# Operational Fidelity in Simulation-Based Training: The Use of Data from Threat and Error Management Analysis in Instructional Systems Design.

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**Abstract.** A crucial aspect of the effectiveness of simulation-based training is the notion of fidelity. Typically, research and development in relation to simulation fidelity has focussed on achieving high levels of visual, kinaesthetic and functional realism. While this approach has lead to significant advancements in simulator-based training, there remains a need to develop mechanisms to ensure that training is responsive to the real operational needs of an organisation. This approach is termed "operational fidelity" and can be defined as ensuring the simulation is an authentic representation of the complex operational environment of an organisation. Methods currently used for understanding the operation of complex systems, such as modern aircraft, frequently adopt an abstracted approach to data acquisition. For instance, Cognitive Task Analysis is used to inform Instructional Systems Design through the decomposition and analysis of individual work elements. While these approaches to Instructional Systems Design provide a robust empirical method for the detailed analysis of system operation, they do not provide sufficient information to an organisation about the complex contextual factors that influence everyday operatoional performance. Accordingly, new tools need to be utilised in order to adopt a data-driven approach to simulator-based training. This paper describes in detail a new methodology to ensure enhanced simulator-based training through increased operational fidelity. Focussing on an example from the commercial aviation setting, the study details how data from the analysis of Threat and Error Management actions undertaken by flight crew during normal operations can be utilised in the development of scenario-based training. The paper outlines a four-stage process in scenario development and highlights the potential for such an approach to Instructional Systems Design in a variety of training environments.

## 1. INTRODUCTION

### 1.1 Fidelity in simulator-based training

A crucial element of simulation effectiveness is the level of fidelity achieved through the simulation. Fidelity, defined broadly as the degree of similarity between the training situation and the operational situation that is simulated, has been approached from a number of perspectives. Two important characteristics of simulator fidelity are frequently the focus of investigation. First, is the notion of *physical fidelity*, which describes the visual, kinaesthetic and spatial similarities between the simulated and real systems. A second area is that of *functional fidelity*, which refers to the degree of accuracy in system operation [1]. These focal points for research and development have resulted in particular emphasis being placed on the equipment and technology used in the support of training.

Further elements of simulation fidelity that have been a focus of research are those of *psychological fidelity*, which refers to the degree of perceived realism, and *task fidelity*, which has been defined as the degree to which a simulation is able to recreate the actual parameters of the operational mission [2]. While task fidelity in particular stresses the importance of creating operationally realistic simulations, it is frequently equated to aspects of physical and functional fidelity of the simulation. This has lead to an over-emphasis on the role of technological advancement in enhancing simulation-based training and a relative lack of emphasis being placed on the role of recreating authentic operational scenarios.

Anther important aspect of simulation fidelity, and one that is definitively linked to training effectiveness, relates to the way in which simulator-based training is designed. There now exists a considerable body of research which suggests that there is not a simple direct relationship between the increased realism brought about by the high-fidelity of advanced technology simulation and enhanced training effectiveness [3, 4]. Rather, increases in both efficiency and transfer of training can occur through the careful process of Instructional Systems Design, and in particular the design of simulation-based scenarios that are responsive to the real operational needs of an organisation.

### 1.2 Operational fidelity

Within the commercial aviation setting, considerable criticism has been levelled at current forms of simulator-based training for their singular focus on the technical skill development of flight-crew in the operation of complex aircraft systems [5]. These criticisms certainly do not suggest that there should be any decrease in the levels of technical skill development achieved through simulator-based training. Rather, the point being made is that the current forms of training do not sufficiently develop the forms of non-technical skills necessary for enhanced operational performance in increasingly complex operating environments. Specifically, the current lack of true integration between the

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development of technical and non-technical skills has been highlighted as a major deficiency in current approaches to flight-crew training [6]. For instance, workload prioritisation, increased situation awareness, crew coordination and decision-making in time critical situations are all examples of crucial non-technical skills which must be developed by personnel to ensure the ongoing safety of operations.

Therefore, a need exists to establish mechanisms for Instructional Systems Design that ensure the authenticity of simulator-based training scenarios. This new approach to enhancing simulator-based training can be termed *operational fidelity*, and involves the creation of simulator-based training that equips personnel with a variety of both technical and non-technical skills for everyday operational performance.

Currently, a number of approaches exist to enable the detailed analysis of the operation of complex systems, such as modern aircraft, in order to effectively inform Instructional Systems Design for simulator-based training. One such approach, that of Cognitive Task Analysis (CTA), has traditionally been an important data source for the development of training interventions [7]. Typically, CTA provides a detailed analysis of both the knowledge and skills required for expert performance through the decomposition and analysis of individual work elements.

Another important source of information for the development of training is that of Work Domain Analysis. This approach, whilst often forming an element of CTA, focuses primarily on the development of fundamental functional boundaries of system performance. Through the definition of a complex system's functional purpose, priorities and values of system operation, as well as the purpose-related and physical functions of elements of a system, an overall understanding of safe and efficient system operation is achieved. This information can then be utilised to define the operation of a system in way that is independent of specific events or scenarios [8].

Although these approaches to Instructional Systems Design provide a robust empirical method for the detailed analysis of system operation, they not provide sufficient information to an organisation about the complex contextual factors that influence everyday operatoional performance. It has been acknowledged that these forms of task analysis have the propensity to provide decontextualised forms of information about effective performance that can be extremely abstracted from the operational environment [9]. Therefore, these forms of task analysis only reinforce the existing emphasis on functional fidelity and offer instructional designers little, if any, information about the real everyday operational factors that influence performance. Given the current limitations of existing data collection tools, in order to improve the operational fidelity of simulator-based training, new tools must be employed to gather detailed operational performance data.

### 1.3 Threat and Error Management

Developed in the context of commercial aviation, a new operational performance evaluation methodology enables new types of data to be collected and used to inform enhanced instructional systems design. This approach to operational performance evaluation, called the Line Operations Safety Audit (LOSA) methodology, provides the tools to collect detailed data in relation to the occurrence of threats and errors during normal operations, and details the types of behaviours personnel employ in response to these threats and errors [10, 11].

Defined as situations, events or errors that occur outside the flight-deck, *threats* are conditions that have the potential to impact negatively on the safety of a flight. In turn, defined as crew action or inaction that leads to a deviation from crew or organisational intentions or expectations, *errors* are taken to be an unavoidable and ubiquitous aspect of normal operations. As these two factors form fundamental causal components of incidents and accidents, it is argued that the management of threat and error must form the focus of any organisation's attempts to effectively maintain safety in high-risk operations [11].

Threat and error management involves the effective detection and response to internal or external factors that have the potential to degrade the safety of operations [10]. From this new approach to safety has emerged a redefined emphasis on training that extends beyond merely technical skill development. The flow-chart in Figure 1 illustrates a model of threat and error management. In response to an external threat, crews undertake some form of management action. If this management action is effective, the threat is safely managed. However, threats are frequently mismanaged by flight crew, and can result in the crew committing an error. Further, sometimes a mismanaged external threat or crew error leads to the aircraft being placed in a situation or configuration that represents an increased risk to safety, termed an undesired state [12].

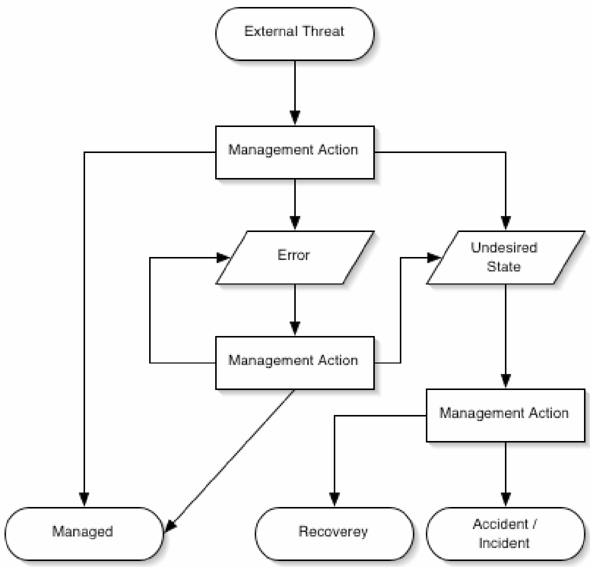


**Figure 1:** An Example Model of Threat and Error Management

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The LOSA methodology enables an organisation to collected detailed data on crews threat and error management performance. One of the major considerations in the utilisation of the LOSA methodology is ensuring that the detailed data produced during an evaluation of normal operations can be effectively used to inform data-driven training interventions. Through a systematic and structured analysis of the complex threat and error management behaviours undertaken by flight crew during normal operations, a considerable amount of information can be obtained for use in enhancing the operational fidelity of simulator-based training. This paper explores one specific use of this new organisational performance evaluation data in the development of enhanced operational fidelity within a large commercial airline.

## 2. METHOD

### 2.1 Participants

Data for this study were collected from two fleets of an Asian airline operating domestic short-haul and international medium-haul routes. The two fleets represented in the study were comprised of Boeing 737 and Airbus A330 aircraft respectively. Flight crew were consistently comprised of a two person active crew of a Captain and a First Officer. Only data from normal line operations were utilised in this study.

### 2.2 Data collection and analysis

A group of 25 senior flight crew from the airline were trained in using an observational methodology adapted from the Line Operations Safety Audit (LOSA) methodology [10, 11]. The observers collected data from the jump-seat during normal line operations. The observational methodology collected data relating to threats encountered by crews and the errors committed by crews. Specific details were collected in relation to the crews' management of threat and error during normal line operations. Data from these observations were collated, and subjected to a variety of descriptive, comparative and multivariate statistical analyses.

## 3. RESULTS

### 3.1 Threat Management Analysis

From the 323 observations of normal flight operations, observers recorded 451 individual threats. This was an average of 1.4 threats per observed flight operation. There were 22 different types of threats faced by flight crews during normal operations. Table 1 shows the distribution of the 10 most common threats, which accounted for 90% of all threats encountered by crews.

On average in the line operation environment the crews effectively managed only 57.4% of threats. As a threat, by definition, has the potential to be detrimental to the safety of the flight, it is desirable that a much larger proportion of threats are effectively managed by the crews.

**Table 1:** The most common threats encountered by flight crews and their management.

| **Threat Type** | Frequency | Managed | |
|---|---|---|---|
| | | Yes | No |
| Weather | 20.6 | 53.8 | 46.2 |
| A/C Malfunctions | 14.4 | 75.4 | 24.6 |
| Operational Pressure | 11.5 | 38.5 | 61.5 |
| Traffic | 7.8 | 54.3 | 45.7 |
| ATC command | 7.5 | 44.1 | 55.0 |
| Airport Conditions | 7.1 | 78.1 | 21.9 |
| Terrain | 6.2 | 53.6 | 46.4 |
| Ground handling event | 5.8 | 42.3 | 57.7 |
| Passenger event | 5.1 | 52.2 | 47.8 |
| Communication event | 4.0 | 72.2 | 27.8 |

*Frequency expressed as a percentage of threats observed (n = 451).*

### 3.2 Simulator Training Scenario Development

The strength of the LOSA methodology lies not only in the identification of significant operational risk factors, but moreover in the detailed data that can be used to develop scenario-based training interventions for use in the simulator. The potential for the use of this type of data in informing an enhanced level of operational fidelity in simulator-based training is considerable.

In order to ensure that training-scenario development is truly responsive to operational needs, a structured process was developed in order to effectively utilise the LOSA data. The diagram in Figure 2 provides an outline of this four-stage process.

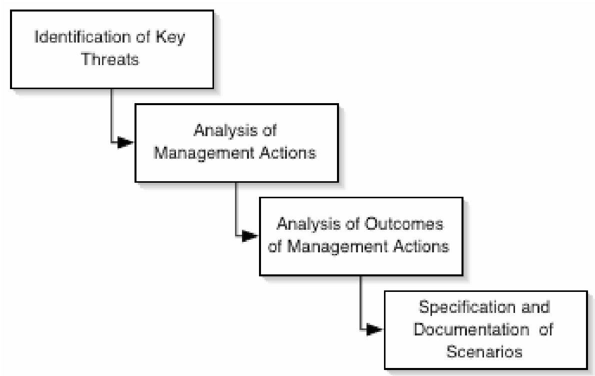


**Figure 2:** The four-stage development process

The first stage in the development of training scenarios is the identification of key threats that must be managed by crews during normal operations. For the organisation involved in this study, Operational Pressure was a frequent, yet the least well managed threat, with only 38.5% of threats in this category being effectively managed by crews. Typical threats that fell within this category of Operational Pressure involved such occurrences as late passenger boarding, late arrive of inbound aircraft, short turn-around time, particularly short flight sectors, or flight sectors late at night. For the organisation involved in this study, the threat of Operational Pressure, along with its consistently poor management, can be identified for this organisation as a significant operational risk factor for which a training intervention is required.

The second stage in the development of data-driven and operationally relevant training interventions is the analysis of threat management actions taken by flight crew. In relation to each threat, the data provided by the LOSA methodology facilitates the identification of core management actions used by crew in both effective and ineffective threat management. The data in Table 2 provides details of the typical actions involved in the management of Operational Pressure threats.

**Table 2:** Typical threat management actions.

| |
|---|
| **Threat Managed** 38.5% (n = 20) |
| - Thorough planning and preparation |
| - Effective time and task management |
| - Increased communication |
| **Threat Not Managed** 61.5% (n = 32) |
| - Inadequate planning or preparation |
| - Rush or omit Standard Operating Procedures |
| - Poor time or task management |
| - Lack of crew coordination |

The third stage in the development of operational scenarios is the analysis of threat management outcomes. According to the model of threat and error management, while effective threat management leads to an alleviation of increased risk, poor threat management is frequently linked to the occurrence of crew error. In this study, the 32 poorly managed Operational Pressure threats were linked to a total of 61 errors. Through the analysis of these errors a more detailed understanding of the areas in which training intervention can be most effectively employed is achieved. Further, this information is used in the development of detailed instructional support materials which outline the most effective actions which can be undertaken by crews, as well as the common pitfalls crews fall into when managing threats or errors. The data in Table 3 provides a summary of the error types linked to the ineffective management of Operational Pressure.

**Table 3:** Error types and typical errors linked to poor management of Operational Pressure threats.

| |
|---|
| **Violations** 54.1% (n = 33) |
| - Checklist performed from memory |
| - Omitted take-off or descent briefing |
| **Procedural Errors** 29.5% (n = 18) |
| - Incorrect automation input |
| - Unstable approach |
| **Communication Errors** 4.9% (n = 3) |
| - Missed ATC call |
| **Proficiency Errors** 1.6% (n = 1) |
| - Incorrect descent profile |
| **Decision Errors** 9.8% (n = 6) |
| - Inappropriate delay of descent |
| - Inappropriate route change |

Of the 61 errors which were linked to poor threat management, 21 were trapped and effectively managed by flight crew. Of the remainder, 12 errors resulted in the aircraft being placed in a state which compromised the safety of the flight. These undesired aircraft states included conflicts with other traffic and terrain, and long landings outside the touchdown zone.

The final stage the process of scenario development involves the specification of the scenario events and the documentation of instructional materials. The development of the scenario events is a relatively simple task of replicating the circumstances and conditions in which the majority of threats of a particular type were encountered by flight crew. For the organisation involved in this study, the majority (76.9%) of Operational Pressure threats occurred during the pre-flight phase and arose from a decrease in time available to perform necessary tasks due to short turn-around times and delays due late incoming aircraft, crew or passengers. These details are then used to create the specific scenario events.

While increased operational fidelity does depend on the development of such operationally relevant training scenarios, the instructional benefit arises from the specific instructional guidance crews receive during simulator-based training. Therefore, the data from threat and error management analysis must be used to create detailed materials to support effective instruction in the simulator.

First, documentation is developed for instructors that provides details of the threat and error management strategies used by crews during real events on the line. Instructors are then able to introduce the individual components of effective threat and error management during their pre-training briefing of the crews, using example from practice, and highlighting both effective and poor techniques used in threat and error management.

Documentation also details the common technical errors crew make during normal operations. Instructors are then able to use this information to improve their monitoring of crew performance during the training session and provide structured feedback to crews. Further, instructors are provided with detailed guidelines for the debriefing of crews after the simulator training event has been completed. This structured debriefing form mirrors the process of threat and error management analysis and allows for debriefing that integrates both the technical and non-technical performances of the crew.

## 4. DISCUSSION AND CONCLUSIONS

As a new task analysis tool, the LOSA methodology enables an organisation to engage in Instructional Systems Design that ensure the training of personnel is highly responsive to real operational needs. This study has shown that the threat and error management data collected by LOSA provides a wealth of information that can be effectively utilised in the enhancement of operational fidelity in simulator-based training. While this form of data should not be seen to replace the existing methods of task analysis, it serves as a mechanism to achieve forms of training that integrate both technical and non-technical skill development.

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Currently, some degree of scenario-based training occurs in the commercial aviation setting through the process of Line-Oriented Flight Training (LOFT). Typically, LOFT involves a "full-mission" operational scenario, presented during Full Flight Simulation, that presents crews with a variety of problems, including multiple aircraft systems malfunctions and other in-flight events, as they complete a simulated flight sector. In such a LOFT session, crews practice both technical and non-technical skills in realistic and challenging flight situations [13]. While traditional LOFT offers one approach to scenario-based training in the simulator, the use of threat and error management data provides a variety of possible advantages.

First, the use of threat and error management data enables scenario design that is more focussed on *realistic* operational events and is highly responsive to deficiencies in an organisation's operational performance. The data collected through the LOSA methodology during normal operations enables an organisation to unmask latent failures in the organisation's operational system and address these deficiencies before they have manifested in an incident or accident.

Second, through the breakdown of training into discrete scenario-based training events, the crews benefit from a more focussed and integrated instructional experience then occurs in traditional LOFT events. The added information provided to instructors enables a higher level of instructional intervention and more finely focussed feedback on crew performance during training.

While the study described in this paper was undertaken in the commercial aviation setting, the broad processes described for Instructional System Design can be extrapolated for use in a variety of settings other than commercial aviation. This type of data collection, analysis and scenario-based training design has the potential to be utilised in a wide range of high-risk industries. For instance, the process lends itself to use in the operative and critical-care medical environments where the use of simulation-based training is now commonplace. Further research is required to both adapt the methodologies described in this paper to a variety of training settings, as well as in relation to establishing empirical measures of training effectiveness through this approach to Instructional Systems Design.

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