RISK ASSESSMENT MODELLING FOR EVALUATING SAFETY AND IMPACT ON BUSINESS VIA A 3D RISK MATRIX

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Abstract

This research investigates a three dimensional parametric risk assessment model considering the 3rd factor to be the impact on business. In order to represent the 3rd order risk assessment matrix monitoring the impact of safety reports on the continuous economical performance of the airline, the other two factors, probability of safety and severity are redefined. Introducing two quantitative and qualitative assessment methodologies, the overall risk of the organization can be studied by means of Analytical Hierarchy Process (AHP), providing an adequate background to define the safety goals of the organization.

1 General Introduction)

A great number of researches have been trying to define the financial and commercial impacts of safety reports on continuous functioning of an organization specifically an airline. It is noteworthy that safety of an airline can be regarded as a fundamental parameter of airline service quality, underlying on quality management system of airline.

For example, Gourdin (1988), enumerates 3 distinct parameters of service quality as price, punctuality (timeliness) and safety. However, Truitt and Hayness (1994) considered more aspects and incorporate two factors of checking process and customers complaints representing safety-security issues affecting the business continuity of an airline. Gilbert and Wong (2003) presented a five dimension representation, which is a revise of that proposed by Parasuraman, Ziethaml and Berry (1985, 1989), and consists of tangability, reliability, responsiveness, assurance and empathy. The lack of considering business continuity disruptions like economical, financial or commercial circumstances on risk assessment can be compensated by inserting the 3rd factor (impact on business) into the model.

One of the main concerns in implementation of a comprehensive risk management system for airlines is the existence of vast number of subsections and operational sectors with common and sophisticated duties leading to interconnected quantitative and qualitative databases. This makes the system to perform inefficiently due to lots of input variables. Therefore, the risk management system is based on the extraction of apparent and hidden risk threats from the safety reports and the decision making process will be based on proactive or reactive approaches. In conclusion, there are risk assessment systems for airline management, but the conventional approaches are incapable of providing a comprehensive risk assessment in different sections, a quantitative risk variable to represent the overall risk status of the system, integrating different databases, considering economical consequences such as labor hours, materials and facilities and credit losses as a result of inappropriate risk assessments.

In order to enhance the conventional risk assessment techniques by compensating for the mentioned deficiencies in these approaches, providing priority of corrective actions, improving the safety level of the organization and considering the economical impacts, a new technique is proposed in the current paper.

2- Explanation of the technique

The safety management system in airlines, such as safety audit/inspection or assessment programs like (IOSA) and SAFA program for European countries, should be implemented in accordance with ICAO regulations (DOC 9859-AN/460) requiring the following actions [6]:

- Identification of safety hazards
- Ensuring that remedial action necessary to maintain an acceptable level of safety is implemented
- Providing a continuous monitoring and regular assessment of the achieved safety level
- Aims at making continuous improvement to the overall level of safety

Establishment of a data/report gathering system is an important step for implementation of a comprehensive safety management system. The essential differences among safety reports including Quantitative Performance Indicator and Qualitative Performance Indicator make declaration of the safety variable, at high-level managerial as a quantitative indicator, a tough decision to make [1]. A quantitative overall safety indicator for the airline assists the board of directors to realize the safety status of the organization, identify the weaknesses, suggest applicable corrective actions and monitor the impact of the decisions continuously. Below an example of safety management system is presented in which data gathering and report analysis subsystems investigate hazard and risk status of the airline. Widespread inputs ranging from technical to operational reports is a barrier in development of an efficient comprehensive system; therefore, perfect classification of inputs is of vital importance. In majority of cases only the reports related to the on board planes and on ground operations performed on the fleet should be considered as follows:

1. On board (flight) data

The reports issued from the moment that the flight license is issued for the plane up to the last moment of operation. This category includes every phases of flight, unexpected events (those led to incidents and those not), human factors, technical objections and weather conditions.

2. On ground data

The reports related to safety issues happening on ground in the nest, during maintenance and taxi. According to the conventional systematic approaches, proactive and reactive, the risks including on board and on ground are categorized and prioritized; then two dimensional risk assessment.

parameters of severity describing financial or fatal losses and probability of accidents/ incidence are defined as follows

Risk Index (RI) = Probability*Severity

Severity – The possible effects of an unsafe event or condition, taking the worst foreseeable situation as reference.

Probability – The likelihood of an unsafe event or condition that might occurIn the proactive approach for risk assessment, probability of accident/ incident can be extracted from the database but the definition of severity is based on decision maker and may not be unique from one system to another. Each organization or company can develop or has its own definition of severity but there are some globally accepted definitions or measure for severity and probability, among them one frequently used in aviation is represented in Figure 1.

Probability Occurrence		
Qualitative Definition	Meaning	Value
Frequent	Likely to occur many times Has occurred frequently	5
Occasional	Likely to occur some times (occurred infrequently)	4
Remote	Unlikely but possible to occur Has occurred rarely	3
Improbable	Very unlikely (Not known to have occurred)	2
Extremely Improbable	Almost inconceivable that the event occur	1

Table1- Typical Definition Of Probability For Assessment Of Risks And Hazard Identification

Different classification of risk levels can be assumed; three levels of (low, medium, high) as shown in Figure 1 and five levels of (very low, low, medium, high, very high).

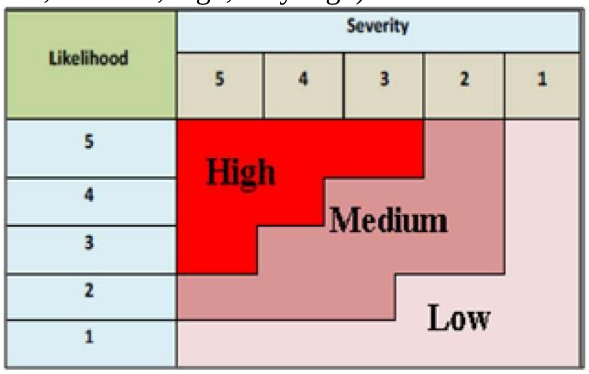

Fig. 1. 3 Risk Levels Matrix

3- Methodology

3.1) Qualitative approach- 3D Matrix

As discussed above, definition of assessment criteria and probability parameter based on the number of received reports in total or in different fields, flight hours/cycles and maintenance schedules in proactive and reactive approaches are challenging factors impacting the efficiency of the proposed model. The main concern is designation of the worst foreseeable situation which is based on human decision and may be different or even sometimes opposite from one expert to another. The proposed methodology in this report includes the following steps:

1. Redefinition of the risk assessment parameters and the criteria for impact on business
2. Generalizing the risk assessment formula
3. Inclusion of two quantitative (AHP method) and qualitative (3D matrices) approaches

Therefore, reliability parameter is substituted for probability of incident, the severity is redefined and the impact on business is added to the model to facilitate development of 3D methods both qualitatively and quantitatively.
The reliability parameter includes the impact of actions, facility errors, human mistakes and environmental conditions affecting the flight safety; such as, inappropriate maneuvers, failure of TCAS system during flight, bird strike, observed engine failure at ECM or FDR.
The severity parameter covers the impact of the actions, human errors and environmental conditions on the health and safety of the passengers and flight crew. The mentioned actions include cabin pressure drop and strike of the ramp carrier vehicle to the plane.
The impact on business deals with the consequences of safety situations on airplane's structure and its ability of flight, the costs due to delay or cancellation of flights and decline of stock values of the airline in the stock markets.
The main reasons behind the applied changes to the proposed model can be explained as follows:

1- In many safety cases, despite the ECM (Engine Condition Monitoring) and refinement/analysis of reports, some minor issues may exist that if are not considered on time may lead to safety risk. This situation especially happens in the reports related to the disturbances like:

- Takeoff abort
- Missed approach
- Aircraft change
- Flight delay

Which are categorized at the level of serious incidents, not resulting to apparent costs but leading to defraud in the credit of the airline.
It is noteworthy to mention a few cases affecting the business continuity plan of the airline that are considered in the proposed methodology as follows:

a. The delays due to

- Passenger boarding/disembarking and Cargo loading/offloading Delays
- Aircraft Taxing/Towing
- Aircraft return
- Aircraft divert
- Aircraft change

b. The consumption or replacement of materials
c. Fuel consumption
d. Labor costs
e. Refreshment of the passengers
f. Airport services and ramp vehicle

In addition, separation of these parameters facilitates the progress of the numerical approaches.
Qualitative assessment despite its lower precision compared to numerical approaches is an efficient risk assessment technique especially when the progress speed and consequent actions are of high priority.
Through detailed investigation of 30 safety reports and field research of four sectors of an Iranian airline, namely Airport Services, Engineering & Maintenance, Flight Safety and Training and by using the experiences of eight experts and retired deans of the quality control and assurance department of the airline; the following cases are considered as instances of the three mentioned parameters (reliability, severity and impact on business). In the definitions below, the words, probability of / possibility of, show compatibility of this technique to the proactive approaches.

Reliability

1	(Likelihood of) main systems total failure (Likelihood of) total loss of aircraft control or integrity Very frequent similar reports in databases
2	(Likelihood of) main systems significant failure (Likelihood of) partial loss of aircraft control or integrity (structural damage) Frequent similar reports in databases
3	(Likelihood of) main systems failure (Likelihood of) minor loss of aircraft control or integrity (structural damage) similar reports in databases
4	(Likelihood of) subsidiary systems failure Superficial damage Very few similar reports in databases
5	No (likelihood of) system failure No (likelihood of) loss of control or damage No Similar reports

Severity

1	No (Probability or Possibility of) human injury, morbidity or mortality
2	(Probability or Possibility of) superficial injuries or botulism
3	(Probability or Possibility of) obvious injury our health problem leading to being hospitalized or partially paralysis
4	(Probability or Possibility of) few Fatalities or harsh injuries leading to being paralysis
5	passenger and crew death on ground or in air

Impact on Business

1	No delay/ change/ return of aircraft Continuation of flight in spite of failure
2	Flight delays less than 30 minutes
3	Aircraft change/Aircraft return delay more than 30 minutes and less than duration of first flight
4	Aircraft ground for more than 1 A check Delays more than duration of first flight
5	Total specific aircraft fleet grounding Aircraft crash

Based on the brainstorming and discussion with the experts and former deans of the quality control and assurance department of the airline the following regions have been recognized as hazard areas. Each of the 3D arrays represents (reliability, severity, impact on business) respectively.

Very high
(1,5,5) (1,4,5) (1,5,4) (2,5,5) (3,5,5) (4,5,5) (5,5,5)

High
(2,4,5) (2,4,4) (2,5,4) (1,3,5) (1,3,4) (1,4,4) (1,4,3) (1,5,3) (1,2,5) (1,2,4) (1,4,2) (1,5,2) (1,1,5) (1,1,4) (2,1,5) (2,5,1) (3,4,5) (3,4,4) (3,5,4) (2,5,3) (2,3,5) (2,4,3) (2,2,4) (2,4,2) (3,5,3) (5,5,4) (4,5,4) (4,4,5) (5,4,5) (2,5,2) (1,4,1) (2,3,4)) 1,5,1(

Medium
(3,3,5) (2,3,3) (3,3,4) (1,3,3) (3,3,3) (3,4,3) (4,3,5)(4,3,4) (4,3,3) (4,4,3) (4,5,3) (2,2,5) (2,2,3) (2,2,2) (2,3,2) (3,2,5) (3,2,4) (3,2,3) (3,3,2) (3,4,2) (3,5,2) (4,5,2) (4,4,2) (4,3,2) (4,2,3) (4,2,4) (4,2,5) (1,2,3) (1,3,2) (5,2,5) (5,2,4) (5,5,2) (5,4,2) (1,1,3) (2,1,3) (2,3,1) (2,4,1) (3,5,1) (4,5,1) (3,4,1) (3,3,1) (3,1,3) (3,1,4) (4,1,4) (5,4,1) (5,5,1) (5,3,5) (5,3,4)

(5,3,4) (5,5,3) (5,4,4) (4,4,4) (5,4,3) (3,1,5) (4,4,1) (2,1,4) (5,1,5)

Low

(4,1,5) (5,1,4) (5,3,3) (5,2,3) (5,3,2) (1,1,2) (2,1,2) (2,1,1) (3,2,1) (3,1,2) (5,1,3) (3,2,2) (5,3,1) (4,1,2) (4,2,2) (4,2,1) (4,3,1) (4,1,3) (1,2,2) (2,1,1)

Very Low

(5,1,2) (5,1,1) (5,2,1) (5,2,2) (4,1,1) (3,1,1) (2,2,1) (1,1,1)

high and very high risk regions compared to low and very low regions contain more pairs which is considered as a strength point of the proposed methodology because addition of the 3rd parameter (impact on business) enables that to capture the costly cases of low severity.

3.2) the numerical approach- AHP method

On one hand taking into account low risk costly safety issues may lead to financial losses in the organization [5], but on the other hand ignoring high risk cases may cause catastrophic incidences; therefore, thorough understanding and knowledge required for proper assessment of damages is of vital importance. The qualitative approach is not precise enough; for instance, in the mentioned cases the items (2,4,5),(3,4,5),(4,4,5) and (5,4,5)were embedded in the high risk region in spite of the wide range for reliability parameter (from 2 to 5).

Sometimes non-significant incidents happen regularly that increases the sensitivity to them. The AHP approach provides the capability of prioritizing among frequency, severity and cost of incidents and each component can be considered with a weighting coefficient indicating its importance compared to others in the analysis. For example, if for an airline the expenses are very important they will need to consider greater weighting factors for them.

The Analytic Hierarchy Process (AHP), known as Saaty method, derived and developed by Thomas. L. Saaty (1980) is a robust but flexible tool of decision making in hands of managers to take the most optimized and efficacious decisions by a pair-wise comparison technique. It is popular and widely used approach in many fields and area from military to aviation industry and even sanitary problems and explains applications ranging from the choice of a new place to live, through to the planning of transportation systems like aviation. It is applied on a wide range of various data and inputs including qualitative and quantitative aspects making them esoteric to compare and prioritize, then consolidate these desperate potpourri of comparisons in shape of a scalar number to facilitate the decision making process. The results finally applied to a various range of fields and areas including business, environment, finance, tourism and military. AHP method provides a suitable structure for modeling unstructured problems into hierarchical forms in which a series of pair wise comparisons is carried out. This comparison technique is accomplished by the aid of using a scale of 1-9, each indicating importance, preference or priority of one component in comparison with another as shown in table 2. For instance, if number 1 is considered for two parameters it means these two factors have the same priority from that airline's point of view. The outcome is a pair-wise comparison of "n" attributes with respect to each other, which are denoted in the form of a N*N matrix. A basic assumption in this method is that if attribute X is remarkably more important than attribute Y and is rated 7, then Y should be surely less important than X and is valued 1/7.

However, the most desired strength of this approach is its capability of considering a factor called consistency which is a tool for assessing how realistically the ratios have been defined. Exaggeration of judgments between the triple parameters may have been resulted by ignorance or randomness of the symptoms. if the Consistency Ratio (CR) has been calculated based on Saaty's formula and it is much in excess of 0.1, the judgments are untrustworthy because they are too close for comfort to randomness and the exercise is valueless or must be repeated.

In conventional techniques the risk criteria is defined as

Risk Index (RI) = Probability*Severity

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Table 2- AHP comparison table

But in the recent formulation the above criteria, is proportional to severity and impact on business and in reverse relation with reliability.

$$RI = RiskIndex = \frac{S^{A} \times I^{C}}{R^{A}} \qquad (1)$$

In which
R=Reliability, S=Severity, I= Impact on Business

- A= Weighting factor for reliability
- B= Weighting factor for severity
- C= Weighting factor for Impact on business

At the first level, the weighting coefficients are needed to be estimated based on previous experiences, database and airline's priority. In this new approach instead of probability, the reliability has been implemented for aircrafts which accounts for important items like

- Dossiers and records in the database
- Frequent carry forwards
- Technical Failure (Engine Shut down, engine stall, engine fire, landing retraction/extension, ...
- Operational Failure (take off abort, aircraft stall, maneuvering, …

The numerical analysis is accomplished in steps below:
1. The Overall Preference Matrix is build based on the pair wise priority and preference of parameters

$$\begin{bmatrix} & R & S & I \\ R & 1 & & \\ S & & 1 & \\ I & & & 1 \end{bmatrix}$$

2. Computation of the corresponding Eigen Vectors to come up with the overall value of each parameter as a scalar
3. Establishing the triple Option Performance Matrices (OPMs) comparing the reports based on reliability, severity and impact on business individually at the desired time schedules. By applying the info obtained from N reports, three N*N matrices are built.

$$\textbf{Relaibility} \begin{bmatrix} & \textbf{Report 1} & & \textbf{Report N} \\ \textbf{Report 1} & & & \\ & \vdots & \ddots & \vdots \\ \textbf{Report N} & & \cdots & \end{bmatrix}$$

$$\textbf{Severity} \begin{bmatrix} & \textbf{Report 1} & & \textbf{Report N} \\ \textbf{Report 1} & & & \\ & \vdots & \ddots & \vdots \\ \textbf{Report N} & & \cdots & \end{bmatrix}$$

$$\textbf{Relaibility} \begin{bmatrix} & \textbf{Report 1} & & \textbf{Report N} \\ \textbf{Report 1} & & & \\ & \vdots & \ddots & \vdots \\ \textbf{Report N} & & \cdots & \end{bmatrix}$$

4. Calculation of Eigen vectors for each of the OPM matrices. This matrix compares the N number of reports based on the three input parameters of reliability, severity and impact on business.

$$\begin{pmatrix} \textbf{Reliability} & \textbf{Severity} & \textbf{Impact On business} \\ \mathrm{R1} & \mathrm{S1} & \mathrm{I1} \\ \vdots & \vdots & \vdots \\ \mathrm{R\,N} & \mathrm{S\,N} & \mathrm{I\,N} \end{pmatrix}$$

5. Calculating consistency ratio (CR) for OPM matrices. If no ratio exceeds 0.1 then the judgments are not rejected.
6. Obtaining the risk index (RI) of each report by substituting the weighting coefficients and triple parameters into equation *(1)*
7. Estimating the field risk as

$$Field \quad Risk \quad (FR)_i = \frac{\sum_{i=1}^{N} (RI)_i}{N} \qquad (2)$$

In which
RI= risk index of report
N = Total number of received reports in the definite field
In this approach the safety criteria (as summation of risks) can be calculated for different fields which help to compare them and identify vulnerable sectors.
8. The Field risks from different sectors, Engineering and Maintenance, Flight Operation, Security, Airport Services, Dispatch, Training and Air Medical Centers, areas like ramp, hangar and … are summed up to result in the Overall Safety Index of the organization;

$$Overal \quad Risk \quad Index \quad (OSI) = \sum_{i=1}^{p} (W_i * FR_i) \qquad (3)$$

In which
FR_i = Field risk
W_i= Corresponding weighting coefficients for each field derived by same AHP comparison method
P=Number of operational fields (sectors/departments/areas).

4 - Practical Implementation

In this section based on the reporting database of an Iranian Airline including on board (flight) and ground reports, 45 flight reports with their Aircraft Technical Flight Logs (ATFL) and 25 ground reports for time duration of 1 month (July) was regarded to assess the risk status of the airline. Among the 45 flight reports, only five of them have been selected to be presented as in table 3 because of security matters. The same procedure will be done for five ground reports. In this reports freq stands for number of same category reports.

Title	Place (Phase)	Result	Freq
Engine Fire	Take off	flight Return 360 Min Delay Flight Cancel	1
Engine Failure	Approach	Emergency Landing	4
TCAS Failure	Cruise	Possibility of impact	10
Air pack failure	Cruise	Aircraft Return/Change 120Min. Delay	2
Tire Burst	Landing	Passenger fear	4

Table 3- Flight Safety Reports In Safety Database System For 1 Month In An Iranian Airline.

The following steps describe implementation of the new technique for these case studies.

1. Establishing the Overall Performance Matrix (OPM)
Based on a questionnaire filled out by the experts and retired deans of different departments including flight operations, engineering and maintenance, training, commerce and financial sector the following OPM is recommended.

$$\begin{bmatrix} & R & S & I \\ R & 1 & 1 & 5 \\ S & 1 & 1 & 5 \\ I & 1/5 & 1/5 & 1 \end{bmatrix}$$

2. The Eigen vector is computed to be **(0.22, 0.22, 0.04)** which shows for this organization reliability and severity of incidents posses the same importance being five times greater than financial concerns.

3. After thorough comparison of the reports the following Option Performance Matrices are obtained.

Reliability

1.00	0.33	0.20	0.14	0.11
3.00	1.00	0.33	0.20	0.14
5.00	3.00	1.00	0.33	0.20
7.00	5.00	3.00	1.00	0.33
9.00	7.00	5.00	3.00	1.00

Severity

1.00	7.00	5.00	7.00	9.00
0.14	1.00	3.00	5.00	5.00
0.20	0.33	1.00	3.00	5.00
0.14	0.20	0.33	1.00	3.00
0.11	0.20	0.20	0.33	1.00

Impact on business

1.00	7.00	9.00	5.00	7.00
0.14	1.00	3.00	0.33	1.00
0.11	0.33	1.00	0.20	0.14
0.20	3.00	5.00	1.00	5.00
0.14	1.00	7.00	0.20	1.00

4. The Eigen vectors of the three Option Performance Matrices indicate the weighted worthiness coefficients of each factor (reliability, severity and impact on business) for each of the reports.

	Reliability	**Severity**	**Impact on business**
Report 1	0.03	0.58	0.58
Report 2	0.06	0.20	0.08
Report 3	0.13	0.12	0.03
Report 4	0.26	0.06	0.21
Report 5	0.51	0.03	0.09

5. The Consistency Ratios (CRs), according to Saati's method, are 0.05, 0.11 and 0.11. the CR for reliability is less than 0.1 but for other two factors it exceeds the 0.1 limit but Saati's algorithm accepts this little different providing no evidence for misjudgment of experts in this analysis.

6. Substituting corresponding values int Eqation *(1)* results in the following risk indexes for flight reports.

Flight Reports Risk Index

Report 1	1.84
Report 2	1.16
Report 3	0.85
Report 4	0.68
Report 5	0.49

Therefore the first report titled "Engine No 2 suddenly got fired and rapidly spread to left wing" owns the highest risk and should be considered as the highest priority. After performing the same calculations regarding five of the ground operation reports the following risk index is obtained.

Ground Reports Risk Index

Report 1	**1.25**
Report 2	**0.43**
Report 3	**0.24**
Report 4	**0.89**
Report 5	**1.08**

7. The field risk of the Engineering and Maintenance sector is calculated based on equation *(2)* from report risks of each individual sector. The AHP technique considers different weighting coefficients for ground, flight and security reports, but here in this investigation only ground operation and flight reports are presented which possess the same importance from expert's point of view resulting in identical weighting coefficients of one. However, based on AHP techniques the field risk of each sector has been calculated.

8. Based on the field risk of various sectors, and by defining weighting factors for each sector based on AHP techniques, the overall risk index of the organization in accordance to *(3)* is found to be 3.104 for this airline for month July.

Engineering and Maintenance	1.004
Flight Operation	0.78
Airport Services	0.45
Security	0.10
Dispatch	0.12
Training	0.42
Air Medical Center	0.23
Overall Safety Index	3.104

Table 4- Overall And Field Safety Index In An Airline

Conclusion

By applying the new technique for a case study, the overall index of 3.104 is allocated to whole airline safety business issues, which is a basis for safety assessment of various sectors and a tool for definition of the safety business goals of the organization. For example decreasing this indicator within different time periods can be presented as safety-business goals of airline.

As it was illustrated, by these methods which cover both quantitative and qualitative approach to business-oriented safety reports, the more general monitoring of different sectors of an airline is viable especially in numerical method which more precisely integrates the qualitative matters in form of a numerical indicator.

Via these methods, all the reports regarding business continuity of airline are integrated in form of an indicator, by which the high ranking managers of airline, as well as safety, commercial or business experts, are able to keep track the situation of safety- business issues, their trends within different time duration, effectiveness of corrective actions and improvement of safety management system and the flaws and deficiencies will be determined [2].

The next stage of studies, providing a comprehensive, pervasive and intuitive perspective, is evaluating safety business issues in airline via fuzzy approach especially utilizing simulation techniques. [3], [4]. By using this methodology, another beneficial tool for analyzing the problematic safety-business issues is provided that can be subject of another paper in aviation risk assessment.

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