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16. ABSTRACT

The Federal Aviation Administration's air traffic control organization (ATO) encompasses a variety of facilities that include towers, terminal radar approach control facilities (TRACONs), and air route traffic control centers (ARTCCs). Well trained air traffic controllers using effective automation can exploit alarms, alerts and warnings (collectively, signals) to build situation awareness and to lessen cognitive workload. The goal of this project is to develop a handbook that will guide air traffic system designers and controller user teams as they collaborate with human factors experts to create or modify air traffic control system alarms, alerts, and warnings. During the first two phases of the project, we have summarized the existing literature on alarms, alerts, and warnings and developed a signaling philosophy. We have now developed a signal taxonomy that can be used to evaluate an existing ATC signal or design a new signal using an objective scoring sheet and a structured interview format with subject matter experts (i.e., air traffic controllers) during the design process. This framework will provide relevant personnel with a common language that allows them to describe, classify, and objectively evaluate signals in air traffic control. After the handbook has been completed, our recommendations will be tested and validated with air traffic controllers during Phase 4. Phase 5 of the project will include further refinement of the signaling handbook as necessary and the development of training materials. At the conclusion of this project, the Air Traffic Organization will have the tools necessary to develop signals that will help to keep the United States' National Airspace System the safest in the world.

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ATC Signaling: The Role of Alarms, Alerts, and Warnings

Phase 3 Interim Report: Handbook Development

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The Federal Aviation Administration's air traffic control organization (ATO) encompasses a variety of facilities that include towers, terminal radar approach control facilities (TRACONs), and air route traffic control centers (ARTCCs). Air traffic controllers continually evaluate the impact of such factors as weather, converging traffic, and emergency situations, using this information to prioritize tasks, solve problems and enhance flight safety. Alarms, alerts, and warnings (collectively called *signals*) help controllers, who rely on automated systems, to build situation awareness and to lessen cognitive workload. The goal of this project is to develop a handbook that will guide air traffic system designers and controller user teams as they collaborate with human factors experts to create or modify air traffic control system alarms, alerts, and warnings. This will enhance the effectiveness of signals in the ATC environment by increasing the utility of signals that are in current use and those that have yet to be developed.

Controllers generally rely on prospective memory, anticipating potential problems and managing traffic proactively to avoid loss of separation and other situations in which an alarm or alert would be required. The purpose of a signal is to get the immediate attention of the controller when an abnormal event occurs. Signals are therefore designed to be intrusive and distracting. Frequent interruptions from nonactionable alarms can disrupt the controller's prospective memory, and there is evidence that improving the design of alarms and alerts can prevent errors. Improving the perceived sensitivity and specificity of alarms will improve controllers' trust in their automation. Further, harmonizing signals across equipment and the ATO may help controllers who move to a new facility.

Signals are ubiquitous in high-risk fields such as aviation but are often designed and implemented without assembling a comprehensive picture of the environment in which they will be used and the needs of operators who rely on them. During the first part of this project, we reviewed literature medicine, human factors, and aviation to identify all relevant properties of alarms, alerts, and warnings and then to create a signaling philosophy. We then used this information to develop a framework that can be used to describe existing air traffic control signals and to develop the specifications for new signals. This framework will be incorporated into a comprehensive handbook on signal design for ATC systems.

The signaling handbook that we are currently writing will help to identify beneficial features and flaws in current signals and help subject matter experts and human factors experts to develop new signals as required. A secondary goal is to reduce redundancy, unnecessary signals, and conflicting information. The research requirements of this project include development of a standardized methodology for how and when to use signals and guidance on how signal development can be incorporated into new equipment designs. We will validate the tools that we describe in the handbook during Phases 4 and 5 of this project. We will also create training programs that will help subject matter experts and human factors experts use the handbook to improve existing signals or develop new ones. Lastly, we will develop training materials that offer controllers guidance for alarm management, to ensure that they avoid inadvertently disabling or suppressing important signals that are presented at their workstation. This controller training material will also suggest when to report nuisance signals and how to request local, second-level engineering adaptations (e.g., inhibit areas for MSAW).

The Handbook

We are currently writing the first draft of the handbook, which will include an introduction, the signaling philosophy developed during Phase 2, and a guide to optimizing alarm displays that is based on human factors. The next sections of the handbook will describe our new work on a signal framework. After describing the new classification system (with scoring sheets and scripts for a structured interview), we will provide examples of how to use the framework to evaluate signals in current use and to develop new signals.

Signal Philosophy

During Phase 2 of the project, we reviewed reports of near misses from the Aviation Safety Reporting System and interviewed former controllers to learn how controllers interacted with signals and how signals contribute to the safe operation of the National Airspace System. This information was used to develop a signaling philosophy. We determined that signals can be divided into four categories that require increasing levels of intervention by the controller:

- Priority 1: Immediate danger requiring urgent controller intervention. (*e.g,* Imminent near mid-air collision [NMAC], flight below MVA, AMASS)

- Priority 2: Risk of harm. Controller intervention will be required soon (*e.g.*, Predicted conflict, airspace alert)
- Priority 3: Informational. Intervention may be required (*e.g.*, Mode C intruder)
- Priority 4 or diagnostic (*e.g.*, Radar outage, localizer malfunction)

The signaling philosophy addresses these four priorities for notifying the controller of important operational events and accounts for varying operating environmental conditions, from the darkened radar room to the bright daytime illumination in the ATC tower cab environment. For example, indicator lights and messages on screens may be less noticeable when displayed in a brightly illuminated control tower environment. In the tower cab, the increased use of auditory signals and display enclosures that enhance the visibility of screens and lights may be beneficial. Tactile displays (i.e., those using the sense of touch) can be used to draw a controller's attention to a potentially life-threatening hazard that requires immediate resolution. Improving the localizability of auditory signals may help controllers diagnose a problem more quickly. The simultaneous use of signals for multiple sensory modalities might be valuable when controller response time is critical. Making signals more acoustically rich and explicitly encoding intended urgency can improve alarm performance. This is supported by studies that have shown that the use of voice alerts to indicate extremely high-priority alarms has been shown to reduce operators' response time in domains outside of aviation. New classes of auditory signals, including earcons and spearcons, may help controllers differentiate between different conditions and further indicate the urgency of a hazard.

Our work in this area also reveals opportunities to improve controllers' trust in their automated ATC systems despite the many and varied signals they often produce. Trust in automation may be improved by incorporating information display strategies that include indicating the level of confidence that the automation has specific situations, such as when notifying the controller of an impending loss of separation.

Human Performance

The design of signals should support the controllers' primary task of traffic separation and supplementary tasks. Signals should also support the early recognition and mitigation of hazards such as traffic conflicts without imposing additional workload associated with nuisance signals. Signal design based on the principles of human factors can help to ensure that new and existing signals help controllers to maintain safety of the National Airspace System. The "high-level" design and review principles contained in the human performance section of our handbook represent the overarching characteristics that will maximize the utility of signals in air traffic control.

Although the handbook will not contain a comprehensive review of equipment design, the principles outlined in this section can be used to support the evaluation of both new and existing signals. Alarms should be easily distinguishable from each other, for example, and should use features such as color, text, and acoustic features to increase their saliency and informativeness. We will describe specific strategies for improving alarm performance with these features. This section will also offer guidance on how to manage signals that can be suppressed by the controller. For example, suppressed alarms may not be presented to the controller, but should be accessible when needed. The method for accessing signals that have been suppressed should be easy for the controller to understand. Moreover, suppressed signals should have the capability of re-activating as necessary. Consider, for example, a VFR aircraft in a location that activates the MSAW. The controller may be able to suppress that signal if the pilot has agreed to maintain visual separation from the terrain if the aircraft does not descend or move closer to the hazardous area. Under these conditions, the MSAW could re-activate, alerting the controller that the situation has changed.

Signal Design Process

Our signal design handbook will include a comprehensive framework that provides subject matter experts, human factors experts, and equipment designers with a way to describe a specific hazard and the alarm that should be associated with it. This framework was originally developed as a generalized taxonomy describing the use of signals in automation (Rice, Ruskin, and Ruskin, submitted for publication) and allows signal developers to perform objective scoring and structured interviews to assess signal efficacy using 14 parameters in three categories: physical, psychological, and performance.

After reviewing the relevant literature on alarms, alerts, and warnings, and conducting our own review of near misses in ATC that were associated with signal design, we have modified and adapted this signal taxonomy for use with ATC signals. This framework can be used to evaluate an existing ATC signal or design a new signal using an objective scoring sheet and a structured interview format with subject matter experts (i.e., air traffic controllers). It is intended to provide designers, engineers, human factors experts, subject matter experts, and vendors with a common language to describe, classify, and objectively evaluate and design signals in air traffic control, with potential applications in other, related domains. The framework includes physical factors (modality, location, exclusivity, and suppressibility), psychological factors (salience, heterogeneity, informativeness, and disruptiveness), and performance-related factors (recipient, accuracy, reliability, priority, and temporality). The process for using the framework is:

For Current Alarms: Existing Alarm Pathway

1. Rate the effectiveness of each characteristic for the current alarm using the objective scoring sheet. Each characteristic is rated on a scale of 0-5 (0 = poorly designed; 5 = perfectly designed)
2. Human factors experts then use a structured interview with air traffic controllers to analyze the qualitative characteristics of the alarm.
3. A new alarm is designed by human factors experts and engineers based on the initial scoring and interviews. After a draft design is completed, controllers can use the objective scoring sheet to evaluate each characteristic of the new alarm on a scale of 0-5 (0 = poorly designed; 5 = perfectly designed)

New Alarm Pathway

1. Rate the importance of each characteristic for the proposed new alarm using the objective scoring sheet. Each characteristic is rated on a scale of 0-5 (0 = Not important at all; 5 = Extremely important)
2. Human factors experts use a structured interview that allows the controllers to analyze the needed qualitative characteristics for the new alarm.
3. A new alarm is designed by human factors experts and engineers based on the initial scoring and interviews. After a draft design is completed, the controllers can use the objective scoring sheet to evaluate each characteristic of the new alarm on a scale of 0-5 (0 = poorly designed; 5 = perfectly designed).

The Framework as Applied to TRACON Signals

	Factor	**Current Signal**	**Future possible improvements**
Physical	Modality (Visual, auditory, tactile, olfactory)	Visual blinking display/ Auditory alert	Add a tactile component
	Location	At controller's workstation	Wearable device with visual, auditory, or tactile components
	Exclusivity	Each signal is unique to a specific hazard (*e.g.*, MSAW)	Different sounds or signals of other modalities (visual, tactile) for different hazards
	Suppressibility	Can be suppressed under specific circumstances	Reactivation under specific circumstances may be desirable
Psychological	Saliency/Noticeability (Contrast, color, size, shape, luminance, amplitude and frequency, texture, speed/pattern)	Current signals consist of pulsed or alternating tones	Add a speech-based component for time-critical or high-hazard situations
	Distinguishability	Pulsed tones may be difficult to distinguish from other alarms if the controller's attention is on another part of the display	Each signal should be unique Auditory icons may be helpful for critical signals
	Informativeness	The data block on a TRACON display include CA for conflict alerts, LA for low altitude alerts, and MSAW for minimum safe altitude alerts	Speech-based signals may enhance a controller's ability to respond to an immediate hazard (e.g., imminent NMAC)
	Disruptiveness	Attracts attention, but is non-specific and frequently sounds at inappropriate times (*e.g.*, during formation flight)	Improve properties of suppressibility, distinguishability, and informativeness

	Familiarity/Recognizability	The signal is easily recognizable by the controller.	Current signals can easily be recognized by controllers.
Performance	Recipient	Heard primarily at the controller's workstation.	Signals may need to be received by personnel at multiple locations (*e.g.*, AMASS alarms in an ATCT.)
	Perceived Accuracy Perceived Reliability	*e.g.*, Inhibit areas configured by local facility	Allowing controllers to adjust the sensitivity of a signal under specific circumstances (*e.g.*, formation flight)
	Priority	No system to suppress lower priority signals	Develop a system to suppress lower-priority signals when specific criteria are met
	Temporality	The signal should activate soon enough that the controller can intervene in a timely fashion.	None

Conclusions

In the past, engineers have typically made a subjective decision about the effectiveness of an existing signal or the design of a new signal. In addition to a comprehensive signaling philosophy and a list of recommendations for alarm design, our signaling handbook will include a framework that allows human factors professionals and subject matter experts to objectively assess the desired characteristics of a signal using an objective scoring system and structured interview format. This framework will give air traffic controllers, FAA personnel, and equipment manufacturers a common language that describes the alarm that should be associated with a specific hazard. It also provides a permanent, written record of why the alarm was chosen and how it performed after implementation. Each of the items in the framework will be described in detail, with examples, in the handbook. After the handbook has been completed at the end of this phase, our recommendations will be tested and validated with air traffic controllers during Phase 4. This process will include review of the handbook contents with subject matter experts and

NATCA union representatives and evaluation of inter-rater reliability with current air traffic controllers.

Phase 5 of the project will include further refinement of the signaling handbook as necessary and the development of training materials. The goal of this phase will be to teach human factors experts and subject matter experts to use the methods described in the handbook to develop effective signals. During this phase, we will also develop optional training materials that will help controllers to make optimal use of existing features that maximize their effectiveness. This final phase of the project will provide the Air Traffic Organization with the tools to develop signals that will ensure that the United States' National Airspace System continues to be the safest in the world.

References

Rice S, Ruskin Clebone A, Ruskin K. A Framework for Alarm Evaluation and Design. *Journal of Clinical Monitoring and Computing*. (Submitted for Publication.)