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**Volodymyr Kharchenko**, Dr. Sci. (Eng.), Prof.  
**Yuriy Chynchenko**, PhD  
**Stefan Raychev**, post-graduated

## THREAT AND ERROR MANAGEMENT IN AIR TRAFFIC CONTROL

*This article describes an overarching safety framework intended to contribute to framework the management of safety in civil aviation operations, known as Threat and Error Management.*

*Розглянуто загальну структуру забезпечення безпеки польотів за допомогою методики керування небезпеками та помилками (TEM) при організації діяльності цивільної авіації.*

### Introduction

Threat and Error Management (TEM) is an overarching safety concept regarding aviation operations and human performance. Threat and Error Management is not a revolutionary concept, but one that has evolved gradually, as a consequence of the constant drive to improve the margins of safety in aviation operations through the practical integration of Human Factors knowledge.

The main objective of introducing the TEM framework to the Air Traffic Services (ATS) community in general, and the Air Traffic Control (ATC) community in particular, is to enhance aviation safety and efficiency.

This is achieved by providing an operationally relevant and highly intuitive framework for understanding and managing system and human performance in operational contexts.

A further objective in introducing TEM is to lay the foundation for ATS providers for the adoption of a TEM-based tool that involves the monitoring of safety during normal operations as part of ATC safety management systems.

The name of this tool is the Normal Operations Safety Survey (NOSS) [1].

It must be made clear from the outset that TEM and NOSS are neither human performance/Human Factors research tools, nor human performance evaluation/assessment tools [2-6].

TEM and NOSS are operational tools designed to be primarily, but not exclusively, used by safety managers in their endeavours to identify and manage safety issues as they may affect safety and efficiency of aviation operations.

### The Threat and Error Management framework

The TEM framework is a conceptual model that assists in understanding, from an operational perspective, the inter-relationship between safety and human performance in dynamic and challenging operational contexts (fig. 1).

The TEM framework focuses simultaneously on the operational context and the people discharging operational duties in such a context. The framework is descriptive and diagnostic of both human and system performance. It is descriptive because it captures human and system performance in the normal operational context, resulting in realistic descriptions. It is diagnostic because it allows quantifying the complexities of the operational context in relation to the description of human performance in that context, and vice-versa.

The TEM framework can be used in several ways. As a safety analysis tool, the framework can focus on a single event, as is the case with accident/incident analysis; or it can be used to understand systemic patterns within a large set of events, as is the case with operational audits. The TEM framework can be used to inform about licensing requirements, helping clarify human performance needs, strengths and vulnerabilities, thus allowing the definition of competencies from a broader safety management perspective [3]. Subsequently the TEM framework can be a useful tool in On-the-Job Training (OJT).

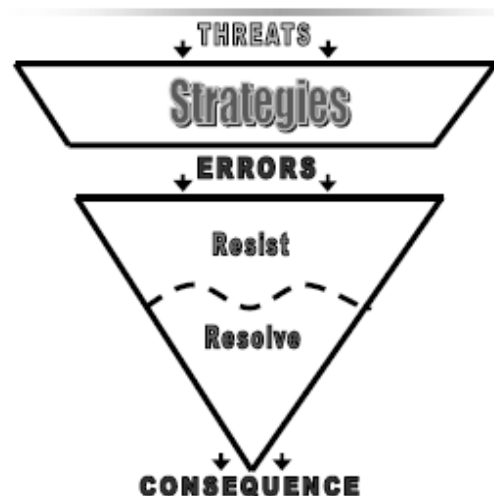


Fig. 1. Threat and Error Management description

The TEM framework can be used as guidance to inform about training requirements, helping an organization improve the effectiveness of its training interventions, and consequently of its organizational safeguards.

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". During typical ATC operations, air traffic controllers have to take into account various contextual complexities in order to manage traffic. Such complexities would include, for example, dealing with adverse meteorological conditions, airports surrounded by high mountains, congested airspace, aircraft malfunctions, and/or errors committed by other people outside of the air traffic control room (i.e. flight crews, ground staff or maintenance workers). The TEM framework considers these complexities as threats because they all have the potential to negatively affect ATC operations by reducing margins of safety.

Some threats can occur unexpectedly, such as pilots carrying out instructions which were intended for another aircraft as a result of call sign confusion. In this case, air traffic controllers must apply skills and knowledge acquired through training and operational experience to manage the situation.

Regardless of whether threats are expected or unexpected, one measure of the effectiveness of an air traffic controller's ability to manage threats is whether threats are detected with the necessary anticipation to enable the air traffic controller to respond to them through deployment of appropriate countermeasures.

Errors are defined as "actions or inactions by the air traffic controller that lead to deviations from organizational or air traffic controller intentions or expectations". Unmanaged and/or mis-managed errors frequently lead to undesired states. Errors in the operational context thus tend to reduce the margins of safety and increase the probability of an undesirable event.

Regardless of the type of error, its effect on safety depends on whether the air traffic controller detects and responds to the error before it leads to an undesired state, or if unaddressed, to an unsafe outcome. This is why one of the objectives of TEM is to understand error management (i.e. detection and response), rather than focusing solely on error causality (i.e. causation and commission). From a safety perspective, operational errors that are detected in a timely manner and are promptly countered (i.e. properly managed), and errors that do

not lead to undesired states or do not reduce margins of safety in ATC operations become operationally inconsequential. In addition to its safety value, proper error management represents an example of successful human performance, presenting both learning and training values.

Undesired states are defined as "operational conditions where an unintended traffic situation results in a reduction in margins of safety". Undesired states that result from ineffective threat and/or error management may lead to compromised situations and reduce margins of safety in ATC operations. Often considered the last stage before an incident or accident, undesired states must be managed by air traffic controllers. Examples of undesired states would include an aircraft climbing or descending to another flight level/altitude than it should; or an aircraft turning in a direction other than flight planned or directed. Events such as equipment malfunctions or flight crew errors can also reduce margins of safety in ATC operations, these however are considered to be threats. Undesired states can be managed effectively, restoring margins of safety, or the air traffic controller's response(s) can induce an additional error, incident, or accident.

An important learning and training point for air traffic controllers is the timely switching from error management to undesired state management. An example would be as follows: if after a data entry error it is found that an aircraft has climbed to a flight level other than it should (undesired state), controllers must give higher priority to dealing with the potential traffic conflict (undesired state management) rather than correcting the data entry in the system (error management).

The training and remedial implications of the differentiation between undesired states and outcomes are of significance. While at the undesired state stage, the air traffic controller has the possibility, through appropriate TEM, of recovering the situation, and returning it to a normal operational state, thereby restoring the required margins of safety. Once the undesired state becomes an outcome, recovery of the situation without loss of safety margins is no longer possible. This is not to imply that air traffic controllers would not attempt to mitigate the impact of the outcome, but that the margins of safety were compromised and must therefore be restored.

Fig. 2 presents a graphic summary of the Threat and Error Management framework. It is suggested that the dotted lines represent paths that are less common than those indicated by the unbroken lines.

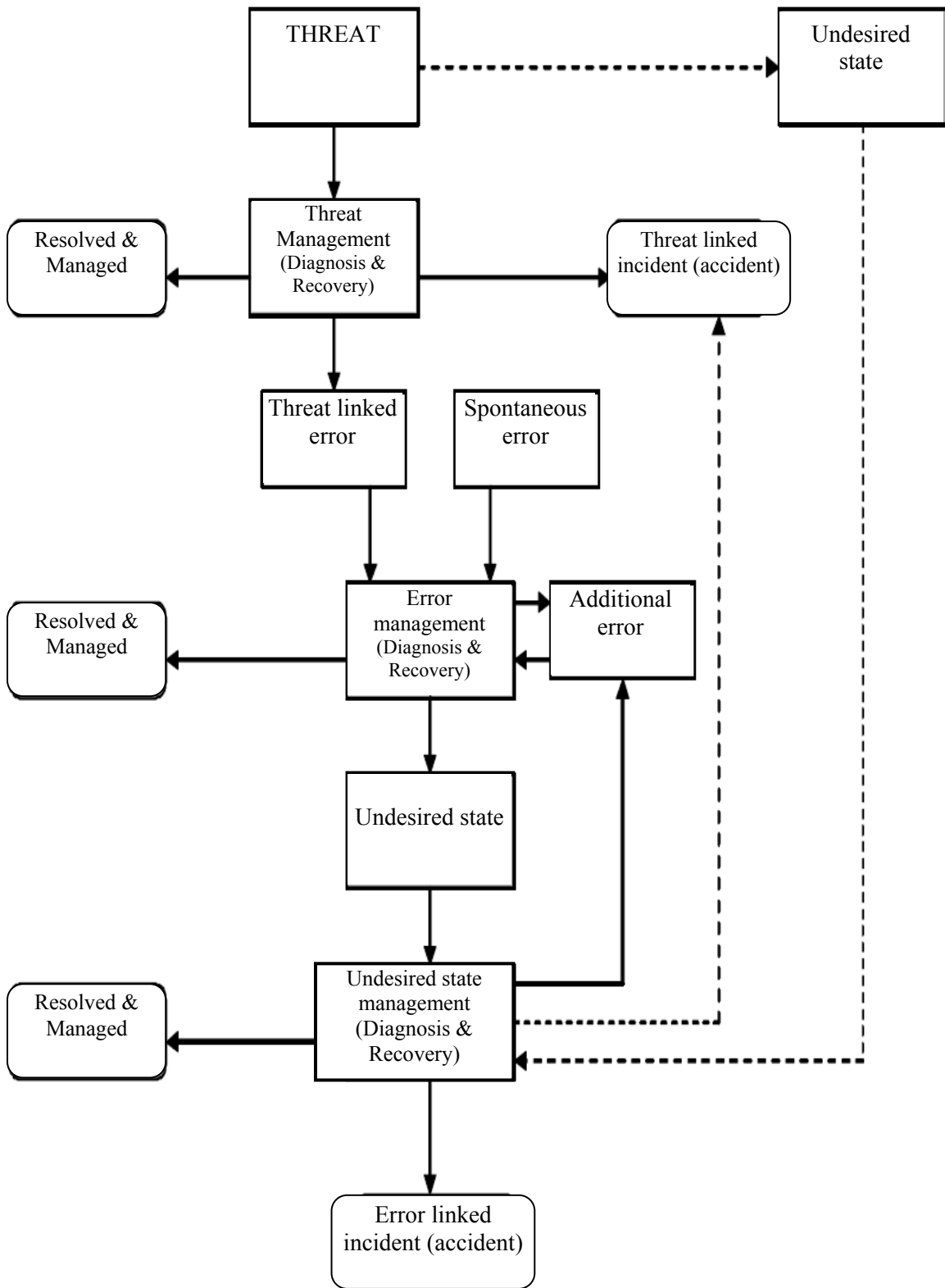


Fig. 2. Threat and Error Management framework

### Threat and Error Management in ATC

When the TEM framework is introduced to operational aviation personnel (air traffic controllers, pilots, etc.) the common reaction is one of recognition. Operational personnel have been aware of the factors that are considered as "threats" in the TEM framework almost since the start of their aviation careers. The difference is that this awareness used to be implicit whereas the TEM framework makes it explicit, principled and therefore manageable.

Threats in ATC can be grouped into the following four broad categories:

- Internal to the Air Traffic Service Provider (ATSP);
- External to the ATSP;
- Airborne;
- Environmental.

These four categories can be subdivided into other categories as presented in the tab. 1 below as an example.

Table 1

Categories of threats

ATSP Internal	ATSP External	Airborne	Environmental
Equipment	Airport Layout	Pilots	Weather
Workplace Factors	Navigation Aids	Aircraft Performance	Geographical
Procedures	Airspace Infrastructure/Design	R/T Communication	
Other Controllers	Adjacent Units	Traffic	Distraction

Awareness about these threats will assist the deployment of both individual and organizational countermeasures to maintain margins of safety during normal ATC operations.

### Errors in Air Traffic Control

Operational personnel in ultrasafe industries, of which aviation is a perfect example, do not adopt courses of action merely by choosing between a good and a bad outcome. Rather they adopt courses of action that seem to be the best in the light of their training, experience and understanding of the situation. They make sense of the operational context in which they are immersed, based upon cues and clues provided by the context of the situation. Only afterwards, when the result of such attempt at making sense is known (the outcome), is it possible to suggest, with the benefit of hindsight, that a different view would probably have resulted in a more desirable outcome.

Under TEM, a threat is not a problem as such in and of itself, but it could develop into one if not managed properly. Not every threat leads to an error, and not every error leads to an undesired state, yet the potential is there and so should be recognized. For example, visitors in an ATC operations room are a "threat": their presence in itself is not a dangerous situation, but if the visitors engage in discussions with the ATC crew or otherwise distract them, they might lead the controller to make an error. Recognizing this situation as a threat will enable the controllers to manage it accordingly, thereby minimizing or preventing any distraction and thus not allowing the safety margins in the operational context to be reduced.

Specific examples of errors in air traffic control from the perspective of TEM are included hereunder (tab. 2). The list is illustrative and not comprehensive.

### A safety investigation perspective

As an example of the retrospective application of the TEM framework the following represents a list (non-exhaustive) of threats from the controller's perspective that could be identified from the investigation into this mid-air collision:

- a) no information was provided to the controller about scheduled maintenance work;
- b) maintenance was scheduled to be performed on multiple systems simultaneously;
- c) the ATC system was only available in a degraded mode with reduced functionality;
- d) no training for working with the ATC system in a degraded mode was provided;
- e) a delayed and unexpected flight to a regional airport in the airspace had to be accommodated;
- f) a second working position had to be opened in order to handle the flight to the regional airport;
- g) there was a technical failure in the back-up phone system (which the controller had to use to coordinate the in-bound flight with the regional airport);
- h) a single-person nightshift culture prevailed at the Area Control Centre (ACC) concerned;
- i) there were blocked simultaneous transmissions in the Radio Telephony (R/T) communication.

If the outcome of the event had been different (i.e. the aircraft had passed each other or separation had been maintained) these same threats would still have existed. From a safety management perspective this suggests that corrective action can and should be taken as soon as threats have been identified (i.e. before any negative outcomes draw attention to their existence).

Table 2

**Specific examples of errors in air traffic control**

Equipment handling errors	<p>Radar usage: selecting an inappropriate radar source; selecting an inappropriate range, not selecting the correct mode (SSR on/off, mode C on/off).</p> <p>Automation: making incorrect inputs to the automated system.</p> <p>Radio/intercom: incorrect frequency selected; selecting an incorrect button/address on the intercom; transmitting while another transmission is in progress.</p> <p>Flight progress strips: incorrect placement of strips on flight progress board; strips placed in incorrect stripholders (colour coding); strips not passed to correct controller</p>
Procedural errors	<p>Handover at working position: omitted/incorrect items; rushed handover; leaving the position before new controller is ready to take over.</p> <p>Information: information about approach/departure procedure not or not timely provided to pilots; information about weather/ATIS not or not timely provided to pilots; information about status of navigational aids not or not timely provided to pilots.</p> <p>Documentation: wrong approach/departure charts used; briefing material not read.</p> <p>Checklists: items missed, checklist not used or at the wrong time.</p> <p>Separation minimums: wrong separation minimum applied (i.e. Wake Turbulence Separation)</p>
Communication errors	<p>ATC to pilots: missed calls; misinterpretations of requests; incorrect hear-back; wrong clearance, taxiway, gate or runway communicated.</p> <p>Controller to controller: within unit miscommunication or misinterpretation; miscommunication or misinterpretation during coordination with an external partner</p>

Table 3

**Threat and error countermeasures for ATC**

Countermeasure	Description
<b>Team Climate</b>	
Communication Environment Leadership Overall Team Performance	<p>Environment for open communication is established and maintained</p> <p>Supervisor shows leadership and coordinated the team/sector/unit activities</p> <p>Overall, team performs well as risk managers</p>
<b>Planning</b>	
Briefing Plans Stated Contingency Management	<p>An interactive and operationally thorough briefing is provided</p> <p>Operational plans and decisions are communicated and acknowledged</p> <p>Team members develop effective strategies to manage threats to safety</p>
<b>Execution</b>	
Monitor/Cross-check Workload Management  Automation Management  Flight Strip Management	<p>Team members actively monitor and cross-check other team members</p> <p>Operational tasks are prioritised and properly managed to handle primary ATC duties</p> <p>Automation is properly managed to balance operational and/or workload requirements</p> <p>Flight strips are properly organized and updated to keep track of traffic developments</p>
<b>Review/Modify</b>	
Evaluation of Plans Inquiry	<p>Existing plans are reviewed and modified when necessary</p> <p>Team members are not afraid to ask questions to investigate and/or clarify current plans of action</p>

## Managing Threats and Errors

The first step in the process of managing threats is threat identification. As an example, a meteorological office that provides regular weather forecasts already constitutes a way to understand bad weather as a threat. Likewise, a controller may ask aircraft about wind (direction and speed) at a certain altitude or level, to be able to provide more accurate radar vectors.

A further step is to share real-time information about the existence of threats with other controllers. To use an example of "aircraft performance", when observing the climb performance of a B747 with a destination relatively close to the departure airport the tower controller could alert the departure controller to the fact that the B747 is climbing faster than average. Passing information about differing wind speeds and directions at different altitudes from one controller to the next is another example of sharing knowledge about threats.

In the case of "environment" being a threat, managing it can be made easier for controllers if the high terrain or obstacles are depicted on the radar map. This applies as well for residential areas that must be avoided for noise abatement purposes below certain altitudes or during certain hours. If these areas can be presented on the radar map when necessary, controllers will be able to manage the threat more adequately.

At the individual level, threats can also be managed by keeping track of the number of threats that are present at any given time. The more threats there are at the same time, the more reason there may be to adjust the operation as it is being carried out at that moment.

As a general rule, it could be said that the greater the lead-time between threat identification and when the threat manifests itself, the better the chance there is that the threat will be adequately managed. Briefings about expected survey flights, photo flights, road traffic control missions, etc. will enable, including this traffic, in the planning. Without a briefing, such additional workload may come as a surprise and could disrupt the operation.

The following tab. 3 shows threat and error countermeasures for ATC.

## Conclusions

The notion of undesired states is unique to the process of monitoring safety in normal operations. An undesired state is transient in nature – it only exists for a limited period of time, after which the undesired state becomes an outcome (that is, either a resolved or managed situation, an incident or an

accident). Conventional safety data collection systems only become active after an outcome is classified as potentially consequential to safety, i.e. after an incident or accident has taken place, or some infringement of regulations, procedures, or instruction has occurred. Nothing can be done to change an outcome, for an outcome is an end-state.

Examples of undesired states – on the ground:

- 1) aircraft continuing taxiing when/where it should stop; aircraft stopping when/where it should continue taxiing;
- 2) aircraft entering a taxiway that it shouldn't use; aircraft not entering a taxiway that it should use;
- 3) aircraft proceeding to another gate/stand than where it should go;
- 4) aircraft making a pushback from the gate when it should hold; aircraft holding at the gate when it should be pushing back;
- 5) aircraft vacating the runway at another position than where it should; aircraft not vacating the runway at the position where it should.

Examples of undesired states – airborne:

- 1) aircraft not turning when it should; aircraft turning when it should not; aircraft turning in direction other than that flight planned;
- 2) aircraft climbing/descending to another flight level/altitude than it should; aircraft not climbing or descending to the flight level/altitude where it should;
- 3) aircraft not reaching the required flight level/altitude at the time/point when/where it should.
- 4) aircraft flying to another waypoint/position than where it should; aircraft not flying to the waypoint/position where it should;
- 5) aircraft flying at another speed than it should.

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