A DYNAMIC RISK ASSESSMENT MODELING BASED ON FUZZY ANP FOR SAFETY MANAGEMENT SYSTEMS

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1. The purpose of the article:

This article aims to propose a new approach for appraising reports one by one in each section, integrating different criteria mathematically into one index in order to derivate an overall safety index of the organization for top management. Using multi-attribute decision-making in conjunction with the implementation of the fuzzy numbers structure can be regarded as an efficacious method for determining the significance of each criterion and option.
Consequently, these criteria will collectively form a numerical safety report index with the aid of the FANP (to implement realistic comparisons as well as precisely draw inferences from each filed expert).

The novelty of this paper is the introduction of a three dimensional exponential (nonlinear) formula for the calculation of risk index instead of the two dimensional linear formula, which enables the definition of safety indicators at low, medium and top-level management of big organizations. It facilitates the definition and monitoring of the safety goals by the management to find the most critical areas with the least cost.

The methodology used in this article is 3D risk assessment of safety-related reports via a Fuzzy ANP (Fuzzy Analytical Network Process) based method which consists of three distinct criteria indicating severity of occurrence, reliability (frequency of occurrence), and the impact on business and also options which indicate the safety reports of several sectors in an airline.

2. Gap analysis:

Current airlines' safety risk assessment:

Employing an efficient method along with realistic pair comparisons, applying subjective inferences of organization experts, and purging the intrinsic ambiguity of inferences, are not reflected in current airlines' safety management.

In two-dimensional risk, the parameters used for the assessment of the severity of financial or fatal losses and the probability of accidents/incidents are defined as follows:

Risk Index (RI) = Probability*Severity

Proposed model:

A new model for risk management and a novel formula for risk index calculation, based on a fuzzy approach, are presented in this study. In this new model, unlike in the traditional approach, the latent aftermath of safety reports, especially those which affect the continuity of the business, is also taken into account. In this model, along with the definition of a new structure for risk management, risk analysis should be restructured. To that end, a two-dimensional classic risk formula was replaced with three-dimensional (nonlinear) exponential ones, considering "the impact on the business" as a source of risk and hazard. For measuring the safety risk using the Fuzzy hierarchical evaluation method, considering experts' opinions, three criteria in four different operational fields were developed. This method employs a Fuzzy ANP to help quantify judgments, make qualitative judgments in the traditional method, and
Weigh the priority of elements contributing to risk.

One of the main concerns for the implementation of a classical risk management system in large organizations is the existence of a vast number of subsections and operational sectors with sophisticated duties. Conventional approaches are incapable of providing a comprehensive risk assessment in different sections, with a tangible quantitative indicator. They are also unable to empower safety management systems to monitor the risk of hazards, define trackable safety goals and prioritize corrective actions.

In two-dimensional risk, the parameters used for the assessment of the severity of financial or fatal losses and the probability of accidents/incidents are defined as follows:

Risk Index (RI) = Probability*Severity,

Different classifications of risk levels can be assumed, based on three levels classified as low, medium, high, or five levels – very low, low, medium, high, very high. The two-dimensional approach has a number of deficiencies.

- Firstly, in the traditional approach, a number or a combination of a number and a letter are assigned to each report. This approach focuses on analyzing each report individually. Although there are advantages for this kind of assessment, such as simplicity, the disadvantages heavily outweigh the advantages. Consideration of each report without a comparison with other reports describing incidents or accidents largely lies in the experience and judgment of the expert. If the expert has no skill in the field, it may cause an overestimation or underestimation of the risk in the report.

- Secondly, without a comparison, the prioritizing of corrective actions and the resource allocation are a matter of difficulty.

- Thirdly, the risk index derived for each report in the classical format is not flexible enough to easily indicate the safety trend of a section, department, or the whole organization. In fact, a multitude of reports with a risk index in digit-letter format, like 5C or a non-normalized number, are yielded. They are regarded solely and could not be integrated in a logical manner to give an indicator for the section reports.

Moreover, in the assessment of risks, the safety policies declared by top-level management are not reflected. Based on their perspective of the probability or the judgment of severity, experts assign the risk index. However, organizations have a mission and vision of operation that meet their requirements. For example, for a military organization, the continuity of work is more important than cost, financial loss, or discontinuity of the operation, whereas in a civil aviation company, like an airline, costs are more important than continuity of operations. These policies shall be considered in the risk analysis in line with the organization's mission. In the traditional risk assessment approach, there is no possibility to include managerial views or organizational policies.

All of these shortcomings are covered in the new model and formula proposed in this article. Because of these drawbacks, researchers are unable to design a Safety Management System that covers all sections and activities of large organizations. As an example, in airlines, the risks for on-board status reports have been identified and categorized. However, the safety reports of on ground status of an aircraft or ground services are mostly ignored or rarely considered. This is a big deficiency of the traditional risk assessment approach. In addition, researchers were primarily unable to propose a safety management system capable of defining a quantitative risk index which could be reliable for investigations and monitoring for all departments and the whole organization.

Therefore, in this paper, along with a review and classification of the proposed criteria, the priority of parameters Influencing the mathematical model is introduced, and, finally, the model and its implementation in a case study Are presented.

Unlike in the classical approach, risk assessment is exponential rather than linear. The advantages of this new form of formula are expressing the priority of importance of the elements contributing to the risk, from the management viewpoint. In simple words, they show for which item, according to severity, probability and impact on business, it is more important or interesting for the company to allocate the resources or prioritize the actions needed. The strength of the new concept is providing the possibility to reflect the mission of operation in its risk management system to each organization. In addition, whenever the mission of an organization changes, new safety policies and priorities can be applied in risk assessment by changing the powers in the formula, something that was missing in the linear two-dimensional formula in classic risk assessment.

The new model also takes the FUZZY approach, because it makes pair comparisons of all reports, something that is not carried out in two-dimensional analysis. Using this approach, two goals are simultaneously achieved. Firstly, prioritization takes place when making the comparisons, which can then be completed by management prioritization in defining the powers. Meanwhile, the normalization of the risk elements, namely severity, probability, and impact on business is performed. One of the main problems associated with traditional risk assessment is the fact that the risk index and its contributing elements are not normalized. A risk index which has not been normalized may drastically affect the risks of reports and cause an error in corrective actions. The results of this approach are normalized digit numbers, which can show more precisely which risks need more attention. Based on their order, the type of action (immediate, normal and no actions) is defined. During the next phase, these risk numbers for each section can be summed up and divided by the number of reports received to deliver the total risk number of the sections. By repeating this for each department or section, a normalized risk index for all departments is yielded.

At this level, each department can depict its total risk index on the axis of time and monitor its safety trend or define the safety goal by specifying a threshold for the safety index to be reached. For example, if the safety risk of a flight operation is 2.1 for the month of January, flight operation managers can define the department's safety goal at 2, to be reached within the next 6 months. Therefore, defining the safety goal by monitoring the safety index is achievable in this method of risk assessment. In addition, top-level managers or chief executives of an organization are able to monitor the safety indexes of all departments and identify the most critical department from the safety point of view.

Another step which can be taken at this level, but is not covered in this study, is defining the weight factor for the departments based on the importance or criticality assigned by the top managers. In this way, the organization decides to put emphasis on some particular safety-related issues. For instance, they can define a greater weight factor for flight operation reports than maintenance or ground services reports. Of course, this step was not taken into account in this study.

Finally, by summing up the total safety risk indices of all departments and dividing them by the number of departments, the overall safety risk index of the whole organization is achieved. Again, like in the case for each department, an organization can monitor the safety trend over time and set a safety goal for it; for example, if the overall safety index of the organization is 3, it can be defined to be lowered to 2.8 within a year.

The features of this new approach which are not present in the classical approach are: normalizing the safety index for each report, lowering the false judgment based on bias or lack of specialized technical knowledge, peer comparison and multiple prioritization of the reports, and defining the total and overall safety index both on a department and organization level. Particular emphasis is placed on introducing the new formula that is the starting point of risk assessment.

As mentioned before, to incorporate the effect of safety policies and organization's mission into the assessment of risk, the exponential form was chosen. Due to the nature of the Fuzzy approach, which delivers the normalized numbers of less than one, the reciprocal of the numbers derived from managing Fuzzy numbers is selected to reflect the increasing and accumulating nature of the parameters. The powers in the exponential formula come from a Fuzzy table formed to reflect the priority and preferences of the organization in weighing the risk elements.

3. Describe the proposed formula

To involve the latent impacts of safety-related accidents and incidents, impact on business was added to the formula. These changes and modifications could be introduced as:

RI = Risk Index = $(p^{1/\alpha} * S^{1/\beta})/I^{1/\gamma}$

Where *P* denotes probability, *S* – severity, and *I* – impact on business, and α, β, γ – the weighting factors for probability, severity and impact on business, respectively. The weighting coefficients need to be estimated based on previous experience, database, and an airline's priority. The methods for finding these factors and parameters will be in accordance with the Fuzzy basis.

1. **The field risk is formulated as:**

$$Field \quad Risk \quad (FR)_i = \frac{\sum_{i=1}^{N} (RI)_i}{N}$$

Where *RI* is the risk index of a report and *N* is the total number of reports received in a definite field. In this approach, the safety criteria (as a summation of risks) can be calculated for different fields, which helps to compare them and identify the vulnerable sectors.

2. **Measurement of the Overall Safety Index of the organization**:

The Field risks from different sectors: engineering and maintenance, flight operation, security, airport services, dispatch, training, air medical centers, and areas, such as ramp, hangar, etc., are summed up to obtain the Overall Safety Index of the organization:

$$Overal \quad Risk \quad Index \quad (OSI) = \sum_{i=1}^{P} (W_i * FR_i)$$

Where *FRi* is the Field risk, *Wi* indicates the corresponding weighing coefficients for each field derived by the same FUZZY-ANP comparison method, and *P* is the number of operational fields (sectors/departments/areas).

4. *Related Table :*

➢ *Weighing Coefficients for each Activity Scope (Department) :*

Activity Scope (Department)	Corresponding Weighing Coefficients for each field
ENGINEERING & MAINTENANCE	36.66666667
FLIGHT OPERATION & DISPATCH	61.33333333
AIRPORT SERVICES	1.333333333
SECURITY	0.666667

➢ *Weighing Coefficients for each Criteria :*

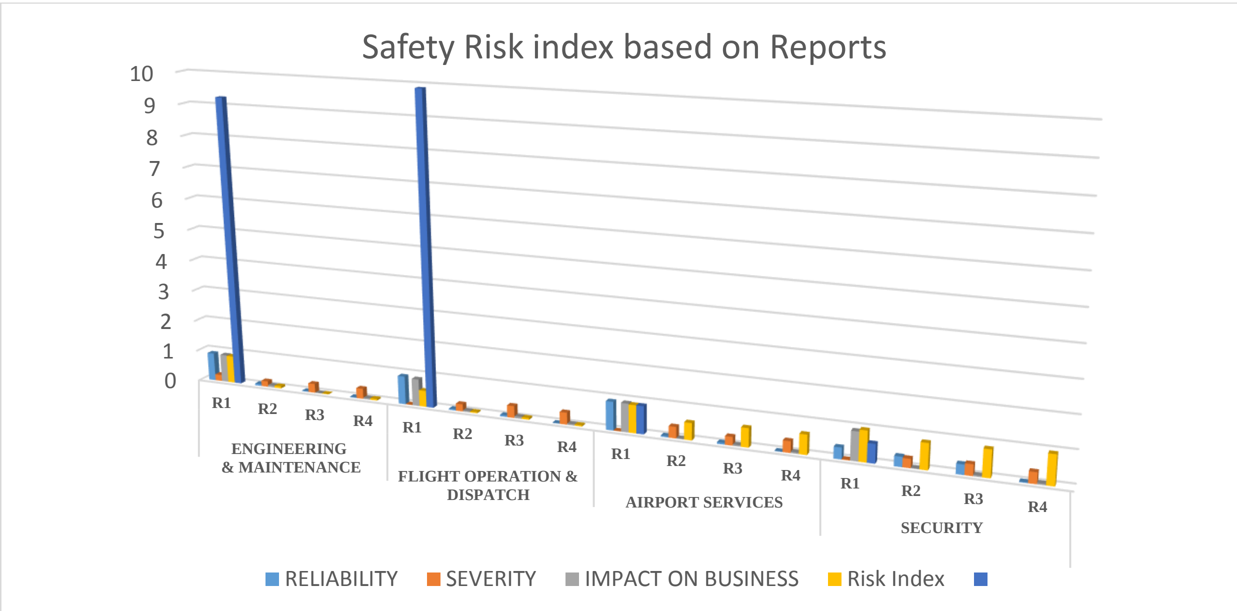
Option	Criteria	corresponding weighing coefficients for each criteria
ENGINEERING & MAINTENANCE	RELIABILITY	17
	SEVERITY	82
	IMPACT ON BUSINESS	1
FLIGHT OPERATION & DISPATCH	RELIABILITY	90
	SEVERITY	9
	IMPACT ON BUSINESS	1
AIRPORT SERVICES	RELIABILITY	54
	SEVERITY	40
	IMPACT ON BUSINESS	6
SECURITY	RELIABILITY	28
	SEVERITY	55
	IMPACT ON BUSINESS	17

➢ *Safety Risk Index :*

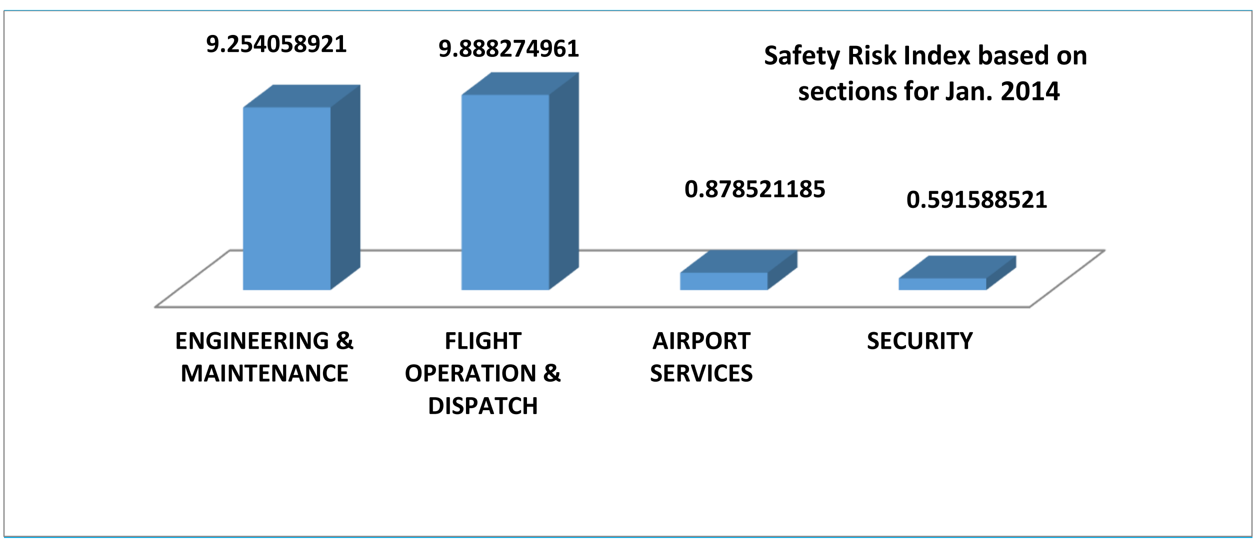
		RELIABILITY	SEVERITY	IMPACT ON BUSINESS	Risk Index	
ENGINEERING & MAINTENANCE	R1	0.9	0.2	0.89	0.878127543	**9.25405892**
	R2	0.06	0.18	0.06	0.069333426	
	R3	0.02	0.29	0.01	0.012398904	
	R4	0.02	0.33	0.04	0.049673827	
FLIGHT OPERATION & DISPATCH	R1	0.9	0.01	0.86	0.516160356	**9.88827496**
	R2	0.04	0.23	0.04	0.035210608	
	R3	0.05	0.38	0.06	0.055707854	
	R4	0.01	0.38	0.04	0.037808679	
AIRPORT SERVICES	R1	0.9	0.01	0.9	0.877447443	**0.87852119**
	R2	0.04	0.36	0.02	0.539055738	
	R3	0.05	0.27	0.04	0.598256245	
	R4	0.01	0.36	0.04	0.620804131	
SECURITY	R1	0.36	0.02	0.9	0.959984804	**0.59158852**
	R2	0.31	0.28	0.02	0.80942119	
	R3	0.31	0.35	0.04	0.846533632	
	R4	0.02	0.35	0.04	0.933589724	

Jan	SUM	20.6124436

➢ *Safety Risk index based on Reports*



➢ *Safety Risk Index based on sections for Jan. 2014*



➢ Safety RISK - 2014

Month	Risk Index
Jan	20.61244359
Feb	0.6
Mar	0.4
Apr	0.56
May	0.95
Jun	1.2
Jul	1.4
Aug	0.56
Sep	0.47
Oct	0.33
Nov	0.69
Dec	0.94