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An Initial Survey of National Airspace System Auditory Alarm Issues in Terminal Air Traffic Control

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16. Abstract

A researcher from the Research Development & Human Factors Laboratory of the William J. Hughes Technical Center conducted an exploratory study to examine current National Airspace System (NAS) auditory alarm issues. The purpose was to identify problem areas related to current auditory alarms and to collect opinions from the users on ways to improve auditory alarms in their work area. Based on availability, the participants were from the terminal (Air Traffic Control Tower and Terminal Radar Approach Control) area. Participants rated 15 potential auditory alarm issues on a scale from 0 to 10 on how problematic each issue was in their work area. Based on the comments participants provided, some of the problems that they reported with auditory alarms could be traced to a few specific systems. Other problems were more general in nature, including alarms being too numerous in the work environment. They also reported problems with too many false alarms. Although this study was not meant to be all encompassing, it provides an initial look at the auditory alarm issues within the current NAS environment.

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Executive Summary

As new tools for the National Airspace System are developed, new equipment is added to existing environments. Many of these new devices use visual and auditory signals to indicate the status of equipment as well as the status of the incoming air traffic. The auditory signals on these devices are often developed without standards or guidelines or a consideration of the auditory signals present on the existing equipment. The result can be an overwhelming cacophony of unique sounds.

The first step toward improving alarm systems is to analyze the common problems associated with auditory alarms in use today. To achieve this goal, a researcher from the William J. Hughes Technical Center Research, Development, & Human Factors Laboratory (RDHFL) surveyed 20 terminal Air Traffic Control Specialists (ATCSs). Many of these controllers had both Air Traffic Control Tower (ATCT) and Terminal Radar Approach Control (TRACON) experience. The researcher asked them to rate the severity of 15 potential auditory alarm issues. In addition, the researcher conducted structured interviews with the 20 ATCSs and supervisors to investigate areas where auditory alarms are problematic. The individuals were from Jacksonville ATCT, Detroit area ATCT and TRACON, Cleveland area ATCT and TRACON, Dallas area TRACON, New York TRACON, Pittsburg TRACON, Philadelphia ATCT, Washington National ATCT, and Baltimore ATCT. The sample only included participants who were available due to their involvement in other experiments with the RDHFL.

ATCSs identified major concerns for the 15 auditory alarm issues and expanded upon them during structured interviews. Some of the major concerns were alarms that could not be silenced even when the user acknowledged the situation, specific alarms that sounded too similar, false alarms on certain systems, alarms interfering with voice communications, alarms that were too loud, and some systems that had no alarms that could benefit from auditory alarms.

Five of the 15 items received a mean rating higher than the midpoint of the scale. These items were that alarms are easily confused because they sound alike; alarms go off too frequently, especially false alarms; alarms are annoying; it is difficult to locate the source of the alarms; and too many alarms go off at the same time. Although participants rated some of the items higher than others, they provided comments for nearly all of the items, citing specific troublesome alarms or situations. We expand upon each of the top rated items in the document.

Based on the comments provided by the participants, it appears that a few alarms or systems cause many of the problems. The Instrument Landing System alarms seem to be problematic for AT (Air Traffic) participants from the terminal area. The AT participants also had many complaints about the Minimum Safe Altitude Warning. Due to the strong negative responses from the participants about these particular alarms, these issues merit special attention when replacing these systems to avoid repeating the reported problems. However, because this study was limited, additional research may be warranted to verify problems reported with these systems.

Other reported problems were more general in scope, including alarms being too numerous, annoying, easily confused, or false alarms. The application of good human factors in alarm design could address some of these problems. Many of the problems reported with auditory alarms underscore a necessity to take into account the environment into which new equipment with alarms is being introduced, including the alarms present on existing equipment. For

example, a new piece of equipment could have a very well designed alarm, but be introduced into an area where there are other similar sounding alarms and end up being masked or confused. Alarms on equipment should be developed with respect to the environment (and existing equipment in the environment) into which the equipment will be introduced.

1. Introduction

Properly designed alarm systems are an important and necessary part of human-system interfaces. Auditory signals have the ability to convey important information or alert the user to an item needing immediate attention, no matter where the user is looking. Improperly designed alarms or an overabundance of alarms, however, have the potential to interfere with the controller's ability to effectively do his or her job and, consequently, have a negative impact on air traffic safety.

1.1 Background

As new tools for the National Airspace System (NAS) are developed, new equipment is added to existing environments. Many of these new devices use visual and auditory signals to indicate the status of equipment as well as the status of the incoming air traffic. The auditory signals on these devices are often developed with minimal use of standards or guidelines or a consideration of the auditory signals present on the existing equipment. The result can be an overwhelming cacophony of unique sounds.

A report by the National Transportation Safety Board ([NTSB], 2000) cites several incidents where accidents happened, and the aural alert portion of the Minimum Safe Altitude Warning (MSAW) was either non-existent or inhibited. According to the report, the presence of an MSAW aural alert might have helped prevent some of these accidents. In one incident cited in the report, heavy paper held in position with tape was covering the MSAW aural alert alarm speaker. From a human factors perspective, one must ask why users might have disabled or inhibited these aural alarms.

The NTSB (2000) report states that the Guam MSAW system had been intentionally inhibited because it had been generating numerous false alerts, up to 18 a day. According to the testimony given following the Guam incident, AOS has developed new tools for analyzing reported false alerts generated by the MSAW and has taken steps to improve the situation, thereby minimizing or eliminating MSAW false alarms (NTSB, 2000). Although steps have been taken to minimize false alarms for the MSAW, there are no data to identify whether false alarms are an issue for other auditory alarms in the NAS. Follow-up research is necessary to determine the extent to which false alarms are a problem for other systems.

The problems with auditory alarms in the NAS environment are likely to be similar to those of other high workload environments, such as nuclear power plants, cockpits, and hospitals. These potential problems may include

a. too many warnings,

b. warnings that are too loud or inaudible,

c. warnings that are confusing, and

d. inappropriate mapping between the sound and its meaning (Meredith & Edworthy, 1994).

Wolfman, Miller, and Volnath (1996) classified problems with alarm sounds in the Air Traffic Control Tower (ATCT) environment into three distinct categories. The first is that audible alarms are too numerous and attempt to convey too much information. The second is that the alarms are counterintuitive, inconsistent, inappropriate, and can be confused or masked. Finally, alarms are too loud, are annoying, and often startle the user and disrupt communication and thought. The categories developed by Wolfman et al. were hypothetical, based on a combination

of problems related to alarms in the literature and their own subjective judgment. The literature provides a list of potential problems with alarm sounds in the NAS; for example, Edworthy and Adams (1996) reinforced the problems listed by Meredith and Edworthy (1994) and added another potential problem with false alarms. It is not clear, however, how many of these potential problems with alarm sounds in the NAS are actually experienced as problematic by the individuals exposed to the alarms and alarm systems on a daily basis.

It is possible that the application of good human factors in alarm design could solve many of the problems identified in the literature (Ahlstrom & Longo, 2003; Federal Aviation Administration [FAA], 1996). However, with decreasing budgets, the FAA needs to identify areas in most need of help. This preliminary survey is a first step toward that goal.

1.2 Purpose

The purpose of this study was to provide an increased understanding and insight into audio alarm problem areas within the NAS. A researcher from the William J. Hughes Technical Center (WJHTC) Research Development & Human Factors Laboratory (RDHFL) designed this study to identify some of the higher priority issues in the area of auditory alarms in NAS environments. This study could also identify problems with auditory alarms so that problems within a particular system can be addressed when the time comes for upgrades or modernization. This study is meant as an exploratory effort and, as such, should be supplemented with additional studies in the future.

2. Method

2.1 Participants

The researcher surveyed 20 terminal Air Traffic Control Specialists (ATCSs) with experience in both the ATCT and Terminal Radar Approach Control (TRACON). The sample only included participants who were available due to their involvement in other experiments with the RDHFL. Although the researcher had intended to broaden the survey beyond terminal ATCSs, at the time of the survey, there were an insufficient number of personnel from other areas to obtain adequate data.

The researcher conducted structured interviews with 20 current and former ATCSs and supervisors to investigate areas where auditory alarms are problematic. The individuals were from Jacksonville ATCT, Detroit area ATCT and TRACON, Cleveland area ATCT and TRACON, Dallas area TRACON, New York TRACON, Pittsburg TRACON, Philadelphia ATCT, Washington National ATCT, and Baltimore ATCT. The following sections detail some of the major concerns identified during these structured interviews.

2.2 Data Collection

In order to identify problem areas in NAS environments, the researcher first conducted a literature survey of problems associated with auditory alarms. These problems stemmed from a variety of different environments, including hospital emergency rooms and aircraft cockpits. The researcher extracted auditory alarm issues that the literature most frequently identified. This resulted in 15 key items covering areas of concern identified for other work environments. Table 1 lists these 15 items. Subject matter experts helped revise the wording of the issues to make them clear and understandable to the target audience.

Table 1. Auditory Alarm Areas of Concern

Problem
Too many alarms go off at the same time
There are too many alarms for a person to learn the meaning of each alarm
Alarms sound more urgent than they should or sound less urgent than they should
Alarms are easily confused (because they sound alike)
Alarms can be masked (difficult to hear over background noise)
Alarms are too loud
Alarms are annoying
Alarms disrupt thought
Alarms startle the user
Alarms interfere with voice communications
Alarms go off too frequently, especially false alarms
Alarms go off so infrequently, that when they do go off, those hearing the alarms don't know their meaning
There are not audio alarms in some situations where there should be audio alarms
It is difficult to locate the source of the alarms
Some alarms which are visual would be better auditory and vice versa

2.3 Protocol

Participation in the interview was entirely voluntary, and the researcher told the volunteers that they could refrain from responding to any or all of the questions and could cease participation whenever they wanted. Volunteers who wished to provide information on auditory alarm issues interacted individually with the researcher.

The researcher explained that the purpose of these 15 items was to identify problem areas and potential solutions for auditory alarms. The researcher provided each volunteer with a written copy of the questions, and they responded verbally to each question as the researcher recorded the responses. Each participant rated 15 potential auditory alarm issues on an 11-point scale from 0 (not a problem) to 10 (severe problem) on how problematic that issue was for them in the environment in which they worked. The researcher also asked the participants to provide comments on specific problems with auditory alarms in their work area. Many participants also volunteered their suggestions for potential solutions to the problems.

3. Results

Many of the participants from the terminal environment had both ATCT and TRACON experience. The controllers' ratings and comments reflect the combination of that experience.

Table 2 presents the average ratings for each item. Five of the 15 items received a mean rating higher than the midpoint of the scale. These items were that alarms are easily confused because they sound alike; alarms go off too frequently, especially false alarms; alarms are annoying; it is difficult to locate the source of the alarms; and too many alarms go off at the same time. Although participants rated some of the items higher than others, they provided comments for nearly all of the items, citing specific troublesome alarms or situations. The discussion that follows will expand upon each of the top rated items.

Table 2. Mean Ratings of Items by Terminal AT Participants

Problem	Mean	St Dev
Alarms are easily confused (because they sound alike)	6.7	3.18
Alarms go off too frequently, especially false alarms	6.4	3.57
Alarms are annoying	6.3	2.53
It is difficult to locate the source of the alarms	5.3	3.26
Too many alarms go off at the same time	5.2	3.33
There are too many alarms for a person to learn the meaning of each alarm	4.9	3.41
Alarms sound more urgent than they should or sound less urgent than they should	4.8	3.16
Alarms are too loud	4.5	2.91
Alarms disrupt thought	4.4	3.66
Alarms can be masked (difficult to hear over background noise)	4.1	3.43
Alarms interfere with voice communications	4.0	2.87
Alarms startle the user	3.8	2.77
Some alarms which are visual would be better auditory and vice versa	3.1	2.84
There are not audio alarms in some situations where there should be audio alarms	2.1	2.29
Alarms go off so infrequently, that when they do go off, those hearing the alarms don't know their meaning	1.9	2.39

1. Alarms are easily confused (because they sound alike)

Participants reported that the MSAW and the Automated Radar Terminal System (ARTS) Conflict Alert (CA) sound alike and are easily confused. For the ARTS II, the MSAW and CA auditory alarms use the exact same tones. The ARTS IIIA uses separate MSAW and CA alarms, but they are similar enough to be effectively indistinguishable. The ARTS IIIE uses the same frequency for the MSAW and CA alarms but with different periodicity, which may be difficult for the user to differentiate when heard in isolation (Ahlstrom, 1999a, 1999b).

2. Alarms go off too frequently, especially false alarms

The participants stated that both the CA and the MSAW alarms go off frequently and, in Visual Flight Rules (VFR) weather, are frequently unnecessary but require controller attention. The MSAW is generally set up to warn controllers when a large commercial aircraft violates

minimum safe altitude limits under Instrument Flight Rules (IFR). However, there are often smaller aircraft at the same airfields that land under VFR. These aircraft do not follow the IFR criteria and thus activate the MSAW alarm. The controller then must check the display to see if the alarm is relevant or irrelevant. If an alarm goes off too frequently when controller attention is unnecessary, there is a risk that the controllers will take it as routine and ignore an alarm for a real condition.

As with the MSAW alarm, the participants reported that the urgency of an Instrument Landing System (ILS) alarm depended on the weather conditions, with the ILS alarms sounding more urgent than they should during VFR conditions.

3. Alarms are annoying

Participants commented that alarms became annoying because they were excessively long, continuing to sound even after they acknowledged the problem. They also cited examples of alarms that would sound even on unmanned positions or unused frequencies. They considered the alarms annoying if it was not possible to acknowledge the auditory portion of the alarm or if the alarm did not provide pertinent information.

4. It is difficult to locate the source of the alarms

The participants commented that it is difficult to locate the source of the alarms, particularly when multiple alarms are going off at once.

5. Too many alarms go off at the same time

Participants reported that there were too many alarms to learn the meaning of each, and it was particularly difficult when more than one alarm went off at the same time. This is particularly true when a storm or power bump occurs.

3.1 Personnel Comments

Some of the major concerns identified by the participants during the structured interviews follow.

- At times, alarms can be annoying; for example, after locating a (75,76,7700) code, the alarm continues to sound.
- The CA and the MSAW sound too similar and are easily confused.
- There are too many false alarms, particularly with the MSAW. After a while, the alarm loses its meaning (i.e., crying wolf).
- The alarms can interfere with voice communications; there is no way to (temporarily) silence (or acknowledge) the auditory portion of the alarm while trying to remedy the situation.
- The Continuous Data Recording (CDR) should have an auditory alarm. Supervisors had to continually check the system to make sure that it was still functioning.
- Several alarms were too loud, causing stress and frustration for the specialists exposed to them. This was particularly true for alarms over which the specialists had no direct control, such as the Emergency Locator Transmitter, the scatter, and the PCS alarms.

Overall, when the participants reported on problems with specific systems, they reported the majority of the problems with auditory alarms were associated with a few systems. One of these

systems, ARTS, is being replaced. The participants made comments specific to the MSAW alarm on the ARTS for 7 of the 15 potential auditory alarm issues. They commented that the MSAW alarm is too loud, interfering with voice communications and startling the users. They also reported that the MSAW and the ARTS CA sound alike and are easily confused.

The participants cited ILS alarms on 5 of the 15 potential auditory alarm issues. They reported that the ILS alarms were easily confused, difficult to locate, and frequently had false alarms. They also reported that ILS alarm volumes were often turned so far down that it was difficult to hear them over the background noise. As with the MSAW alarm, the participants reported that the urgency of an ILS alarm depended on the weather conditions, with the ILS alarms sounding more urgent than they should during VFR conditions.

There was one case where the participants said that they would benefit from an auditory alarm where there currently is none. The AT participants said that they were responsible for ensuring that the CDR was working. Without an auditory alarm to alert them to a malfunction, they had to keep checking the equipment. The addition of an auditory alarm to indicate malfunction would relieve them of this vigilance task.

Another participant commented that many of the controllers have some degree of hearing loss either from having previously worked in high noise areas or advancing age. New alarms should be designed so that people with limited hearing can hear them.

4. Conclusions and Recommendations

This section provides conclusions and recommendations for audio alarms, focusing mainly on the top five issues identified by the users. The following recommendations should receive consideration in future alarms for terminal area operations.

1. Alarms are easily confused (because they sound alike)

By design, alerting and warning systems should be unambiguous, with a clear indication of the cause for the alert. Varying frequency, modulation, or both, can accomplish this. Alarms should be separated by at least 400 Hertz in frequency. Although people can discriminate frequencies closer than this in a laboratory, the operational environment is more acoustically complex than a laboratory (Newman & Allendoerfer, 2000). Alarms should also differ in periodicity, taking care to avoid continuous signals (Ahlstrom & Longo, 2003). Continuous tones are the most easily confused signals, even if they vary considerably in pitch. Furthermore, the human auditory system quickly adapts to continuous auditory stimulation (Merideth & Edworthy, 1994).

2. Alarms go off too frequently, especially false alarms

The time needed to determine whether an alarm is irrelevant or requires action by the controller can take time away from other important tasks and can increase workload. The criteria for conditions that cause frequent false alarms should be evaluated, and a concerted effort should be made to reduce the number of irrelevant alarms.

3. Alarms are annoying

There are many things that make an alarm annoying, such as a sudden loud (1dB/msec or greater) onset that startles the user, and alarms that are too loud (above 90 dBa) (Sorkin, 1988). High frequencies tend to be perceived as more annoying than low frequencies. Dissonance, overtones, and irregular beats or changes in a tone are considered annoying, as is a slow repetition rate. Finally, alarms that operators cannot turn off after receiving the information are

annoying (Edworthy & Stanton, 1995). Based on the user comments, the primary causes of annoyance in the terminal environment were alarms that either provided no information to the user or alarms that operators could not turn off after receiving the information.

There should be an easy way for users to, at least temporarily, silence the auditory portion of an alarm as they address the problem. However, this acknowledgement should not inhibit or slow the response to the condition initiating the alarm (Ahlstrom & Longo, 2003).

We recommend providing a simple, consistent means for turning off non-critical auditory alarms. This should occur without erasing any displayed message that accompanies the auditory signal once the user has acknowledged the alarm or corrected the condition generating it (Ahlstrom & Longo, 2003). Alternately, the system could include a sensing mechanism that automatically shuts off the auditory portion of the alarm once it no longer provides useful information, consistent with the operational situation and personnel safety (Ahlstrom & Longo).

4. It is difficult to locate the source of alarms

There are several ways to improve the localization of alarm signals. Alarms that are in the mid frequencies (1500-3000 Hz) are the most difficult to localize (Sanders & McCormick, 1993). Alarms that are directly in front or in back of the user's head are difficult to localize. In addition, sounds can reverberate from hard surfaces in the environment, creating echoes that further complicate localization. Several strategies can maximize the ability to localize auditory alarms. Alarms can be made with a broad spectrum, avoiding the mid frequencies. Alarms can be located off to the side instead of directly in front or in back of the user. Minimizing hard surfaces in the environment can decrease echoes.

Another approach is to minimize the need for localization by providing a centralized alarm panel or window indicating the alarm status for most alarms. Auditory alarms could be consolidated into a centralized alarm panel or window only if immediate identification of the appropriate visual display is not critical to personnel safety or system performance (Ahlstrom & Longo, 2003).

5. Too many alarms go off at the same time

Research shows that people can learn between four and seven alarms reasonably quickly; however, performance decreases dramatically for additional alarms. Because four is the lower limit, when absolute identification (the user is required to identify the alarm based on the auditory portion alone) is required, the number of signals to be identified should not exceed four. Up to nine alarm signals can be used if they are presented regularly because users can retain the meanings associated with up to nine alarms if the alarms are presented regularly (Ahlstrom & Longo, 2003; Patterson, 1982; Stanton & Edworthy, 1994). When relative discrimination is required instead of absolute identification, the number of alarm signals can be expanded up to 12 (Stanton & Edworthy).

In the event of a complete system failure, the system could, by design, integrate messages and report the system failure with a single auditory alarm rather than generate auditory alarms for each of the failed components (Ahlstrom & Longo, 2003).

4.1 Additional Comments

A participant commented that many of the controllers have some degree of hearing loss, either from having previously worked in high noise areas or advancing age. New alarms should be

designed so that all users can hear them. Hearing loss associated with age generally starts with the higher frequencies (above 2000 Hz). Providing volume control with sufficient volume and avoiding higher frequencies can help ensure that those suffering from hearing loss can hear the alarms.

Participants provided comments on specific systems such as the ILS, ARTS and the CDR. Applying the recommendations provided previously can address most of the issues with ARTS and the ILS. The CDR should have an auditory alarm. Supervisors had to continually check the system to make sure that it was still functioning. Thus, serious consideration should be given to adding an auditory alarm to the CDR.

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Acronyms

ARTS	Automated Radar Terminal System
AT	Air Traffic
ATCS	Air Traffic Control Specialist
ATCT	Air Traffic Control Tower
CA	Conflict Alert
CDR	Continuous Data Recorder
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MSAW	Minimum Safe Altitude Warning
NAS	National Airspace System
NTSB	National Transportation Safety Board
RDHFL	Research Development & Human Factors Laboratory
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
WJHTC	William J. Hughes Technical Center

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