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ANALYSIS OF THE AVIATION SAFETY ISSUES USING TEM FRAMEWORK

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Subject review

This paper analyzes safety issues using Threat and Error Management (TEM) framework. Safety reports for the last decade were analyzed with special emphasis on year 2008. Causes of the accidents were determined and top three contributing factors were defined. Most common end states were identified and chains of events that led to them were analyzed. Furthermore, countermeasures were proposed in order to mitigate those safety concerns. Special care was taken to correctly identify those safety issues that stemmed from inefficient safety management systems, especially on the Operator's level. Even though there is a general industry standard regarding safety management systems, it still has to be customized and optimized by each operator in order to gain the most out of it. Organizational procedures vary significantly from one operator to the other, reflecting size and structure of the monitored fleet, size of the operator and its engineering power. Therefore, it is often hard to adapt the safety management system to fit these organizational procedures. This inconsistency is a common contributing factor to aviation accidents.

Keywords: *accident analysis, aviation safety, safety management system, TEM framework*

Analiza sigurnosnih problema u zrakoplovstvu korištenjem TEM metode

Pregledni članak

Ovaj rad analizira sigurnosne probleme korištenjem modela upravljanja ugrozama i greškama (TEM – Threat and Error Management). Analizirana su izvješća o nesrećama koje su se dogodile u proteklom desetljeću, s posebnim naglaskom na 2008. godinu. Utvrđeni su njihovi uzroci te tri faktora koja su najviše doprinijela njihovom događanju. Identificirana su najčešća krajnja stanja i lanci događaja koji su doveli do njih. Predložene su protumjere sa svrhom ublažavanja ovih sigurnosnih problema. Poseban je naglasak dan na pravilnu identifikaciju sigurnosnih problema koji su proistekli iz neučinkovitih sustava upravljanja sigurnošću, posebno gledano iz perspektive zrakoplovnih prijevoznika. Iako postoji općeniti industrijski standard primjene sustava upravljanja sigurnošću, on ipak mora biti prilagođen potrebama pojedinog prijevoznika, kako bi se osiguralo njegovo optimalno iskorištenje. Zbog razlika u veličini i strukturi flotâ prijevoznika, organizacijski postupci značajno se mijenjaju te je često teško prilagoditi sustav upravljanja sigurnošću tim organizacijskim postupcima. To je često faktor koji pridonosi nesreći.

Ključne riječi: *analiza nesreća, sigurnost u zrakoplovstvu, sustav upravljanja sigurnošću, TEM metoda*

1 Uvod
Introduction

The International Air Transport Association (IATA) represents around 230 airlines comprising 93 % of scheduled international air traffic. IATA's global reach extends to 115 nations through 73 offices in 67 countries [1]. At the beginning of each year the IATA publishes the annual safety report for the past year, so, at the beginning of 2009 IATA published the safety report for the year 2008.

The purpose of this paper is to clearly show areas of concern and to help airline industry manage safety issues that were dominant in the previous year and the whole decade. This paper analyzes accidents that occurred during the 2008, finds causes for these accidents and prescribes solutions and improvement guidelines for the future.

2 Decade in review
Pregled desetljeća

The last decade has seen the constant increase in traffic, from around 1 700 million passengers carried in 1999 to around 2 500 million passengers carried in 2008 [2]. Even though the traffic has been increasing, the fatality rates have continued to decline on a 10-year basis due to technical and operational improvements (Figure 1). When comparing 2008 to 2007 regionally, the accident rates in the Commonwealth of Independent States (CIS), Latin America and the Caribbean, the Middle East and North Africa, North America and Europe increased while in Africa, Asia/Pacific and North Asia, the accident rates decreased.

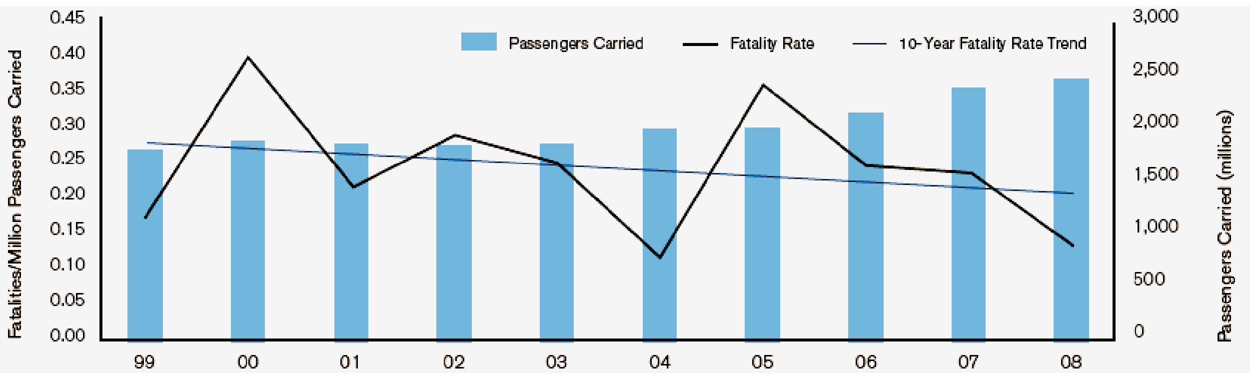

Figure 1 *Western-built Jet Aircraft: Passengers Carried and Passenger Fatality Rate (1999-2008)* [2]
Slika 1. *Zapadni mlazni zrakoplovi: Broj prevezenih putnika i stopa pogibelji putnika (1999.-2008.)* [2]

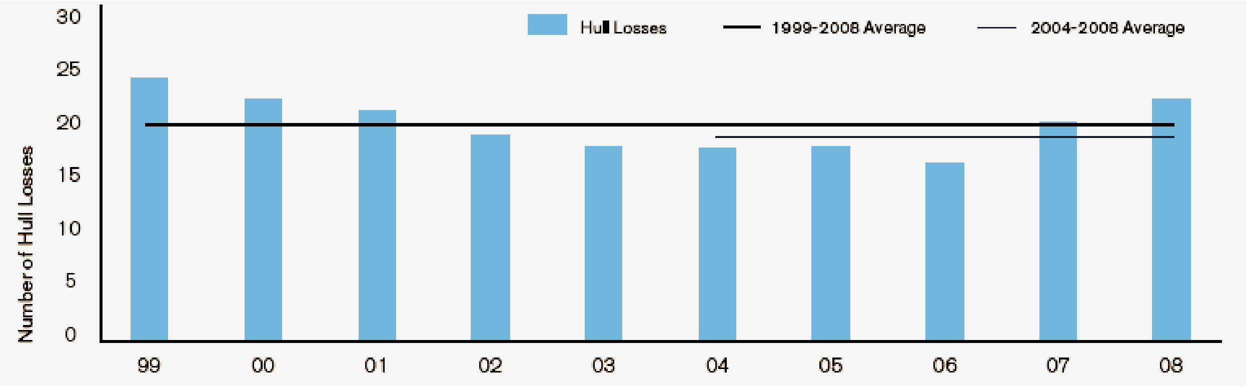

Figure 2 *Western-built Jet Aircraft Hull Losses (1999-2008)* [2]
Slika 2. *Broj uništenih zapadnih mlaznih zrakoplova (1999.-2008.)* [2]

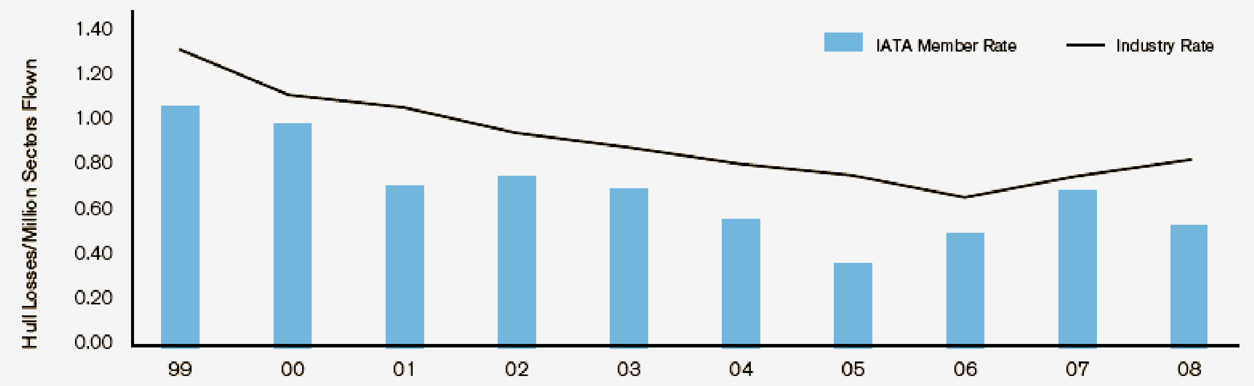

Figure 3 *Western-built Jet Aircraft Hull Loss Rate: IATA Member Airlines vs. Industry (1999-2008)* [2]
Slika 3. *Stopa uništenih zapadnih mlaznih zrakoplova: Članice IATA-e i ukupno (1999.-2008.)* [2]

The last 5-year average number of hull losses is marginally lower than the 10-year average number of hull losses (Figure 2), however, when the increase in traffic is accounted for, decline in hull loss rate is obvious (Figure 3). Also, when comparing overall industry hull loss rate with IATA members hull loss rate, the latter is significantly lower, thus indicating superior safety standards (Figure 3).

3
Year 2008 in review
Pregled 2008. godine

During the year 2008 global airlines operated a fleet of around 33 100 aircraft, of which the majority were western-built jet aircraft (21 514) followed by western-built turboprop aircraft (7 345). The rest were eastern-built aircraft.

The western-built jet aircraft account for 86 % of total hours flown worldwide with western-built turboprop aircraft accounting for additional 11 %. Among themselves, they carried 2 618 million passengers which is 98,5 % of all the passengers carried during the 2008 worldwide.

109 accidents occurred during the year 2008, out of which 30 % involved IATA member airlines. Out of these 109 accidents, 23 were with fatalities and the total number of fatalities was 502.

The most dangerous part of the flight was landing with 43 % of accidents happening during that phase of flight. Half of accidents resulted in hull loss and the other half in substantial damage.

4
Threat and Error Management (TEM) framework
Metoda upravljanja ugrozama i greškama (TEM)

Threat and Error Management (TEM) was developed as a conceptual framework to interpret data obtained from both normal and abnormal operations. It assists in understanding the relationship between safety and human performance, from an operational perspective, in challenging and dynamic operational contexts [3]. The TEM framework is used to describe and diagnose both human and system performance. It can be applied, as an analytical tool, to a single accident or it can be used to understand patterns within a large data set.

The TEM framework can be summarized as shown in Figure 4.

Latent Conditions: Conditions present in the system before the accident, made evident by triggering factors. These often relate to deficiencies in organisational processes and procedures.

Threat: An event or error that occurs outside the influence of the flight crew, but which requires flight crew attention and management to properly maintain safety margins.

Flight Crew Error: An observed flight crew deviation from organisational expectations or crew intentions.

Undesired Aircraft State (UAS): A *flight-crew-induced* aircraft state that clearly reduces safety margins; a safety-compromising situation that results from ineffective threat/error management. An undesired aircraft state is recoverable.

End State: An end state is a reportable event. An end state is unrecoverable.

Figure 4 *TEM framework* [2]
Slika 4. *TEM metoda* [2]

Distinction between "Undesired Aircraft State" and "End State": An unstable approach is recoverable. This is a UAS. A runway excursion is *unrecoverable*. Therefore, this is an End State [2].

Analyzing the path from threats to end states can be most easily explained by using TEM subframework for analyzing flight crew's responses to threats and errors (Figure 5). When considering risk-threat relation it is obvious that risks come from both expected and unexpected threats. Expected threats include such factors as terrain, predicted weather, and airport conditions while those unexpected include ATC commands, system malfunctions, and operational pressures. Risk can also be increased by errors made outside the cockpit, for example, by ATC, maintenance, and dispatch. That is the point where flight crew TEM model receives input from ATC, maintenance or dispatch TEM model. External threats are countered by the defenses provided by crew resource management (CRM) behaviors. When successful, these lead to a safe flight.

The response by the crew to recognized external threat or error might be an error, leading to a cycle of error detection and response. In addition, crews themselves may errors in the absence of any external precipitating factor. Again crew resource management behaviors stand as the last line of defense. If the defenses are successful, error is managed and there is recovery to a safe flight. If the defenses are breached, they may result in additional error or an accident or incident [4].

Types of accidents, or End States in TEM framework terminology, can be divided into following categories: controlled flight into terrain, gear-up landing/gear collapse, ground damage, hard landing, in-flight damage, loss of control in-flight, mid-air collision, runway collision, runway excursion, tailstrike and undershoot.

Referring to these accident categories helps an operator to:

- Structure safety activities and set priorities
- Avoid "forgetting" key risk areas, when a type of accident does not occur on a given year
- Provide resources for well-identified prevention strategies
- Address these categories both systematically and continuously within the airline's safety management system [2].

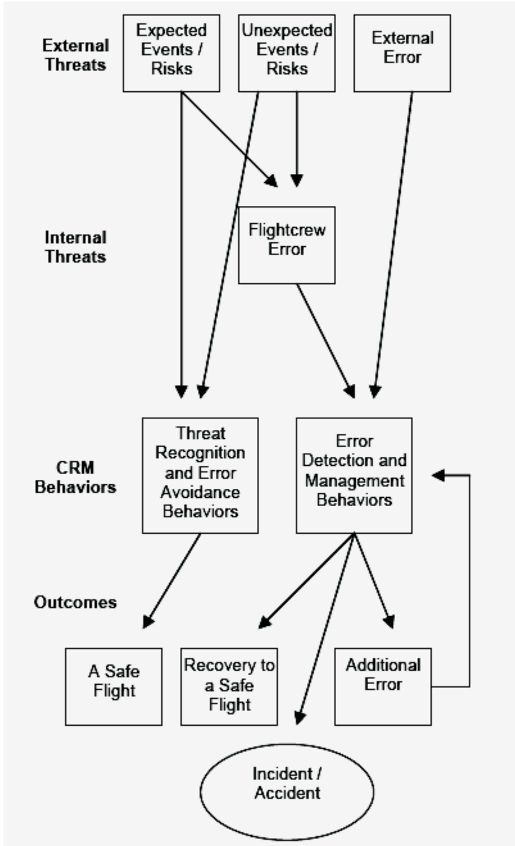

Figure 5 *The Model of Flight Crew Error Management* [2]
Slika 5. *Model upravljanja greškama kod posade zrakoplova* [2]

5
Analysis of accident data
Analiza podataka o nesrećama

This safety report relies on data collected through national accident reports which are, in some cases, hard to get by in time for completion of the report. Surely, accident reporting should be timelier than it is now. In other cases, unfortunately, causes of accidents were not known and investigations were still underway. For those accident reports that were timely and comprehensive, a list of top three contributing factors has been made (Table 1).

5.1
Runway Excursion
Izlijetanje sa staze

- Runway excursion was the most frequent type of accident in 2008, accounting for 25 % of accidents.
- Over half (57 %) of runway excursions resulted in a hull loss and 14 % of them involved fatalities.
- Flight crew handling errors, deficient airport facilities and aircraft malfunctions were among the top contributing factors in this type of accident.

Table 1 *Top 3 contributing factors according to the TEM framework*
Tablica 1. *Tri glavna faktora koja su pridonijela nesreći po TEM metodi*

	Top 3 Contributing Factors
Latent conditions (deficiencies in...)	1. Safety management 2. Regulatory oversight 3. Flight operations: training systems
Threats	1. Aircraft malfunction 2. Meteorology 3. Airport facilities
Flight crew errors relating to…	1. Manual handling/flight controls 2. SOP adherence/cross-verification 3. Pilot-to-pilot communication
Undesired Aircraft States	1. Vertical, lateral or speed deviations 2. Long, floated, bounced, firm or off-centreline landing 3. Unstable approach
End States	1. Runway excursion 2. Ground damage 3. In-flight damage

5.2 Ground Damage
Oštećenje na zemlji

- Ground damage was the second most predominant type of accident, following runway excursions.
- Ground damage events accounted for 17 % of all of last year's accidents; half of these involved IATA member airlines.
- Well over a third (38 %) of ground damage accidents cited ground events, such as errors by ground handling personnel, as a contributing factor.

5.3 Safety Management System
Sustav upravljanja sigurnošću

- In almost a third (30 %) of accidents, deficient safety management on the part of the Operator was noted as a contributing factor.
- This includes deficiencies with regard to the Operator's safety policies and objectives, risk management, safety assurance and safety promotion.
- The majority (69 %) of accidents involving deficiencies in the Operator's safety management also implicated deficient regulatory oversight by the State.

5.4 Safety in Maintenance Operations
Sigurnost pri održavanju

- Almost half (42 %) of the accidents in 2008 related to an aircraft malfunction.
- In over half (57 %) of the accidents involving a maintenance event, deficiencies in the Operator's maintenance operations were also noted as a contributing factor.
- These include: deficiencies in technical documentation, unrecorded maintenance, the use of bogus parts, unapproved modifications and deficient training of maintenance personnel.

5.5 Regional Safety Issues
Regionalni sigurnosni problemi

- Operators based in the Commonwealth of Independent States (CIS) and Latin America and the Caribbean, had the highest regional accident rates in 2008 and experienced the highest increase in their accident rates, when compared to 2007.
- Almost a third (30 %) of the accidents involving CIS Operators were fatal; over a quarter (26 %) of those implicating Latin American and the Caribbean based carriers, also resulted in fatalities.
- Aircraft malfunctions, deficiencies in the Operator's safety management and the State's regulatory oversight as well as non-adherence to Standard Operating Procedures by flight crews were among the top contributing factors to accidents involving Operators from these two regions.

6 Proposed Countermeasures
Prijedlog protumjera

Based on the statistical analysis, this section presents some countermeasures that can help airlines enhance safety, in line with the analysis of all accidents in 2008.

Countermeasures are aimed at two levels:

- The Operator or the State responsible for oversight. These countermeasures are based on activities, processes and systemic issues internal to the airline operation or State's oversight activities.
- Another set of countermeasures are aimed at flight crew, to help them manage threats or their own errors during operations.

6.1 Countermeasures for the Operator and the State
Protumjere za prevozitelja i državu

Safety management (Operator): The concept of safety management is becoming more and more prominent in the aviation sector. Air vehicle airworthiness has been assured, historically, by the application of design specification and regulations. However, in order to maintain airworthiness and safety in future, ICAO has introduced new 2008 (Annex 6) regulations requiring operators in the civil aerospace regime to have generated and be operating a Safety Management System (SMS) within two years [5].

The Operator should implement a safety management system accepted by the State that, as a minimum:

- Identifies safety hazards
- Ensures that remedial action necessary to maintain an acceptable level of safety is implemented
- Provides for continuous monitoring and regular assessment of the safety level achieved
- Aims to make continuous improvements to the overall level of safety.

Regulatory oversight by the State of the Operator: States must be responsible for establishing a safety programme, in order to achieve an acceptable level of safety, encompassing the following responsibilities:

- Safety regulation
- Safety oversight
- Accident/incident investigation
- Mandatory/voluntary reporting systems
- Safety data analysis and exchange
- Safety assurance
- Safety promotion.

Flight operations - Training systems: Adequate training must be in place including: language skills, a set minimum qualification of flight crews, continual assessment of training and training resources including training manuals or computer-based training (CBT) devices.

Flight Operations - SOPs & checking (Operator): Ensure the Operator addresses clearly: Standard Operating Procedures (SOPs), operational instructions and/or policies, company regulations, controls to assess compliance with regulations and SOPs.

Maintenance Operations: SOPs & checking (Operator, even if outsourced): Ensure the Operator addresses clearly: Standard Operating Procedures (SOPs), operational instructions and/or policies, company regulations, controls to assess compliance with regulations and SOPs for maintenance activities, whether these are conducted in-house or they are outsourced.

- Includes verification of proper technical documentation, records of maintenance activities and the use of approved parts/modifications

Properly maintained reliability program enables operators to monitor and gradually improve fleet reliability by optimizing maintenance program and taking other measures in improving its organization. Reliability program discovers problems in the operators system and trends that are triggered by many events. Such problems have large impact on flight safety and/or economics of an operator [6].

6.2 Countermeasures for the Flight Crews
Protumjere za posade zrakoplova

Monitor/cross-check: Crew members should actively monitor and cross-check flight path, aircraft performance, systems and other crew members. Aircraft position, settings, and crew actions are verified.

Overall crew performance: Overall, crew members should perform well as risk managers. Includes Flight, Cabin, Ground crew as well as their interactions with ATC.

Contingency management: Crew members should develop effective strategies to manage threats to safety (i.e., threats and their consequences are anticipated; use all available resources to manage threats).

Communication environment: Environment for open communication is established and maintained. Good cross talk – flow of information is fluid, clear, and direct. No social or cultural disharmonies. Right amount of hierarchy gradient. Flight Crew member reacts to assertive callout of other crew member(s).

Leadership:

- **Captain** should show leadership and coordinated flight deck activities (e.g., In command, decisive, and encourages crew participation).
- **First Officer** (FO) is assertive when necessary and is able to take over as the leader (e.g., F/O speaks up and raises concerns).

7 Conclusion
Zaključak

This paper used data from the ICAO Safety Report in order to assess major safety concerns of the year 2008. For the purpose of that analysis threat and error management (TEM) framework was used. Some of the major safety issues identified were:

- Runway excursion
- Ground damage
- Safety Management System issues
- Maintenance issues
- Regional safety issues.

Also, based on statistical analysis, ten countermeasures were proposed; five for the Operator and the State, and five for the Flight Crews. Countermeasures for the ATC or ground crews were not considered.

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