to deviations from organizational or air traffic controller intentions or expectations. Unmanaged and/or mismanaged errors frequently lead to undesired states. Undesired states are defined as operational conditions where an unintended traffic situation results in are duct ion in margins of safety.

In 2011, 75 irregular events were received in China ATC system, which were 5 less compared to that of the year before. Causes to these irregular events were ATC factors, system failures, conflicts with military activities, factors of flight crews, runway incursions, electromagnetic interference, communication failures, etc. TEM model will be employed to analyze the threat (T), error (E), and undesired states (U) that were existed in every event in ATC, as was shown in Appendix 1, and Table 1 is a sample.

Based on the analysis of air traffic irregular events with TEM model in 2011, statistics of threats (T), errors (E) and undesired states (U) factors were shown in Table 2. From the result, Threat types involved in internal threat (T_1), external threat (T_2), aerial threat (T_3) and environmental threat (T_4). Error(E) types involved in Communication error(E_1). Undesired states(U)Types involved in Ground undesired states(U_1) and Aerial undesired states(U_2). All of these factors' tapes were based on the TEM (International Civil Aviation Organization, 2008) that was presented by International Civil Aviation Organization (ICAO).

With the statistical results, the most frequently occurred factors that includes the Internal Threat(T_1), Aerial Threat(T_3), Environmental Threat(T_4), Communication Error(E_1), Ground undesired states(U_1)and Aerial undesired states(U_2) were used as research objects for the establishment of the Bayesian Network model to find out posterior probability of threats or errors under certain circumstances.

2.2. Construction of the Bayesian Network Model

2.2.1. Introduction of the Bayesian Network Model

The Bayesian Network is a directional graphic model with a network structure. It is the combination of artificial intelligence, probability theory, graph theory and decision theory. It uses directional graphs to express relationships and influence degrees between factors, and uses node variables to express factors, while each node can represent any of the factors such as time of the incident, the environment, and humans, and has its own probability distribution. And it also uses directional arcs to represent the association of different elements, thus the Bayesian Network can also be called Casual Graph. The conditional probability table is used to express influence degree between different elements. As shown in Fig. 1, V_1 is the parent node of V_2 and V_3, while V_2 and V_3 are child nodes of V_1.

Set of variables is $V=(V_1,V_2,\ldots,V_k)$, where $V_1,V_2,\ldots,V_k$ are network nodes. $P(V_1 = v_1, V_2 = v_2,\ldots,V_k = v_k)$ represents the joint probability distribution of the set of all variables. The expression (1) where$(V_{i-1},\ldots,V_1)$ is the set of the parent node of Vi. Vi is independent on other nodes except its parent node, therefore it can use such in-dependency to reduce the amount of calculation. When all the values of the joint probability distribution were obtained, the marginal probability of each random variables can be calculated, namely the expression (2), with the joint probability and marginal probability, conditional probability can be calculated by the expression (3) (Coper, 1990). Generally for a multi-valued random variable, Bayesian expression is $P(Y|X)\Big| = \frac{P(X|Y)P(Y)}{P(X)}$, where "P(X|Y)" is prior probability, it repents the probability when Y event occurred lead to X event occurrence, and P(Y|X) is posterior probability, it repents the probability of Y event occurrence Under X event circumstances. For purposes of computing correlation between nodes, the prior probability is used to calculate the posterior probability, while latter one represents the probability of occurred events under certain circumstances. These values are computed as follows:

$$P(V_1= v_1, V_2= v_2,\ldots, V_k= v_k) = \prod_{i=1}^{k} P(V_i|V_{i-1},\cdots,V_1) \quad (1)$$

$$P(V_i = v_i) = \sum_{V_i=v_i} P(V_1, V_2,\cdots,V_k) \quad (2)$$

Table 1
A sample of TEM analysis model of irregular events.

Event overview		Flight PAL338 was into the runway
Threat	Classification	Internal Threats: procedure
	Description	The airport using mixed landing runway
Error	Classification	Communication Errors:Controller- plane Captain
	Description	The controller to send the wrong command: using the D3-A3c 17L PAL338 flight across the runway
Undesired states	Classification	undesired states in Ground: The flight during its stopping place continues to slide
	Description	Flight PAL338 should Wait at 17L but not wait for
Undesired states management	Classification	Execution Countermeasures
	Description	The controller was In command of flight PAL338 brake in time