Human-Automation Teaming:

Unintended Impacts and Mitigations for Degraded NextGen Operations

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Philip J. Smith, Cognitive Systems Engineering, Inc.
Emily Baumann, American Institutes for Research

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16. ABSTRACT The goal of this report is to provide insights regarding the potential unintended negative impacts that the introduction of automation can have on human performance and resultant system behavior when a decision support system fails or exhibits degraded performance. It further provides human factors guidance on methods to mitigate potential risks to efficiency and safety resulting from such impacts on human-automation interaction. These conclusions are developed based on lessons learned from the past introduction of automation in aviation, nuclear power and naval operations, as well as in healthcare, and are then applied to provide guidance for the design and use of automation to support trajectory based operations for the Next Generation Air Transportation System (NextGen).		
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The views expressed in this report are those of the authors. They do not necessarily reflect the views of the Department of Transportation, the FAA, NATCA, or any other organization.

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Executive Summary

Background

The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) is implementing new capabilities to improve air traffic operations within the National Airspace System (NAS). Some of these capabilities involve automation—primarily information automation in the form of decision support tools (DST) that are intended to improve NAS efficiency through an increase in capacity, an increase in predictability, and a reduction in fuel consumption, while maintaining or increasing safety. Although the intended benefits are well understood, the FAA is concerned with the possible long-term risks to human performance, such as knowledge and skill degradation. For example, after long-term use, if the DSTs become unavailable because of a degradation or failure, can air traffic controllers (ATCs) revert back to previous "manual" operations to maintain acceptable levels of efficiency? Because such questions are difficult to answer prior to operations, the FAA tasked the American Institutes for Research (AIR) to gather actual automation experiences from past FAA air traffic control operations and from analogous domains with high-consequence operations.

To address the specific FAA concerns, this report focuses on lessons learned from the introduction of and subsequent user dependence on automation. This report applies those lessons learned, including potential unintended impacts and mitigation strategies for those impacts, to DSTs that will be implemented as part of the NextGen initiative. The goal of this report is to raise awareness and identify unintended negative impacts from the operation of new DSTs and provide the FAA with human factors guidance to help mitigate any potential risks to efficiency resulting from a DST failure or degradation.

Methodology

In order to better understand the potential long-term risks that DSTs pose to human performance, we gathered and synthesized information from a variety of sources, including other industries or aviation operations where, during an extended time period, the human operator has relied heavily on a DST to make decisions.

This work was performed in four steps. First, because different DSTs will have different impacts on human performance, we began the work by narrowing down which NextGen capabilities to consider, with a focus on the implementation and integration of time, speed, and spacing (TSS) tools and operations. More specifically, this report looks at two capabilities that are in final stages of development and testing, Terminal Sequencing and Spacing (TSAS) slot markers and speed advisories associated with Ground Interval Management-Spacing (GIM-S).

As a second step, we conducted a literature review to guide our research based on previously studied long-term effects of the introduction of automation and to identify operational domains for further study. Next, we conducted interviews with experts about analogous situations where automation such as DSTs has been implemented for an extended period and which human operators have used regularly for making operational decisions. Lastly, we developed an impact analysis and guidance to help mitigate unintended impacts of TSAS and GIM-S capabilities. We drew on the lessons learned from the literature review and interviews and applied them to an evaluation of this new NextGen automation.

Results of Interview Study

To gain a variety of perspectives, experts were interviewed from four different operational domains that were deemed informative: naval operations, medicine, nuclear power plant operation, and aviation. Within aviation, three distinct job positions were interviewed: airline dispatchers, pilots, and Air Traffic Controllers (ATCs). Experts were interviewed to gain insight on two fundamental questions:

1. Can the introduction of automation have unintended negative impacts on human performance?
2. What mitigation strategies can be used to avoid or reduce these potential negative impacts on human performance and on system performance?

Based on our synthesis of the interview data, we identified five potential negative impacts of automation that were present in multiple examples and multiple operational domains:

(a) Degradation of Knowledge and Skill;

(b) Reliance on Automation as the Primary "Agent" to Detect Problems;

(c) Reduced Attentiveness and Preparation to Deal with Automation Degradations or Failures;

(d) Alarm Fatigue, False Alarms, and Ignoring Alarms;

(e) Automation-Induced Effects on Team Situational Awareness and Teamwork.

We further identified six types of strategies to mitigate these potential negative impacts:

(a) Providing Effective Training and Experience;

(b) Supporting Effective Teamwork;

(c) Learning from Past Performance Through Data Analytics;

(d) Developing and Using Contingency Procedures and Checklists;

(e) Designing Technology to Support Effective Human-Automation Teaming;

(f) Designing Effective Buffers and Safety Nets.

The results of these interview data are important because they point to overlap between different operational domains and suggest that, because similar unintended impacts of automation can be found in other domains, similar mitigation strategies could be used to diminish the effects of those impacts. If these potential impacts are identified and the associated mitigation strategies are implemented, the potential for such unintended negative consequences could be reduced, and the risks to efficiency and safety could be diminished.

Application to TSS Tools and Procedures

It should be expected that, if GIM-S speed advisories and TSAS slot markers perform well and become the dominant mode of operation, controllers will learn to rely on this information automation to perform certain tasks, which in turn may affect their ability to develop and maintain the automatic perceptual and cognitive skills that they use today without such software support. As an example, because TSAS slot markers project where an aircraft should be in order to maintain spacing and arrive at its scheduled time, there could be a degradation in the terminal controller's skills at object projection because the graphic overlay provides the projection for the controller. Although the associated information display is not as visually compelling, it can be expected that routine reliance on GIM-S speed advisories would similarly change the automatic perceptual and cognitive processes developed by controllers to determine whether and when use speed control to maintain spacing, potentially degrading the perceptual and cognitive processes necessary to control traffic if these speed advisories are unavailable. In addition, if the use of such tools to support time-based metering are routinely effective, a second consideration is the potential degradation of traditional skills for vectoring and holding aircraft if they are not practiced as often.

If such a degradation of skill does result, the impact is likely to be primarily on efficiency when the controller needs to revert back to traditional "manual" methods without the support of these new capabilities. Very simply, in such cases the controller may feel the need to increase separation in order to ensure a safe operation. The findings from our interview studies further suggest, however, that there are a number of mitigations (listed above) that can help to reduce these unintended consequences, helping to improve the performance of the human-automation team and thus helping to ensure safe and efficient operations that take advantage of the benefits of these new tools and procedures.

Future Research

We have illustrated how the impact and mitigation categories that we have developed based on this study of multiple operational domains can be used to provide guidance in the development and implementation of new capabilities for NextGen. This report, however, was limited in scope to certain functions embedded in TSS tools and operations, specifically to TSAS slot markers and GIM-S speed advisories, which are expected to be deployed in the near term. We recommend that this same type of impact analysis and mitigation guidance be applied to other NextGen tools that are expected to be deployed in the mid- and far-term.

Organization of the Report

This report is organized into three chapters. Chapter 1 provides background on the research objective and provides an overview of the methodology. The synthesis of the results of interview data with experts in various operational domains is described in Chapter 2. Chapter 3 describes potential unintended consequences from the introduction of GIM-S speed advisories and TSAS slot markers on ATC performance. It also provides guidance for the mitigation of these impacts. The appendix provides detailed information from the interviews, including descriptions of concrete examples and specific mitigation strategies associated with these examples.

Chapter 1. Introduction

1.1. Background

The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) is implementing new capabilities to improve air traffic operations within the National Airspace System (NAS). Some of these capabilities involve automation—primarily information automation in the form of decision support tools (DSTs) that are intended to improve NAS efficiency through an increase in capacity, an increase in predictability, and a reduction in fuel consumption, while maintaining or increasing safety. Although the intended benefits are well understood, the FAA is concerned with the possible long-term risks to human performance, such as knowledge and skill degradation. For example, after long-term use, if the DSTs become unavailable because of a degradation or failure, can air traffic controllers revert back to previous "manual" operations to maintain acceptable levels of efficiency? Because such questions are difficult to answer prior to operations, the FAA tasked the American Institutes for Research (AIR) to gather actual automation experiences from past FAA air traffic control operations and from analogous domains with high-consequence operations.

To address the specific FAA concerns, this report focuses on lessons learned from the introduction of and subsequent user dependence on automation. This report applies those lessons learned, including potential unintended impacts and mitigation strategies for those impacts, to DSTs that will be implemented as part of the NextGen initiative. The goal of this report is to raise awareness and identify unintended negative impacts from the operation of new DSTs and to provide the FAA with human factors guidance to help mitigate any potential risks to efficiency and safety resulting from a DST failure or degradation. Although the primary focus of this report is on efficiency impacts, safety and efficiency are both discussed as they are closely intertwined in air traffic control since the impacts associated with proactively ensuring safety or in reacting and responding to a safety event can introduce inefficiencies.

The expectation is that implementation of the identified mitigations as part of the introduction of new DSTs will help reduce impacts on efficiency or safety in the event of an automation degradation or failure (Figure 1).

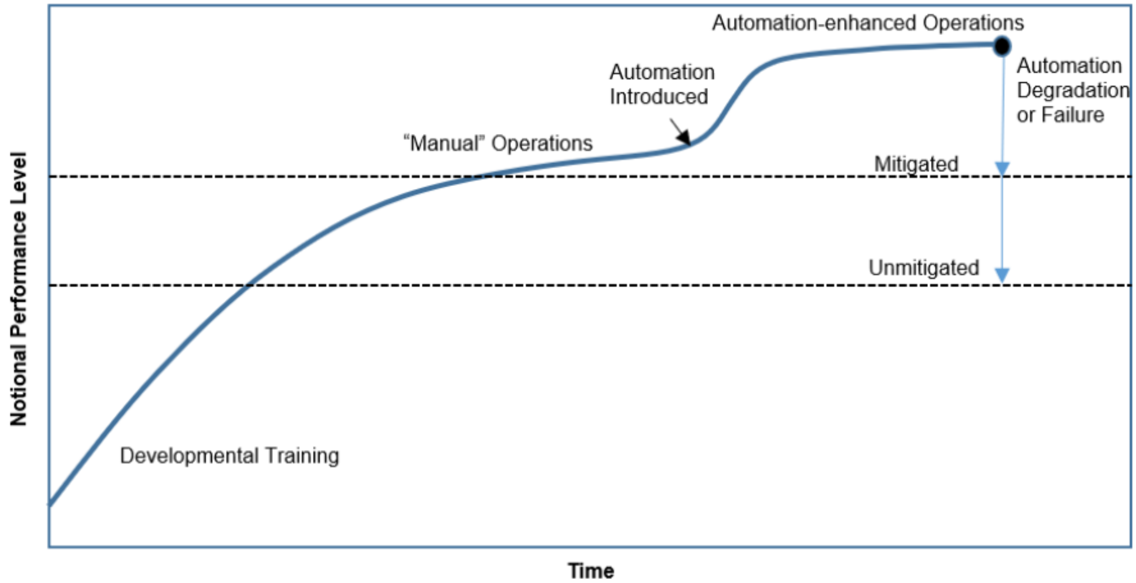

Figure 1. Notional Description of Long-Term Use of Decision Support Tools and Effects of Applied Mitigations

1.2. Methodology

In order to better understand the potential long-term risks that DSTs pose to human performance, we gathered and synthesized information from a variety of sources, including other industries or aviation operations where, during an extended period, the human operator has relied heavily on a DST.[1]

This work was performed in four steps (Figure 2). The following section provides a brief overview of each step. Detailed results for Steps 3 and 4 are described later in the report.

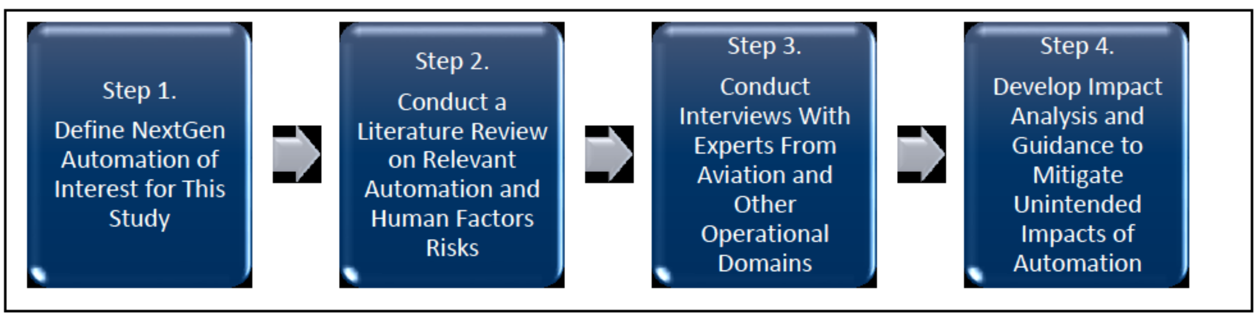

Figure 2. Steps for Determining Human Performance Considerations and Potential Mitigations for NextGen Capabilities

[1] Because this research is future-oriented and the actual long-term effects will not be measurable for many years, the ability to conduct informative research in a laboratory, such as through human-in-the-loop simulations, is limited.

Because different DSTs will have varying impacts on human performance, we began the work by first narrowing down which NextGen capabilities to focus on after completing the interview studies. Functions within two time, speed, and spacing (TSS) tools, the Terminal Sequencing and Spacing (TSAS) slot markers and the speed advisories associated with Ground Interval Management-Spacing (GIM-S) were selected as a focus. These two capabilities were selected as examples for analysis because:

- They are at a state in the development and evaluation process where any desirable mitigations to deal with potential degradations in these functions need to be considered in order to have an impact before their full operational distribution.

- They represent clear examples illustrating the introduction of information automation to support users through the incorporation of new information fusion and display capabilities.

- They support an air traffic control function that is of central importance in efforts increase or maintain efficiency and safety.

As a second step, we conducted a literature review to guide our research based on previously studied long-term effects of the use of automation and to identify operational domains for further study. As part of this review, we searched for publications on topics such as TSS tools and operations, NextGen and its impacts, human performance and automation, skill decay, impact of degraded environments, training and experience in manual mode, resilience and mitigations. We reviewed publications on the operational domains of air traffic control, flight deck operations, health care, automobiles, military, and human-computer interactions.

Next, we conducted interviews with experts about analogous situations where automation such as DSTs have been implemented for an extended period and human operators have used these regularly for making operational decisions. For the purposes of this study, along with air traffic controllers (ATCs), experts were selected from other domains (i.e., medical, naval, and nuclear operations) that, like air traffic control operations, can have high consequences in terms of safety and efficiency if responses are not timely and effective when automation performance degrades or when the automation fails. Experts from airline operations (dispatchers and pilots) also were selected for their shared focus on safety and efficiency. The results of these interviews are described in detail in Chapter 2.

Lastly, we developed an impact analysis and guidance to help mitigate potential unintended impacts from the introduction of TSAS slot markers and GIM–S speed advisories. We drew on the lessons learned from the literature review and interviews and applied them to this new

NextGen automation. The potential impacts and mitigations that were identified are described in detail in Chapter 3.

Chapter 2. Results: Interview Data from Other Operational Domains

This section presents the results of interviews with professionals from a variety of operational domains where significant automation has been previously introduced and where potentially high consequences for safety or efficiency exist if neither the human-automation team nor broader safety nets are sufficient to ensure an acceptable outcome. Experts from these operations were interviewed to gain insight on two fundamental questions:

1. Can the introduction of automation have unintended negative impacts on human performance?
2. What mitigation strategies can be used to avoid or reduce these potential negative impacts on human performance and on system performance?

The following sections describe the participants in more detail and the procedure used during the interviews.

2.1. Participants

To gain a variety of perspectives, experts were interviewed from four different operational domains that were deemed informative: naval operations, medicine, nuclear power plant operation, and aviation. Within aviation, three distinct job positions were interviewed: airline dispatchers, pilots, and ATCs. A total of 21 individuals participated in interviews (Table 1).

Table 1. Experience of Interview Participants

Domain/job position	Number of participants	Average years in industry
Naval operations	1	32
Medicine	2	20
Nuclear power plant operations	1	31
Aviation/dispatcher	6	27
Aviation/pilot	6	37
Aviation/ATC	5	29

The interviewed participants had an average of 30 years of experience in their respective operational domains. In addition, 14 participants had extensive experience in a supervisory or training role.

2.2. Procedure

The interviews averaged 90 minutes, with follow-up interviews of some participants of up to an additional 90 minutes. The interview protocol was based on Flanagan's critical incident technique (Flanagan, 1954).

To better understand the potential negative impacts of the use of automation on the human operator, participants were asked to provide specific examples to illustrate these impacts. These could be instances that they have personally experienced, or incidents with which they are familiar as a result of their role in their operations. Next, the interview participants were asked to describe what solutions were implemented or should have been implemented to mitigate the negative impacts that they described in order to prevent or reduce the likelihood of recurrence or to reduce those impacts. Last, the interview participants were asked to assess the risk (i.e., likelihood of occurrence and potential severity) of their most informative examples and rate the potential success of the mitigation strategies proposed for these examples.

2.3. Interview Results Regarding the Impacts of Automation on Performance

In this section, we summarize the results of the interviews with these 21 specialists in medicine, nuclear power, naval operations and aviation. These interviews support the belief that the introduction of automation offers an opportunity to significantly increase safety and efficiency (PARC, 2013). This is true whether this is "information automation" (providing alarms; integrating and displaying information to support user decision making; recommending courses of action) or "control automation" that performs actions without continuous input from the users (Volz et al., 2016).

However, the interviews further illustrate that, based on past experience, whether the users make use of information automation or control automation within complex systems, the automation must be assumed to be brittle, even with careful verification and validation of the software and of human-automation interactions. Such brittleness can be due to a variety of overlapping and interacting causes:

- Scenarios that the designers have not anticipated and that are consequently outside of the competency limits of the automation.
- Known or unknown limitations in the explicit or implicit completeness of the model of the operational environment used by the technology employed by automation.
- Unanticipated emergent behaviors resulting from the processing of the automation (or due to the interactions of multiple automated functions, often developed by different design teams).
- Slips or mistakes made by the designers in specifying the design.
- Errors in the knowledge base/database accessed by the automation.

- Errors in the real time data accessed through sensors or human input.
- Programming errors.
- Hardware failures.

Thus, the interviews demonstrate that there are a number of underlying causes as indicated in the list above that can result in unintended, undesirable performance by the automation or the human-automation team for the reasons listed above (Smith, 2018).

In all of the interviews, the participants recognized that automation designers often deal with the potential brittleness of their automation by indicating that the automation should be operated by, or supervised by, a person or a team of people (Parasuraman & Wickens, 2008). In many such designs, the role of the human(s) is to act as a safety net, detecting and intervening when the automation exhibits brittleness that can affect efficiency or safety. Alternatively, the designers may assign the person the primary role as monitor or operator, with the automation providing an alert or enforcing a constraint when the user fails to detect a problem or appears to be responding ineffectively or incorrectly.

In either case*, the assumption is that the human-automation team (Endsley, 2017; Sheridan and Parasuraman, 2006) working together will ensure more robust performance than either alone.* A third paradigm is to design for richer cooperative, interactive problem-solving or system operation by the human-automation team. However, this latter paradigm is still largely a research topic.

In all of the domains explored, the interviews indicate that there is a further assumption that, *even with a well-designed human-machine team, brittle performance will occasionally emerge.* To reduce the likelihood of such an outcome, the participants illustrated and recommended a number of mitigations in order to improve both system design and user performance, and to reduce the impact if the human-machine team should prove inadequate in a given scenario.

This latter mitigation is in essence an application of Reason's Swiss Cheese Model (1991), and is illustrated in some of the interviews through the introduction of other layers of safety that go beyond the functioning of some specific human-automation team within the broader system. Whether the goal is to maintain a high level of safety or efficiency, these "safety" nets are intended to add additional robustness to cope with anticipated scenarios or classes of scenarios and to add additional resilience to deal with unanticipated situations (Smith & Billings, 2009). Inclusion of an alternate airport by the dispatcher as a contingency plan in a flight release when its destination airport has a forecast indicating possible pop-up thunderstorms would be an example of such robustness in response to an anticipated possible scenario, helping to ensure an efficient and safe operation. The FAA's requirement for commercial flights to always include a certain minimum reserve fuel (providing greater latitude to deal with unexpected problems that could arise) would be an example of increased resilience to adapt to a wide range of unanticipated scenarios.

Below, we summarize the results of these interviews in support of the above perspective on the design of robust and resilient systems that incorporate increasingly powerful roles for automation. Additional details on the results are provided in the appendix.

These results are organized into abstract categories regarding potential impacts and recommended mitigations associated with the introduction of automation. More specifically, the following types of negative impacts were noted in multiple examples across the different operational domains:

- Impact 1: Degradation of knowledge and skills[2]
- Impact 2: Reliance on automation as the primary "agent" to detect problems
- Impact 3: Reduced attentiveness and preparation to deal with automation degradations or failures
- Impact 4: Alarm fatigue, false alarms, and ignoring alarms
- Impact 5: Automation-induced effects on team situational awareness and teamwork

We now present a summary of human factors implications for each impact. For a full description of the identified examples and associated risk ratings, see the appendix.

2.3.1. Impact 1: Degradation of Knowledge and Skills

Impact 1 concerns the potential for the user's knowledge and skills to degrade, reducing the ability to detect, assess and respond to a situation using more "manual" methods that require reduced (or no) reliance on the automation for support. This degradation of knowledge and skills (relative to "manual" performance prior to the introduction of the automation) can develop in two ways:

- The user routinely relies on the automation and, as a result, the user's knowledge and skills to degrade over time, reducing the ability to detect, assess and respond to situations using more "manual" methods (PARC, 2013; Volz et al., 2016). This

[2] Impacts 1-3 are often referred to in aviation as "automation dependency." See, for example, ICAO Working Paper A40-WP/296.

degradation can arise even though the individual has developed the necessary knowledge and skills during initial training.

As one of the interviewed physicians noted,

> Physicians also can lose knowledge and skills relevant to the treatment of a patient because they routinely rely on automation to perform those actions.

- The organization has changed the nature and reduced the amount of training and experience traditionally provided in order to develop and maintain the knowledge and skills necessary to apply "manual" methods. As a result, there is an overall institutional degradation in such knowledge and skills.

  This second concern regarding insufficient training on how to detect and deal with brittleness in the automation was reflected in statements by controllers,

  > We're often not briefed on the quirks of the system. Some of the younger folks don't have the training and experience to be proficient [in working without the automation] in the first place.
  >
  > If they're mostly being taught how to use the automation, the new people won't have a tool box that is as full.

Appendix A.1 provides a number of examples of these concerns, providing illustrations regarding the performances of physicians, pilots, controllers and dispatchers. Appendix A.1 also describes mitigations that were identified as part of the interviews in order to avoid or reduce the impacts of this degradation of knowledge and skill.

2.3.2. Impact 2: Reliance on Automation as the Primary "Agent" to Detect Problems

Impact 2 involves the potential for users to wait passively for an alarm to be displayed, rather than proactively observing the automation displays and the operational environment for evidence of trends that merit response prior to an alarm. Examples in this category demonstrate cases in which users have become reliant on alarms to detect problems for them, even though it is expected that, as part of their job, they will actively monitor conditions. These examples highlight the potential for individuals to have delayed (or no) detection and reaction to a problem.

Participants who were pilots and doctors provided examples for this category, noting that this dependence on automation also may contribute to the decay of the knowledge and skills needed for monitoring, diagnosis, and intervention for a problem (Impact 1). One pilot explained,

> You have to anticipate what the automation is going to do. And you can lose some of that skill over time or you can get too reliant on the automation and not stay ahead. *If you're just waiting for alerts to do something, you're going to be too late sometimes. The pilot needs to be proactive. Pilots need to know what to monitor, how to recognize when to intervene, and how to intervene.*

One of the doctors made a similar point, stating,

> The doctors also get rusty. They lose the skill and no longer follow the routine of looking at the patient to see what's going on. *Half the problem is reliance on the alarms and half is a loss of the skill and the habit of looking at the patient to see how he is breathing and whether there could be an obstruction.* The resident will look at the monitor and will say: The oxygen saturation is fine, but it takes a little while for that to drop once the patient stops breathing. Even when they look at the patient, they don't recognize the problem until the monitor alerts them.

This same doctor went on to explain that the alarms should be the back up to the doctor and not the other way around. This participant noted,

> I'll see residents relying on the alarms that are part of the monitors and ventilators. They'll be looking at their phones instead of the patient. And they're not necessarily looking at something pertinent to the case. They're relying on the alarms and the technology. For example, a resident might check to see the carbon dioxide level on a capnograph without looking at the patient's chest. *They could see something going on if they looked but won't react until an alarm goes off. They are less engaged. The alarm should be a supplement to watching the trends and looking at the patient.*

Additional examples are provided in Appendix A.2 based on input from the physicians, pilots and controllers.

2.3.3 Impact 3: Reduced Attentiveness and Preparation to Detect and React to Automation Degradations or Failures

Impact 3 focuses on concerns that the user may become less attentive in monitoring for:

- A failure of the automation to provide an alert.

- Failure of the automation to provide an appropriate alert or recommendation.
- Degradations or failures of the automation to appropriately perform some task.

Note that this overlaps with the previous impact as:

- In order to detect the failure of the automation to provide an alert, the user must be proactively monitoring the situation.
- In order to determine whether an alert, recommendation or response made by the automation is appropriate, the user must have an understanding of the situation. However, this situation awareness and assessment could be developed in response to (and after) the automation has displayed an alert or recommendation or has initiated some action.

Such inattentiveness can impact the user's ability to detect and respond effectively in a timely manner when the automation exhibits brittleness (Lee & See, 2004; Parasuraman et al., 1993; Parasuraman & Manzey, 2010; Parasuraman & Riley, 1997; Riley, 2009; Strauch, 2017). Pilots, dispatchers and controllers provided examples for this category and indicated that some individuals have become so confident in the automation that they do not always check responses made by automation.

As a special case, one pilot discussed scenarios in which the initial problem is an operator input error rather than an automation failure. The pilot explained, "One of the things we struggle with is that the automation has been so good that the pilots trust it almost to a fault. They need to monitor it because errors can be introduced through programming errors. For example, a pilot input error such as entering a wrong altitude or putting the airplane in the wrong mode could cause an airspeed control or heading control problem".

Another important case regarding concerns associated with Impact 3 involves the detection and handling of sensor failures. Participants in the medical and nuclear power plant domains provided examples that emphasized the importance of cross-checking data to ensure that sensors are operating correctly. One doctor said, "There's a tendency to have an unwavering belief in what one monitor is telling you. … You need to cross-check your monitors."

Additional details are provided in Appendix A.3.

2.3.4. Impact 4: Alarm Fatigue, False Alarms, and Ignoring Alarms

The examples of Impact 4 emphasize the effect on human performance of automation that generates numerous alerts, namely that the person does not respond to an important alarm because it is embedded in what an anesthesiologist described as a “cacophony of alarms”, some of which do not merit a response or do not require an immediate response (Cvach, 2012; Sendelback & Funk, 2013). Participants who were controllers and doctors provided examples for this category and indicated that the frequent occurrence of alarms, whether valid or false, can desensitize individuals. One controller explained, “We’d get a ton of false alarms—nuisance alerts. Then you wouldn’t notice when there was a legitimate alert. It’s like the boy who cried wolf.” When individuals develop alarm fatigue, they may have longer response times to attend to an alert or completely miss an alert. One doctor noted,

> Alarm fatigue seems to be one of the big problems. If you’re relying on patient monitoring to tell you when something is going wrong, it’s easy to ignore an alarm, thinking: I’ll get to that in a moment because it becomes part of that background milieu. You get habituated to the noise.

According to the participants, contributors to nuisance alerts include the tight alarm limits often set by manufacturers and the limited ability of automation to consider the actions individuals plan to perform (intentions), thus making an alarm unnecessary.

The naval officer provided examples for this category and indicated that when individuals are distracted or double tasked, they may suppress or silence an alert to attend to a task they feel needs more immediate response. He further noted more than one instance when a valid alert was silenced repeatedly, leading to an accident.

Additional details are provided in Appendix A.4.

2.3.5. Impact 5: Automation-Induced Effects on Team Situational Awareness and Teamwork

The examples of Impact 5 involve the effects that the capabilities and the implicit demand characteristics embedded in automation can have on the extent and effectiveness of communication and coordination, thus influencing a team’s shared situational awareness and teamwork. For example, one doctor explained that electronic notes lend themselves to generic copy and paste instead of providing more specific notes for each patient, and lead to the use of shortcuts by just checking boxes on the notes page rather than providing more details. These details can be important if another doctor examines the patient and only has those generic notes to access. As a result, the team’s shared situational awareness can be diminished.

Another example, provided by the nuclear power expert, explained how the early designs of automation for nuclear power plants enabled many functions to be a one-person operation rather than the highly interactive crew operation that it had been previously when controls were less automated. The amount of interaction between the crew was significantly reduced, and the roles and responsibilities of the human crew members were changed. Crews felt their interactions and teamwork skills were greatly diminished.

Although reduced teamwork on its own is not necessarily a negative impact, participants across the operational domains indicated that a design that supports effective teamwork can serve as part of the safeguard and solution for problems associated with automation. For example, team members can catch slips, mistakes, unexpected events, or communication errors that are made or overlooked by other team members. Team members also can provide multiple perspectives as they draw on their individual situational awareness, knowledge, and skills to help the team detect and deal with a problem. The participants further indicated that teams are necessary to distribute task demands to limit the cognitive complexity and mental workload for any one individual. Thus, a reduction in effective teamwork as a result of the design of the automation can take away a layer of redundancy in the event of an automation failure or degradation.

The examples of this impact emphasize that teams should maintain shared situational awareness and teamwork when interacting with automation.

Additional details are provided in Appendix A.5.

2.4. Results of Mitigations to Deal with Potential Negative Impacts

In the preceding section, we presented a variety of unintended impacts that could result from the introduction of automation. As indicated by the cited references, we can find discussions of many of these impacts in the literature. Mitigations, however, are less well characterized.

Thus, similar to the discussion above on impacts, we synthesized the information provided by participants who were asked to identify specific mitigations that were applied to each example and to recommend mitigations that should have been applied (PARC, 2013; Smith, 2018). In this section, we categorize those mitigations separately from the impacts because they often are appropriate across many different scenarios with multiple impacts. We identified the following mitigation categories:

- Mitigation 1: Providing effective training and experience
- Mitigation 2: Supporting effective teamwork
- Mitigation 3: Learning from past performance through data analytics

- Mitigation 4: Developing and using contingency procedures and checklists
- Mitigation 5: Designing technology to support effective human-automation teaming
- Mitigation 6: Designing effective buffers and safety nets

The importance of these mitigations arises because, although the introduction of automation is intended to increase overall system safety and efficiency, it is generally acknowledged that such technologies will at times degrade or fail. It is further generally accepted that it is important to design automation such that the involvement of human users/operators in the functioning of the automation provides a safety net for degradations or failures in the technology. As discussed earlier, awareness and trust in such safety nets by operational staff can provide the comfort levels necessary to operate the system at a higher level of efficiency. This design applies to the detection of a problem; the diagnosis of the contributing causes; and the generation, selection, and execution of responses to deal with the problem. However, as the previously discussed examples clearly indicate, the introduction of the automation can influence the development and retention of cognitive knowledge and skills and impact the cognitive processes and behaviors of individual users in undesirable ways, making them less effective as a safety net.

In the following subsections, we summarize each mitigation category. For a more detailed description of specific mitigations for each example and the associated effectiveness ratings, see the appendix. It should be noted, however, that although the different mitigation strategies identified by participants in various operational domains are intended to decrease the risks to safety and efficiency associated with unintended impacts, they are not guaranteed to mitigate all risks, emphasizing the importance of Mitigation 6 (Design Effective Buffers and Safety Nets).

2.4.1. Mitigation 1: Providing Effective Training and Experience

Training was identified by every participant as a valuable mitigation strategy to reduce the potential negative impact of automation on the user. The participants noted the need to provide appropriate initial and recurrent training when introducing new automation, and emphasized specific types of training to focus on including the following.

Training to Treat Alarms as a Backup Safety Net. One strategy that was identified by both the doctors and the pilots was to assign the person the primary role of detecting a problem. The participants emphasized that the person should not play a passive role, waiting for an alarm from the automation to begin determining what is wrong and how to respond. Thus, whenever possible, alarms should be treated as a backup to detect a problem that the person has not yet detected.

It was further noted by participants that this strategy had the additional benefit of helping the user maintain certain skills on the job. First, by proactively detecting problems, the user's skills at the detection and diagnosis of problems are less likely to degrade. Second, in the process of watching for trends that may be shown by the information displays and by attending to the broader operational environment (e.g., the patient, the broader surgical environment, the aircraft, conditions of the airspace in terms of weather and traffic, voice communications between pilots and ATC), the person is likely to maintain more complete and accurate situational awareness, making it possible to respond effectively in a timely manner when a problem is detected.

Training to Focus First on Keeping the System in the "Safety Envelope." Both the pilots and the nuclear power expert indicated the importance of intervening as necessary to ensure that the system stays within its immediate safety envelope before focusing on diagnosis and the determination of a broader response to a problem (such as diverting to another airport). The nuclear power expert explained,

> In an emergency, they're not responding to individual alarms. The first step is to recover the safety profile of the system, the pressure of the reactor, the temperature of the reactor, without doing diagnosis. Then you figure out what is going on.

Pilots made similar comments.

The participants further indicated that one way to respond to a failure or degradation in the automation, while keeping the focus on safety rather than diagnosis, is to train the user to immediately shift away from reliance on the functions of concern when a problem with automation is identified and, if the initial response isn't adequate, to progressively reduce reliance on the automated functions in question until the situation is stabilized.

Training that Goes Beyond the Knobs and Dials of How to Use the Automation. Participants from all operational domains suggested that users need to better understand how automation works, including the underlying principles and factory settings for automation (PARC, 2013). The nuclear power expert clarified,

> With the automation, you can lose some of your skill sets. What is going on behind the glass matters. If you understand it, maybe you can influence and control it. It's not just learning if-then rules. You need to know why you're doing this.

Other participants made similar comments that users need to understand more than just how to use the automation; they also need to understand how the automation works and what the automation knows.

Training that Includes Experience with the Detection and Response to Off-Nominal Situations. Participants in all operational domains expressed the need for users to know when and how the automation may not work effectively. One pilot clarified as follows,

> Training tends to focus on how to use the interface, how to get in and out, how to select something, what to look at. [Too often] they don't handle all of the things that can go wrong, the gotchas. They don't tell you what you have to do for all of them. … You need to train on partial failures, including where one system is talking to another, leading to a lot of complexity when something goes wrong. You need to learn how to recognize a partial failure. And you need to know how to deal with a failure. You also need to learn how to deal with the unknown because the engineers can't anticipate everything.

Participants indicated that users need to understand how to identify and respond to both partial automation failures and multiple, complex automation failures. Users may get training on full automation failures or types of failures that are most likely to occur, but they cannot get training on every possible type of automation failure or degradation. Thus, training should focus on increasing the sensitivity of the user to detect the onset of partial or multiple failures as well as internalize the deeper knowledge and skills necessary to respond effectively in such situations.

Training of Cross-Checking Skills. One of the doctors and the nuclear power expert emphasized the importance of training users to cross-check the data provided by individual displays and associated sensors with the data provided by other displays and sensors that are relevant to the same information. The dispatchers and pilots further emphasized the importance of cross-checking to help detect a case where the automation is no longer displaying important alarms or messages or the case where some information display is indicating incorrect information because of a user input error or an automation error.

Training to Ensure the Maintenance of Backup Skills and Knowledge. Several participants across the different types of operations expressed concern that training can focus on the use of the automation, without adequate development or maintenance of the knowledge and skills that may be necessary if the person needs to operate with less support from the automation. One pilot commented,

> When hired by the airlines, the pilot is usually a great stick and rudder guy, so we need them to demonstrate that they have mastered the automation. We focus

> on that. After 2 years, those stick and rudder skills and the other knowledge they need to make decisions have seriously atrophied.

2.4.2. Mitigation 2: Supporting Effective Teamwork

Teamwork also was identified by participants across the operational domains as a valuable mitigation strategy to reduce the potential negative impact of automation failure or degradation on an individual user. As discussed earlier in the impact section, the design of the automation and associated procedures can potentially diminish the team's situational awareness and teamwork skills. Thus, it is important to design the automation and associated procedures in a way that supports effective teamwork. For example, the nuclear power expert illustrated how they mitigated the loss of teamwork and team situational awareness from early automation designs by explaining, "In the newer systems, they built in stopping points to coordinate with each other and were given more specific communication and diagnosis roles than they used to have."

2.4.3. Mitigation 3: Learning from Past Performance through Data Analytics

Participants across all operational domains indicated the importance of providing structured approaches to learn from past experiences to help the user respond better and mitigate similar future incidents of automation failure or degradation. One doctor said,

> Best practices have to evolve. In medicine, it depends on what you do after those incidents to make it better. There has to be a willingness to accept that their performance was a problem instead of wiping their hands since they had transferred the patient. You need to make the process better so [that] it never happens again. Locally, you need a debrief and then a root cause analysis to get an outside perspective to make the system better. Globally, there are doctors who write about what they have done based on personal experience in order to become better.

The participants noted that historical data, including incident reports, can be used to gather performance information on the automation and also on user responses to automation failures or degradations. They cautioned, however, that users need a safe environment in which to honestly report incidents, one that emphasizes the importance of continued learning and responsiveness to incidents from which every user can benefit. One controller stated,

> The more failures we see when using new automation, the less controllers tend to report them. They think: We've bought it. We've just got to live with it. And when we don't see changes [in the software], we just give up.

Participants from several domains indicated that while learning from past events is worthwhile, actions need to accompany any insights learned.

The participants also cautioned that developing and maintaining a structure to collect and analyze historical data takes time and resources. Thus, organizations need to be willing to invest such resources into data analytics in order to enable responses to automation failures or degradations.

2.4.4. Mitigation 4: Developing and Using Contingency Procedures and Checklists

Many of the practitioners noted the importance of well-designed and accessible procedures to mitigate the negative impacts of automation on the user by providing the user with procedures to respond to an automation degradation or failure. Participants noted that the procedures should (a) limit distractions to individuals, (b) enforce teamwork and communications to help ensure shared mental models, and (c) clearly define the roles of team members. Participants also noted that these procedures may be within and across facilities and thus must be supported higher up in the organization.

2.4.5. Mitigation 5: Designing Technology to Support Effective Human-Automation Teaming

The participants indicated that the design features of the technology itself are an important consideration to mitigate negative impacts of automation on the user. They suggested the following potential improvements to design.

Design the Automation so that It Can Be Operated in a Manner that Keeps the Operator(s) Both Informed and Engaged. The nuclear power expert explained,

> Procedures are almost all available with full-blown automation now [where the automation automatically responds to situation that it has detected], but the operators can choose the level of task automation. In emergencies, the software can operate everything through procedures. But the operator can choose whether to operate by consent or operate by exception. For operation by consent, the software stops at each step and waits for the operator to say OK. Go ahead. That way the operator is the manager, asking: Is this procedure achieving the goals I need? The operators tend to not use the highest level [operation by exception] because they lose situation awareness.

Other participants made similar comments and indicated that better design can reduce reliance on automation and the associated risk of losing situational awareness thereby delaying a reaction to a problem (Endsley, 2009; Popkin & Krems, 2001). As an example, the pilot described a case where the master caution light indicates a malfunction in the airplane's air conditioning system, drawing the pilot's attention to the problem. After the alert, the automation will automatically reconfigure the airplane's air conditioning system to resolve the problem, for instance, by isolating a leak in the ducting. In this case, the pilot can call up the system's schematic and watch as the airplane goes through its routine to do this, monitoring the automation to see if he/she is satisfied with the outcome. This participant noted that this design solution helps ensure that the pilot maintains familiarity with the standard procedure for dealing with this problem, while also helping ensure that the pilot stays sufficiently engaged to detect an anomalous situation where the automated response could be inadequate.

These design solutions, however, need to be balanced against the risk of information overload for users.

Enforce Consistency Across Vendors. The participants noted that it can be difficult for users to learn how to use systems with different design features— which can especially be a problem when organizations use different vendors to provide different pieces of automation and the vendors are not managed so that they adequately coordinate with each other and as a result design systems that implement the automation and associated interfaces in different ways.

Design an Interface that Makes It Easy to Access the Necessary Information Displays in Response to an Alarm. The Naval Officer indicated that they need "a simple, clean, modern interface, not a menu with multilevel drill downs" because when there is an alarm or alert, the user needs to efficiently find the root cause.

Avoid an Excessive Number of Alarms. The participants noted that this could be done by having less strict default values for alarms or by having the automation better understand and anticipate the actions a user will take to avoid alarms. The participants noted that this could help prevent alarm fatigue and the subsequent desensitization to alarms that could lead to ignoring or suppressing alarms.

Make Alarms and System Status Indicators Sufficiently Salient. Because there could be multiple alarms and alerts in the operational environment, make sure that any alarms or alerts are designed to get the user's attention and don't become lost in a "cacophony" of lights and noises in the operating environment.

Design Displays so that the Operator Can View the Same Data that the Automation is Using. The participants noted that automation often has multiple sources of data, but for convenience, displays may show the user only one source. This can be problematic if the source being shown to the user is not the same source being used by the automation for a particular task or decision. For example, the source on the monitor could be faulty even though the automation is using correct data, prompting the user to incorrectly shut off the automation. Or vice versa. The information on the monitor could be correct, but the automation is using a different faulty source of data, thus prompting the user to take no action because he/she assumes the automation is making correct decisions based on good information.

2.4.6. Mitigation 6: Designing Effective Buffers and Safety Nets

The five mitigations described above emphasize the importance of taking steps to ensure the human-automation team performs as effectively as possible. However, although they can significantly improve safety and efficiency, these mitigations do not guarantee success. Thus, in all of these domains, at least as important as applying the mitigations described above in order to improve the performance of a given human-automation team is the need to:

- Build in safety buffers, so that if the human-automation team exhibits degraded performance, there is sufficient leeway to still complete the mission safely. As noted earlier, an important indirect benefit also is provided to efficiency if there is awareness and trust in these safety nets by operational staff, as this can provide the comfort level necessary to operate the system at a higher level of efficiency.

- Design the system so that is has multiple layers to ensure safety (Reason, 1991; Smith & Billings, 2009) so that if one particular human-automation team fails to produce the desired performance, some other layer will either catch this problem and correct it or, if that is not possible, will support some other action that provides a safe and efficient outcome.

These layers of safety come in many forms, including:

- Assigning multiple people with the task of helping to monitor and manage an operation, each with a somewhat different set of knowledge and skills, roles, responsibilities and perspectives, in order to increase the chances that one of them will detect and be able to contribute to dealing with a problem. This includes participation in contingency planning as well as adaptive response to issues as they arise.

- Designing the automation itself to provide alerts or incorporate display designs that make the occurrence of anomalous conditions highly salient and to support effective response to such conditions based on the state of the operational environment. (The latter could involve the incorporation of envelope protection to help constrain responses to safe ranges, or automated functions that have been integrated into the automation to support rapid response to certain situations - such as the go-around button in the flight director of an aircraft that, when pushed, disconnects the autopilot and sets it for 7.5 degrees pitch up with wings level).

- Designing the broader system (including the technologies used by all of the involved people) such that each individual has effective access to the information necessary to perform his/her role and the ability to determine and perform necessary actions when some type of intervention is necessary. This includes the support of communication and coordination among the different individuals.

- Designing the operational environment (such as requirements for minimum separation) so that there are sufficient buffers (time, space, resources such as fuel for an aircraft or additional sources of water for a nuclear power plant, etc.) to enable an effective response to an anomaly.

As one pilot noted, "There's a bunch of other safeguards, old fashioned eyes, the controller, and there's the TCAS [traffic alert and collision avoidance system]. All of these other safety nets help ensure that an accident won't happen." And in aviation, this is just the tip of the iceberg in terms of the human safety nets to help ensure safe and efficient operations. Controllers, traffic managers, pilots, dispatchers, maintenance specialists and others all take on a number of different roles as part of their responsibilities to provide a safety net. The same is true in the Navy, healthcare and nuclear power.

Thus, all of the domains studied here provide important illustrations of this concept: Design the broader system to avoid a situation where any one system designer, individual, automation function or human-automation team can be a single point of failure that results in an accident or significant loss of efficiency.

2.5. Conclusions from the Interview Data

The results of these interview data, organized in terms of the identified classes of impacts and mitigations, are important because they point to overlap between different operational domains, identifying similar unintended impacts and similar mitigation strategies that could be used to diminish the effects of those impacts. The interviews further suggest that if these potential impacts are identified and the associated mitigation strategies are introduced prior to the implementation of any new automation, unintended negative impacts can be reduced, diminishing risks to efficiency and safety. Thus, we use these data in the next section to identify any unintended potential impacts of NextGen automation in the air traffic control domain and determine potential mitigation strategies to mitigate those impacts.

Chapter 3. Impact Analysis and Guidance to Mitigate Potential Impacts of NextGen Automation on Air Traffic Controllers

This chapter illustrates the application our impact analysis to identify potential unintended consequences of new NextGen tools and operations for ATCs. It also presents recommendations to mitigate the identified potential impacts.

As stated in Chapter 1, the focus for this analysis will be the potential impacts resulting from routine use of the capabilities provided by NextGen tools, specifically the impacts that such reliance can have on the controller's knowledge and skills when it is necessary to revert to more "manual" methods of control because of a degradation or failure without the same degree of support from the automation. The focus of this analysis also will be on TSS capabilities, specifically the use of GIM-S speed advisories and TSAS slot markers. Because this automation is new and has not been fully implemented yet, our analysis is a priori in nature; thus, any identified impacts and recommended mitigations should be taken as possibilities, not concrete conclusions. To ensure the identified impacts and recommendations are reasonable deductions, we use the results of the interview data described in Chapter 2 to inform our analysis.

We begin this chapter by describing the NextGen capabilities of interest. Each capability is a form of information automation, serving as a decision support function. We then describe potential ATC knowledge and skills that could be affected by these capabilities. Next, we identify potential impacts on knowledge and skills resulting from long-term use of the automation. Finally, we provide guidance for mitigations to reduce such impacts or to prevent or reduce negative outcomes when such impacts arise in spite of the mitigations that have been applied.

3.1. Description of Time Speed and Spacing Tools and Operations

GIM-S speed advisories and TSAS slot markers re part of the broader concept of time-based flow management (TBFM), which is "the hardware, software, methods, processes, and initiatives to manage air traffic flows based on time to balance air traffic demand with system capacity" and to support scheduled times of arrival (STAs), which are used by controllers as a benchmark that must be met as part of their tactical air traffic management (N JO 7110.698). STAs, also referred to as "times on glass," are a calculation of "the desired time that an aircraft should cross a certain point (landing or metering fix)" to maintain an optimal flow of traffic (N JO 7110.698). The STAs are determined by a DST in TBFM that takes into account traffic, airspace configurations, optimized spacing and aircraft performance characteristics.

3.1.1. Description of Speed Advisories

Arrival metering and extended metering using TBFM both support time-based separation of aircraft in the en route environment to deliver aircraft to the terminal airspace boundary at STAs using speed advisories. Speed advisories are provided by a DST designed to help aircraft achieve their STAs.

Speed advisories are calculated by GIM-S automation and can be displayed for air route traffic control centers (ARTCC) controllers as a suggested speed in the data block for aircraft on their En Route Automation Modernization (ERAM) monitors. They will be displayed only if the estimated time of arrival (ETA) differs from the STA by five seconds or more, and if the advised speed will resolve the difference between the ETA and the STA. Controllers can choose to accept and assign this speed to the pilot as a speed clearance, or they can reject this speed and send a cancellation to the automation. If a speed advisory cannot resolve the difference in time between ETA and STA, an early/late indicator will be displayed. Speed advisories are used by controllers to aid in the accurate delivery of aircraft to assigned meter points.

Speed advisories are one of the key functions of GIM-S and part of the broader concept of TBFM, which aims to enhance time-based metering operations. They are for the benefit of NAS performance and are intended to increase accuracy and efficiency and reduce costs. Speed advisories are designed so that controllers can more easily use speed control to get aircraft to their metering points, rather than vectoring them to absorb delays.

Currently, GIM-S, and therefore speed advisories, have been deployed at three locations: Albuquerque Air Route Traffic Control Center (ZAB), Denver Virtual Air Route Traffic Control Center (ZDV), and Seattle Air Route Traffic Control Center (ZSE). According to the FAA, "analysis at Phoenix showed that 80.1 percent of flights that accepted a speed advisory arrived within 30 seconds of the STA, compared to 57.4 percent of flights that declined an available speed advisory" (FAA, 2017).

3.1.2. Description of TSAS

TSAS extends time-based management into terminal airspace by continuing to deliver aircraft to terminal metering points (TMPs) at STAs using slot markers, thus completing the time-based solution to air traffic management. TSAS provides terminal controllers with information to help them keep aircraft appropriately spaced on a specific route and allow them to keep properly equipped aircraft on their PBN-enabled approaches.

TSAS provides information to terminal controllers that supports time-based separation of aircraft in the arrival flow to a runway. The information provided to controllers is calculated by TBFM with input from other ATC automation platforms: Standard Terminal Automation

Replacement System (STARS; aircraft position data), ERAM (aircraft position data), CTAS Remote Weather System (CREWS; weather data), and TFMS (Traffic Flow Management System; track and flight data). TSAS information is displayed for terminal controllers on the STARS display in the data block or as an overlay to the approach. Specific information to be provided includes the following:

- STAs for each terminal metering point (overlay)
- Sequence number that tells the controller where to fit the flight into the arrival flow to a particular runway (data block)
- Required navigation performance symbol that indicates whether the aircraft/crew have the capability to fly a PBN-enabled route (data block)
- ETA (data block)
- Indicated airspeed (IAS) calculated as a function of the ground speed (overlay)
- Slot marker provided as a graphical position indicator that "flies" the required path and speed to reach each metering point by the required STA (see Figure 3 for a notional depiction of the graphic overlay on a STARS display)
- Slot speed that tells the controller the current IAS at which the slot marker is moving to reach the metering point by the STA (overlay)

Nine sites are expected for initial operational capability by 2022 including George Bush Intercontinental Airport in Houston, Texas; Seattle-Tacoma International Airport in Seattle, Washington; Los Angeles International Airport in Los Angeles, California; Hartsfield-Jackson Atlanta International Airport in Atlanta, Georgia; Sky Harbor International Airport in Phoenix, Arizona; Denver International Airport in Denver, Colorado; San Francisco International Airport in San Francisco, California; Charlotte Douglas International Airport in North Carolina; and McCarran International Airport in Paradise, Nevada. Because TSAS best supports controlled operations such as PBN-enabled approaches, it is likely to be deployed only to sites that serve well-equipped aircraft.

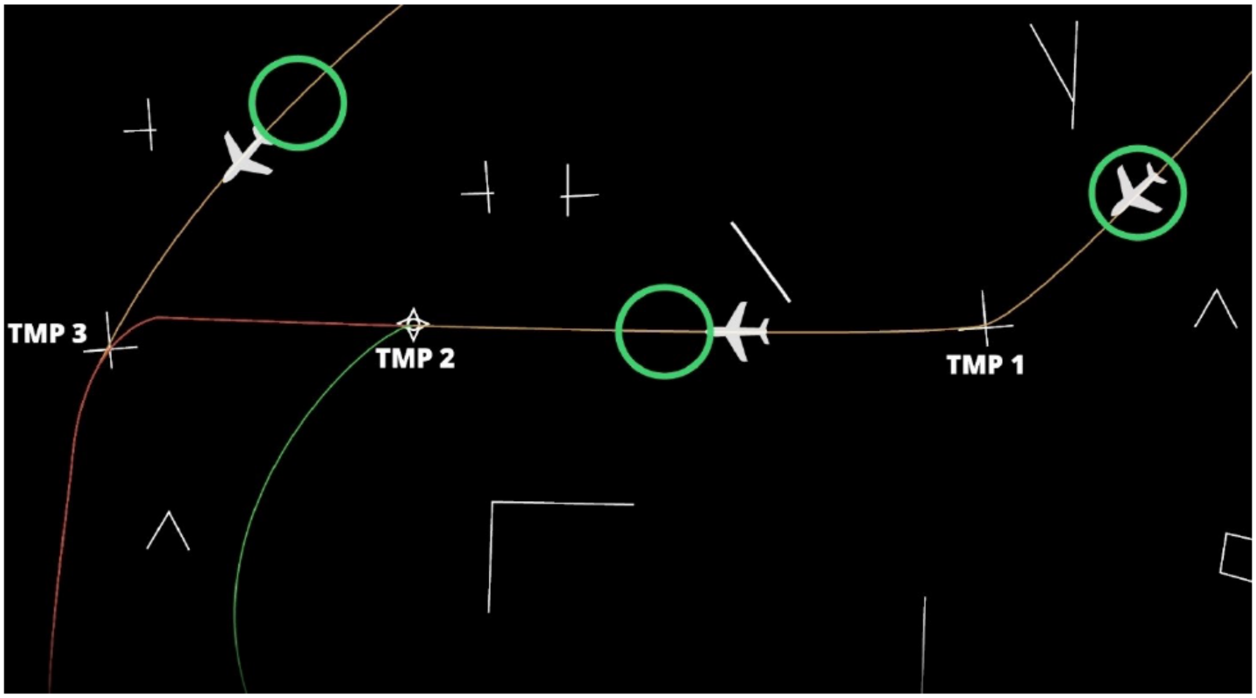

Figure 3. Notional Image of STARS Display with TSAS Slot Marker Overlay

3.2 Potential Unintended Impacts of TSAS and GIM-S Speed Advisories and Associated Mitigations

Below we first describe potential effects on the perceptual and cognitive processes of controllers on the floor that could result from routine reliance on the software computations that produce the information presented regarding GIM-S speed advisories and TSAS slot markers if, as intended and as should be expected, they become integrated into the routine scan patterns of controllers on the floor. We then describe the further potential for a degradation of knowledge and skill in dealing with off-nominal situations if the use of TBO routinely keeps the "trains on the track" while using these two capabilities.

Changes in Automatic Perceptual and Cognitive Processes. Without the assistance of TSAS slot markers or GIM-S speed advisories, today controllers rely on the trajectories and data blocks for the aircraft on the scope to assess the relative positions and speeds of the aircraft, and to make decisions about the need for speed adjustments, vectoring, etc. They have developed highly skilled scanning patterns supported by automatic perceptual and cognitive processes that allow them to quickly and efficiently maintain a mental model of current and future aircraft positions and trajectories. They use this direct perception (Smith et al., 2006) to assess whether there is a need to issue instructions to any of the aircraft in order to achieve the desired spacing and sequencing. This applies to aircraft in both en route and terminal airspace. In other words, relative to longitudinal spacing, TSAS slot markers and GIM-S speed advisories provide an output equivalent to the product of these automatic perceptual processes in the controller's mind without the need for the controller to any longer directly consider and integrate certain aspects of the raw data presented by the tracks and data blocks on the scope.

In short, routine reliance on the TSAS slot markers could lead to a degradation in the controller's traditional automatic perceptual and cognitive processes. As one of the interviewed controllers put it regarding the slot markers in TSAS, "In terms of dealing with the scan, we train people to scan data block to data block. Would they be looking at the diamond instead of the speed?"

GIM-S speed advisories could have a similar effect. If arrivals are being managed effectively though the scheduling component of TBFM and only require minor speed adjustments based on the GIM-S speed advisories, then it is not necessary for the controller to mentally process certain detailed information from the tracks and data blocks in order to determine whether an adjustment is necessary and, if so, what that change in speed should be. As a result, if TBFM scheduling does a good job of "keeping the trains in the track" and controllers routinely rely on these advisories then, as with TSAS, there could be a degradation in the controller's traditional automatic perceptual and cognitive processes.

Thus, based on consideration of the results of our interviews from medicine, nuclear power, dispatch, controller and flight deck operations, it is highly likely that, if the TSAS slot markers and GIM-S recommendations for speed adjustments perform well and their use is the dominant mode of operation, many controllers will learn to rely on this information as their primary method for detecting an aircraft in a flow that is moving outside of its desired longitudinal spacing envelope. As one controller noted, "I think it's analogous to operations with simultaneous arrivals at an intersection. Now that you've got the automation that's monitoring that for you [TSAS and GIM-S], that skill set will atrophy."

However, *when performance is sufficiently stressed such that control using GIM-S speed advisories and/or TSAS slot markers needs to be temporarily discontinued* (due to brittleness in the performance of the software or the human-automation team, or due to operational conditions such as convective weather or a case where TBFM delivers aircraft to the ARTCC or TRACON that are not conformant with the modelled plan in terms of spacing and airspeeds), if the skills used by controllers to assess and manage longitudinal separation have atrophied, *there is a potential impact on efficiency in order for the controllers to remain confident that they are managing the aircraft safely.*

Case 1. Consider first the performance of controllers *who have been on the job well before the use of TSAS and GIM-S speed advisories becomes routine*. Through training and on-the-job experience, these controllers will have previously developed the automatic perceptual and cognitive processes necessary to efficiently control an arrival flow without such automation support. There is some empirical support to suggest that such automatic processes are less susceptible to degradation (Druckman & Bjork, 1991; Volz et al., 2016) after a period of limited (or no) use. The literature also suggests that automatic perceptual skills may be less susceptible to degradation than higher order cognitive skills (Casner et al., 2013).

Thus, for this group of controllers, Impact 1 (Degradation of Knowledge and Skill) may be less of an issue, but with the caveat that, even for this group of controllers there could be some (but less) degradation in the use of these perceptual and cognitive processes when the controller has to revert back to traditional performance without the support of TSAS slot markers and GIM-S speed advisories. This is analogous to the observations of two of the pilots interviewed,

> Pilot 1: There's a group of pilots with core skills that they developed and used over years. There's another group that was only trained with the automation. The differences are pretty astounding. The good news is that those with extensive previous experience with manually flying the aircraft are not reluctant to revert to that when the automation fails in some way. They're not quite as quick as they used to be, but they can fly the plane. The other group, though, tends … to freeze because they are not confident. They don't get enough specific training to transition to manual control.
>
> Pilot 2: Ten years ago the pilot was better at assessing and purposely flying the airplane. Because of the continual use of the automation, his reactions are now much slower and sometimes incorrect.

The caveat is important, however, suggesting the need to assume that, without practice in using these perceptual and cognitive processes, there could be at least some limited degradation in traditional skills even for these controllers who have previously developed the traditional automatic perceptual and cognitive processes. *At a system performance level, if this occurs, in order to assure a safe operation when they are not using TSAS slot markers or GIM-S speed advisories, we would expect these controllers to cope by personally applying Mitigation 6 (Designing Effective Buffers and Safety Nets)* by increasing the spacing between aircraft. While, to be more certain, this prediction requires further empirical testing, the net result could be a reduction in efficiency (throughput) relative to the spacing used by experienced controllers today *when they are not using TSAS slot markers or GIM-S speed advisories*.

For Case 1, though, there could be a built-in mitigating factor, consistent with Mitigation 1 (Providing Effective Training and Experience), that could limit this impact. That is the fact that, in regions of the country where there is significant convective weather, TBFM and TSAS will have to be turned off periodically, providing these controllers with an opportunity to get continued experience in controlling aircraft without TSAS slot markers and GIM-S speed advisories. In addition, if aircraft are not always delivered to sectors in a manner that is close to the arrival plan as modeled and scheduled by TBFM, and if as a result TBFM and TSAS have to be turned off because a revision of the TBFM plan is insufficient, then again these controllers will get practice.

In short, regarding Case 1, focusing on controllers with extensive prior operational experience in working without TSAS slot markers and GIM-S speed advisories, the expectation is that, if they continue have regular opportunities to manage the traffic without the support of these capabilities then, *when TSAS and/or TBFM have to be turned off, there might be only very limited reductions if any in throughput relative to performance today*. This is a hypothesis consistent with the available data, but the extent of those data are limited. Additional studies could provide insights into the degree to which such ongoing experience reduces or eliminates this impact on efficiency and the frequency with which such recurrent on-the-job experience with “manual” methods needs to occur.

This analysis further implies the need to apply Mitigation 2 (Supporting Effective Teamwork) in the sense that the traffic managers doing the scheduling for TBFM need to be effective at continuously delivering well-behaved flows to the ARTCC and TRACON controllers so that these capabilities do not need to be temporarily turned off as often. It also suggests the value of applying Mitigation 3 (Data Analytics: Learning from *to provide an additional safety buffer when TSAS and TBFM are turned off.* The mitigations discussed above for Case 1 apply here as well in terms of both ensuring adequate initial and recurrent training and on-the-job experience, but become even more important in terms of reducing impacts on efficiency.

Delayed Response Due to Reliance on Automation. The third potential issue focuses on Impact 3 (Reduced Attentiveness and Preparation to Deal with Automation Degradations or Failures). The concern here is with the timely detection of a problem (partial degradation or complete failure) of the automation. This issue is illustrated by experience with the use of optimal profile descents for RNAV arrivals, [Controllers] “get used to a certain amount of separation between arrivals after they say ‘descend via’. That’s normally all you have to tell the pilot and then the next contact is with Approach Control to hand them off. If the controller is not paying attention to speeds, though, and [the airplanes] get too close, it can be too late to use speed to separate.”

With TSAS slot markers and GIM-S speed advisories, this could arise for a number of reasons, including:

- Speed controls are not sufficient to manage spacing for a variety of reasons, including inaccuracies in modeling the impact of winds or equipment performance. This possibility was highlighted by one of the controllers, "Does it take winds into account adequately and update the model when there is new data? You can have different winds at different altitudes. You could have a strong tailwind on downwind and turn on final and hit a strong headwind."

- Pilot or controller actions (deliberately or as the result of an error) create a scenario that is outside the competency limits of TSAS or GIM-S. This possibility was noted by three other controllers,

> The preferred controller action is a vector. Speed is the last choice. … Pilots don't like to speed up and slow down. They prefer vectors. … If you can leave the planes at 230 kts. and give one aircraft a shortcut, that's the solution every controller would use instead of speed.
>
> The software may give me strategies that decrease efficiency and the controllers are going to ignore them.
>
> If there's a 5 mile shortcut available, does the software realize this and not slow down the guy behind?

- An unanticipated source of brittleness occurs due to the design or functioning of TSAS or GIM-S that impacts the adequacy of the slot markers or recommended speed adjustments.

If, because the controller has become reliant on the software to detect a problem because it is highly reliable, he/she may be slower at detecting and reacting to a concern with longitudinal spacing along the arrival flow, even though the controller will necessarily be engaged in observing the display to assess relative altitudes for all of the aircraft in the sector (Khang et al., 2014; Rantanen & Nunes, 2005). This could result in a safety issue. The resultant response could in turn disrupt traffic and affect efficiency for that immediate scenario.

Note that a similar end result - reduced attention and delayed reaction to information indicating the need for a speed adjustment – also could result from an excessive number of false alarms (Impact 4. Alarm Fatigue, False Alarms and Ignoring Alarms). This concern would include Mitigation 5 (Designing Technology to Support Effective Human-Automation Teaming) to the list of important interventions to consider.

Degradation of Knowledge and Skill to Manage Off-Nominal Events. The discussion above in this section dealt with the case where TSAS slot markers and GIM-S speed advisories are temporarily degraded or unusable. Another scenario raises the question: If the "trains are on the tracks" almost all the time because TSS is working very well, will controllers get rusty in terms of their skills to deal with a situation where some more significant intervention beyond speed control or vectoring is necessary? This concern was raised by four of the controllers,

> If the use of TSAS makes things run smoothly almost all of the time, controllers could lose some of their skill in dealing with situations where they need to intervene. Things like holding.
>
> You could have situations with approaches where planes are handed off to the … controller who is buried and has to put them in a hold. It has to be done right. If it's rarely used, controllers could lose the skill to issue a hold in a timely and effective manner. They could stumble through, but in the terminal area you just don't have time.
>
> What if one day it breaks and I don't know what to do? Am I at an appropriate altitude to vector? What about the guys behind him? It's the lead aircraft and there are 10 guys behind him. Slowing down is not an option. Is this my airspace to vector?
>
> If PHX gets a thunderstorm over the field, you have to start holding people. The controllers are good over published fixes, but the less experienced controllers are not as skilled at holding flights further away. They can give lengthy, wordy, uncoordinated instructions to hold. A minor situation can become difficult. They don't teach them 'present position hold'.

The concern here is with the potential for the controller's knowledge and skill to undesirably degrade in terms of directing maneuvers such as holding because the frequency of such events has been significantly reduced (a good thing) through the combination of the scheduling and monitoring/controlling functions in TBFM (including the GIM-S speed advisories) and TSAS. In other words, this concern raises an issue regarding the possibility that, if TBO significantly reduces practice in responding to such off-nominal scenarios, then there could be a potential loss of skill in handling such scenarios, most likely with an impact on efficiency as the affected controllers work to manage them, but there is also a possible impact on safety.

If such scenarios still occur with some frequency even with TBO (due to weather, inadequate scheduling when using TBFM, etc.), then as was indicated in the earlier discussion, this potential for loss of skill may not be much of an issue. If, however, it does become an issue because TBO significantly reduces the occurrence of such off-nominal events, then the controllers interviewed recommended consideration of the necessary recurrent training (Mitigation 1. Providing Effective Training and Experience) to maintain such skills, which in turn requires sufficient management support. Note that that an appropriate level of confidence by the controller in his/her abilities is important as well as the actual level of knowledge and skill.

3.3. Summary of Potential Impacts and Mitigations for TSAS and Speed Advisories

The discussion above largely focused on strategies for achieving overall improvement in system performance by mitigating potential impacts that could lead to decreases in efficiency (throughput) while maintaining safety. This is because the buffers and safety nets existing today already provide protections to help ensure safety. Such protections include the specification of minimum separation standards and the distribution of overlapping responsibilities among several roles in addition to the controllers (such as the pilots and the Area supervisor in the FAA facility). However, these buffers could take on increased importance if the mitigations to the potential impacts of automation on reliance and skill degradation are not applied successfully.

Generalization of Analysis. Above, we have illustrated how the categories that we have developed based on this study of multiple domains, along with an understanding of how they apply to specific examples as illustrated within these domains, can be used to provide guidance in the development and implementation of new capabilities for TBO. This applies to a wide range of other controller tools such as the Converging Runway Display Aid (CRDA). For example, like GIM-S speed advisories and TSAS slot markers, routine successful use of CRDA to blend curved RNAV/RNP approaches with straight-in approaches at an airport could result in reliance, with an associated effect on skill degradation (Impact 1. Degradation of Knowledge and Skill) and attentiveness (Impact 3).

3.4. Study Limitations and Generalizations

We have illustrated how the impact and mitigation categories that we have developed based on this study of multiple operational domains can be used to provide guidance in the development and implementation of new capabilities for NextGen. This report, however, was limited in scope to TSS tools and operations, and specifically TSAS slot markers and GIM-S speed advisories, which are tools expected to be deployed in the near-term. We recommend that this same type of impact analysis and mitigation guidance be applied to other NextGen tools beyond the range of TSS and other tools that are expected to be deployed in the far-term.

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Appendix. Interview Data from Naval Operations, Medicine, Nuclear Power Plant Operations, and Aviation

In the Chapter 2, we described the intent and procedure for conducting interviews with experts in various operational domains where significant automation has been previously introduced and where potentially high consequences for safety or efficiency exist if neither the human-automation team nor broader safety nets are sufficient to ensure an acceptable outcome. We also synthesized the interview data into categories for unintended negative impacts from the introduction of automation and categories characterizing potential mitigations.

In this appendix, we provide detailed information on specific examples elicited from the interviewed experts and the mitigations that were applied or were recommended for each example. We also present the ratings provided by the interviewed experts regarding the risk associated with each type of example and the effectiveness of the associated mitigation strategies.

Below, these examples and their associated mitigations are organized based on the impact categories presented in the body of the report.

A.1. Degradation of Knowledge and Skill

Examples of this impact concern the potential for the user's knowledge and skills to degrade from routine reliance on the automation, reducing his/her ability to detect, assess and respond to a situation using more "manual" methods that require reduced (or no) reliance on the automation for support (Volz et al., 2016). This impact was illustrated by the following examples provided by doctors, pilots, controllers, and dispatchers.

A.1.1. Doctors' Degradation of Manual Knowledge and Skills

One doctor expressed the concern that routine reliance on automation degrades skills for patient treatment, which can become particularly important during an emergency situation when there is no automation. This doctor provided the following example,

> We routinely use airway devices to ventilate the patient. As a result, doctors lose the ability to mass ventilate the patient for an extended length of time. This is an important skill that is particularly important in an emergency or off nominal situation, and it's a skill that is being lost. They have to call someone else or look around for a device to use. Fortunately, there is usually some help nearby that knows how to do this.

A.1.2. Pilots' Degradation of Knowledge and Skills

Pilots: Example 1 - ILS PRM Approaches. This concern regarding a degradation of knowledge and skill was further highlighted by a pilot. In this example, if a pilot on an ILS (instrument landing system) PRM (precision runway monitor) approach into weather gets a breakout call from ATC, the pilot must turn off the autopilot and autothrottle while close to the ground. The pilot stated, "An ILS PRM breakout is a dicey clearance for the pilot." In this scenario, the pilot must determine the solution by deciding the correct pitch attitude, vector, approach speed, and power adjustment without the aid of the automation. The pilot explained,

> When hand flying the transition, the pilot must remember the pitch attitude to get it right. And he should know if he needs a 55% power adjustment instead of 40%. Pilots get worse at this without practice. If the pilot hasn't practiced this, he may not know what to do and has to just try something and adjust. That's not as safe. He can't be looking these numbers up at this point.

The pilot noted that the solution to this problem is continued practice. Pilots need to be required to do manual flying in the simulator and get practice in actual in-line operations (but under circumstances that are favorable). This participant further noted that the airline can track when pilots are turning off the autopilot and doing more manual operations through the flight operational quality assurance (FOQA) data, providing information to indicate whether, as a group, such practice needs to be exercised more often.

Pilots: Example 2. Optimized Profile Descents. A second pilot identified a concern with the calculation of the approach trajectory by the automation. His discussion indicated a concern regarding a potential loss of skill and confidence in dealing with the situation when the pilot detects that the aircraft may miss the altitude restriction at a given fix. This pilot stated,

> The Airbus can compute a trajectory that tries to save gas along the early part of the descent but that misses a window [to cross a fix] at the bottom [of the descent]. The pilot has to see this and deal with it. The pilot has to put the airplane where it needs to be. You see a degradation in both the manual flying skills and the cognitive skills necessary to assess the thrust and speed necessary to make adjustments for the last part of the descent. In addition, when pilots don't practice these skills, they become reluctant to fly the plane manually. They don't have the confidence to fly the plane manually and try to use the automation to maneuver the airplane instead of turning off the autopilot. If the pilot is unable to control the speed and descent well enough to make the window, this may result in a missed approach.

Thus, the pilot's reliance on the automation may lead to a decay in his/her skill to evaluate the validity of a descent profile and also a degradation in his/her skill to respond to such a descent profile when deciding whether to make corrections manually or make adjustments with the airplane's automation. If the pilot decides to fly manually, the pilot may be less skilled in deciding how much thrust and speed to apply. Furthermore, this discussion emphasizes that "confidence" is an important component that can result in failure by the pilot to apply relevant cognitive knowledge and manual flying skills.

According to this participant, the likelihood of this scenario (i.e., an airplane's automation developing an erroneous descent profile and the pilot not detecting this mistake in a timely manner) occurring in the next 5 years is very high, and the potential negative impacts to safety also are high (see Table A1).

Table A1. Scenario: When the Pilot Does Not Detect and Intervene in Response to the Automation's Computation of an Erroneous Descent Profile on an RNAV Approach in a Timely Manner

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.				X	
If such an incident occurs, it could have a significant impact on efficiency.		X			

To mitigate this scenario, the participant indicated that training is needed to ensure that pilots understand the importance of proactive assessment of the descent profile planned by the automation. According to the participant, the effectiveness of this response to mitigate the problem is very likely to be effective.

Pilots: Example 3. Another Illustration with an Optimized Profile Descent. This concern over the degradation of knowledge and skill associated with optimized profile descents was echoed by a second pilot. He noted that, when an airplane's automation determines that it cannot make one of the altitude restrictions on an area navigation (RNAV) approach, it will display a "steep descent" message to the pilot in the scratch pad. This pilot stated,

> This message does not appear often, so many pilots have forgotten the significance of this message and will clear it from the scratch pad without making

> any mental calculations or adjustments. When the aircraft approaches this fix, the flight management software automatically changes mode from vertical navigation (VNAV) path to VNAV speed. There is no alert tone or light that indicates this change has been made. The only change is that the mode indicator, which remains green, will display VNAV speed instead of VNAV path in very small font. In VNAV speed mode, the airplane will not comply with the altitude restriction and could cause a loss of separation with surrounding air traffic if the pilot does not realize the airplane is in this mode and make the necessary adjustments, such as informing ATC that they will not make the restriction ahead of time.

This participant noted that although this is not a routine problem for most approaches, it is for some. If a pilot regularly flies one of the approaches where this is a routine problem, then the pilot will be primed to detect and handle it through experience. However, pilots who do not regularly fly one of these approaches may not register the significance of the message when they encounter it. As a result of this lack of reinforcing experience or recurrent training with this type of problem, some pilots fail to maintain the level of understanding, knowledge, and skill necessary to detect the problem and adjust for it.

According to this pilot, the likelihood of this type of problem occurring in the next 5 years is very high and the potential negative impacts to safety and efficiency can be significant (see Table A2).

Table A2. Pilot Fails to Note Alert That Automation Cannot Meet Altitude Restriction

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]				X	
If such an incident occurs, it could have a significant impact on efficiency.			X		

[a]The participant explained, “There is a definitely a potential loss of separation for the airplane. In some cases, there may be another airplane above or below. The reason this is not a ‘5’ is because a controller will always intervene.”

In response to the problem in this example, this pilot's airline identifies RNAV approaches that are routinely problematic by reviewing RNAV standard terminal arrival route (STAR) reports. The pilot indicated that when such problematic RNAV STARs are identified, his airline responds in two ways:

- For these identified approaches, the cover sheet of the flight release will alert or prime the pilot to be especially vigilant in watching for a message from the automation that a "steep descent" is required to meet an altitude window at a fix along the STAR.
- For some approaches, the airline may simply refuse to have its pilots fly them because a note on the cover sheet is easy to miss among all the other information contained in the cover sheet.

According to the participant, the effectiveness of these two responses to mitigate the problem differs, with the addition of a note in the cover sheet likely to be less effective than simply not flying problematic approaches (see Table A3).

Table A3. Effectiveness of Mitigation Strategies When Pilot Fails to Note Alert that Automation Cannot Meet an Altitude Restriction[a]

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
A note about a probable steep descent concern is included on the flight release cover sheet.			X		
The airline prevents pilots from flying problematic RNAV approaches.					X

[a]The ratings regarding the effectiveness of mitigation strategies (reported in tables throughout this appendix) do not mean the risks associated with the use of automation will be completely eliminated. Rather, they indicate the extent to which a given mitigation strategy, along with other complementary approaches, is likely to *significantly help* reduce the likelihood that a risk associated with the use of automation will be reduced, or that its impact will be reduced.

Pilots: Example 4. Go-Arounds. A third example provided by a pilot further demonstrates a scenario in which the pilot struggles to recall specific knowledge and skills when needed because certain tasks are rarely performed on the job. One pilot described the following scenario,

> Go-arounds are a good example where you can lose cognitive skills. The first 20–30 seconds are one of the most busy times of our lives. You might do one once a year or none a year. You're normally using the automation for landing, and

> you're not maintaining that knowledge. The pilot has to recognize where he is in the approach and apply the appropriate parts of the procedure. Without practice, you may not remember how to best respond or may not respond as quickly.

Pilots: Example 5. Inadequate Training of Manual Skills. Another pilot indicated that the expectation at his airline is that pilots have already been trained on flying the airplane manually, so training at this airline is focused on flying with automation. In this case, lack of recurrent training on manual flying skills may exacerbate the potential for degradation of these skills. This pilot stated,

> When hired by the airlines, the pilot is usually a great stick and rudder guy, so we need them to demonstrate that they have mastered the automation. We focus on that. After 2 years, those stick and rudder skills and the other knowledge they need to make decisions have seriously atrophied. After 4–5 years flying with the autopilot, they're an autothrottle cripple. … However, automation failures, such as a flight director failure or an autopilot disconnect, can occur. In these instances, pilots need to be able respond correctly and fly the airplane manually.

According to this participant, the likelihood of a flight deck automation failure with the autopilot disconnecting occurring in the next 5 years (as an example of a case where the pilot may need to fly the airplane manually) is very high, and the potential negative impacts to safety and efficiency also are very high (see Table A4).

Table A4. Autopilot Disconnects

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge was or could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.					X
If such an incident occurs, it could have a significant impact on efficiency.					X

To address these types of problems, airlines are giving pilots training based on specific events that happen in operations, including automation failures and how to respond to these failures. This training is based on data that show which areas most pilots are deficient in during evaluations, which will include scenarios where pilots need to respond to automation failures by changing the mode of automation or by flying the airplane manually. According to this pilot, the effectiveness of this response to mitigate the problem is likely to be effective.

A.1.3. Controllers' Degradation of Knowledge and Skills

The ATCs similarly indicated a concern with the potential for skill degradation, noting that, if actions that are routine today become less prevalent, they can be expected to get "rusty".

Controllers: Example 1. High Altitude Holding. One example focused on high-altitude holding, indicating that, while using TBFM, ATCs will sometimes have to stop time-based metering and go into high-altitude holding. One controller clarified as follows,

> High-altitude holding is always a concern to me. If you have to hold six to seven aircraft that are at the same altitude, you have to give six to seven different altitudes for holding and then start descending them. Anyone coming in as an overflight you have to vector around. Or you could have two in holding and four guys on vectors. They train on metering constantly, not these backup skills.

This participant indicated that although ATCs receive training on managing high-altitude holding, they may not maintain sufficient knowledge and skills to do this as effectively as they have in the past if they have become reliant on TBFM. Although they receive recurrent training on time-based metering, they do not necessarily receive as much training on the backup skills sometimes necessary when TBFM is stopped.

This controller indicated that the likelihood of a sudden cancellation of time-based metering resulting in high-altitude holding occurring in the next 5 years will likely happen and is likely to have potential negative impacts on safety and efficiency in a case where the controller has had reduced experience with such a maneuver (see Table A5).

Table A5. Risks of Cancellation of Time-Based Management Resulting in High-Altitude Holding in a Facility Where the Controller has had Reduced Experience with Such a Maneuver

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.					X
If such an incident occurs, it could have a significant impact on efficiency.					X

This controller recommended two strategies to deal with this risk:

- More training on backup skills for sudden cancellation of TBFM.
- Increased staffing of the traffic management unit (TMU) so that the TMU is not overworked and can therefore be more proactive rather than reactive.

According to the participant, the effectiveness of both strategies to mitigate the risk would be high (see Table A6).

Table A6. Effectiveness of Mitigation Strategies for Cancellation of Time-Based Management Resulting in High-Altitude Holding in a Facility Where the Controller has had Reduced Experience with Such a Maneuver

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
More training				X	
Increased staffing of the TMU				X	

Controllers: Example 2. Aircraft Spacing. Another example from a controller regarding concern over loss of skill because of routine reliance on the automation was illustrated by the following statement,

> If you're used to having the machinery do the coordination, you may forget that a certain degree turn over a certain time will give you the spacing you need. [For example,] turn 40 degrees at 250 knots left for 2 minutes and then proceed direct to the next fix will give you the extra spacing you need.

A.1.4. Dispatchers' Degradation of Knowledge and Skills

The interviews with airline dispatchers further illustrated concerns with the degradation of knowledge and skills as a result of a lack of practice. As an example, consider a scenario in which there is a faulty anti-ice valve on an Airbus. In this case, one participant explained, "The dispatcher must determine the weight and fuel penalties, which depend on the details of the flight plan. Although the automation will calculate the weight penalty upon request, the dispatcher must manually calculate the fuel penalty."

Normally, the dispatcher does not have to complete manual calculations for minimum equipment lists (MELs) because such calculations are performed by automation. However, in this case the dispatcher must perform one of the calculations. The participant noted, "It could be once every 3 years that a dispatcher might see an anti-ice valve problem." According to this participant, the highest error rate in the fleet (about 80%) is for cases like this one where the automation performs one part of the procedure, and the dispatcher is supposed to perform the other part. Thus, the expectation that the automation will complete all the necessary calculations, along with a lack of practice, significantly increases the chances that the dispatcher will fail to perform the necessary computation.

To reduce this type of error, the participant indicated that the airline has employed a couple of strategies:

- The airline has developed a new training module on how to manually apply MELs.
- The airline has created a new format for competency checks, including manually applying MELs.

This participant noted that these two mitigations have "significantly reduced the number of errors."

A.2. Reliance on Automation as the Primary "Agent" to Detect Problems

Examples of this impact concern the potential for users to passively wait for an alarm to be displayed, rather than observing the automation displays and the operational environment for evidence of trends that merit response prior to an alarm. This impact was exemplified by the following scenarios provided by doctors, pilots, and controllers.

A.2.1. Doctors' Failure to Act as the Primary "Agent" to Detect Problems

Both doctors identified a concern with passive reliance on alarms to detect problems. One doctor explained,

> The patient is hooked up to monitors, and the doctor assumes everything is okay because there are no alarms. A skilled doctor will be watching and catch a problem earlier than the alarm, seeing a trend far before the alarm reaches its critical threshold. When you wait for the alarm, you're now in a game of catching up, sometimes requiring a different intervention. You're reactive instead of proactive.

The other doctor described the following scenario:

> Every so often somebody's heart will just stop during an operation. Seconds count to deal with this. A practical example is [as follows]: The same nerve that tells the heart to slow down supplies the membrane around the brain. When you're trying to control bleeding around this membrane, the heart can stop. You have to tell the surgeon to stop immediately. I've seen residents miss this. It takes the machine 5 seconds before it chimes. That's extra delay. And I've seen residents reach up and silence an alarm because you sometimes get false alarms.

According to this participant, the likelihood of inappropriate reliance on the alarm as the primary detector is very high, and the potential negative impacts to safety also are very high (see Table A7).

Table A7. Inappropriate Reliance on the Alarm as the Primary Detector[a]

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.[b]					X
If such an incident occurs, it could have a significant impact on safety.					X

[a]This participant did not provide a rating for impact to efficiency of this scenario because, according to the participant, "I'm not sure how it would affect efficiency. It's not really applicable." [b]The participant stated, "I see this week to week."

To mitigate this problem, the participant recommended to the following strategies:

- Have a senior person in attendance as well (such as the area supervisor in an ATC tower). This will allow for a second person to be monitoring the situation, including any attendant alarms, and increase the likelihood that someone will respond to valid alarms.
- Improve the salience of the alarm. This participant noted, "Automation is a fact of life. You need to improve the quality of the signal so [that] the alarm is more likely to get the person's attention."
- Provide training on how to manage automation. This participant remarked, "Training is very worthwhile. We need more education around what safety really is and how to manage automation. We get no formal training on that."
- Remove other distractions. For example, do not let doctors bring cell phones into the operating room (OR), so that their attention is focused on the patient and the automation.

According to the participant, the effectiveness of these responses to mitigate the problem are strong or very strong (see Table A8) with improving the salience of the alarm and removing other distractions likely to be more effective than the others.

Table A8. Effectiveness of Mitigation Strategies for Ineffective Incorporation of Alarms into Work Practice as a Backup to Monitoring Trends in the Displayed Data and Observing the Patient

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Have a senior person in attendance.[a]				X	
Improve the salience of the alarm.					X
Provide training on how to manage automation.				X	
Remove other distractions.[b]					X

[a]This is not a 5 because, according to the participant, "A second pair of eyes can be very helpful, but that person can be distracted too." [b]This would be a very effective strategy, but the participant noted: It's not easy to do this. It's not easy to tell them not to bring their cell phones into the OR."

A.2.2. Pilots' Failure to Act as the Primary "Agent" to Detect Problems

Pilots: Example 1. Maintaining and Using a Mental Model. One of the pilots emphasized the philosophy that pilots should be proactively detecting problems by monitoring the state of the "system" (both information displayed by the automation and awareness of relevant considerations in the operational environment) while also emphasizing that partial failures often are the most hazardous. This participant stated, Partial failures are a big problem. You might, for example, still have lateral, but you don't have your pitch bar, or you might have an unreliable airspeed indicator. If you don't have a mental model of the situation, then you're not ready to take over. *You need to be able to develop a mental model, picture it in your head. And you need to share it with the other pilot. You have to anticipate what the automation is going to do.* And you can lose some of that skill over time or you can get too reliant on the automation and not stay ahead. *If you're just waiting for alerts to do something, you're going to be too late sometimes. The pilot needs to be proactive. Pilots need to know what to monitor, how to recognize when to intervene, and how to intervene.*

According to this participant, the likelihood of a partial system failure occurring in the next 5 years when the pilot has been reliant on the automation as a monitor instead of actively maintaining a mental model of the situation and assessing safety is very high, and the potential negative impacts to safety also are very high (see Table A9).

Table A9. Partial System Failure Occurs While Pilot Has Been Reliant on the Automation as a Monitor Instead of Actively Maintaining a Mental Model of the Situation and Assessing Safety

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]					X
If such an incident occurs, it could have a significant impact on efficiency.[b]		X			

[a]The participant noted, "Most of the time the airplane will land safely, but it could result in an accident." [b]The participant rated this as 2 saying, "Unless there is a crash, the impact on efficiency is small. But if there is a crash, the impact can be significant."

This participant indicated that potential mitigations to this problem include the following:

- Providing more training on the underlying system functions and associated design features.
- Providing training to the instructors on how to teach effectively because "the effectiveness of this training will be somewhat dependent on how well the instructor teaches."
- Providing more training on how to detect and deal with different kinds of partial failures. This training should include a range of scenarios associated with particular classes of problems and scenario-specific responses. The participant noted, "I've seen it work well if

done well. We see significant improvement if the pilot has seen the situation before and remembers it."

- Developing or improving procedures but with a caution to not overproceduralize. The participant remarked, "Procedures have to go along with training that is generic enough that it can cover everything."
- Improving the design and testing of automation so that problems are less likely to occur and are easier to detect and diagnose if they do occur. The participant explained,

> A lot of training is because the software is not designed well enough. For example, some FMCs [flight management computers] just put a line through the altitude to indicate that the automation can't hold the altitude, while others have a more visible alert. It's better to design the problem out instead of relying on training. But you're not going to design out all problems.

According to the participant, the effectiveness of these responses to mitigate the problem varies with the development and improvement of procedures and the improvement of the design and testing of automation (see Table A10).

Table A10. Effectiveness of Mitigation Strategies When a Partial System Failure Occurs while the Pilot has been Reliant on the Automation as a Monitor Instead of Actively Maintaining a Mental Model of the Situation and Assessing Safety

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Providing more training on system functions and design features.			X		
Providing more training on how to detect and deal with a range of partial failures.			X		
Developing or improving procedures.				X	
Improving the design and testing of automation.				X	

This scenario also was identified by another pilot, emphasizing that the pilot may not be routinely doing the necessary mental backup for the automation because he/she feels confident in the automation's capability and sheds this task in favor of other competing tasks, including distractions such as questions from the flight crew. This participant explained,

> The more capable systems lull pilots into a sense of security, and they get too relaxed about the need for a mental backup. They're not doing the mental

> gymnastics. [As a result,] the pilot may not see an alert until 3–4 miles before an altitude constraint, indicating that they are not going to make it and having to inform ATC that they are going to be high by 500, 1,000 feet, or more. . . . RNAV arrivals require [pilots] to thread the eye of the needle at certain altitudes and airspeeds. Pilots must be proactive and recognize the need to intervene early enough during a descent profile for these arrivals.

Pilots: Example 2. Loss of Situational Awareness. Pilots emphasized that when individuals are relying on automation to monitor the situation and detect problems, they not only diminish their skill at detecting a problem on their own but also lose their situational awareness, making it more difficult for them to respond to any detected problems. One pilot provided the following example,

> Pilots can rely too much on the automation on the flight deck to call attention to problems. For instance, on the 777, the electronic check list provides written instructions for the pilot for normal and abnormal situations. Based on sensors, the automation can mark items on the checklist indicating to the pilot that a given check has been completed instead of requiring the pilot to indicate this item has been completed.

In this example, a pilot's overreliance on the automation to run through the electronic checklist could lead to a situation where items are being checked as complete by the automation without sufficient supervision by pilot. This pilot indicated that such design-induced reliance, with the associated risk of losing situational awareness through the use of the electronic checklist, can be reduced through better design.

As an example of a good design, he described a situation where a master caution light has indicated a malfunction in the airplane's air conditioning system, drawing the pilot's attention to the problem. After the alert, the participant noted,

> The automation will automatically reconfigure the airplane's air conditioning system to resolve the problem, for instance, by isolating a leak in the ducting. In this case, the pilot will call up the system's schematic and can watch as the airplane goes through its routine to do this, monitoring the automation to see if he is satisfied with the outcome.

The participant indicated that this design solution helps ensure that the pilot maintains familiarity with the standard procedure for dealing with this problem, while also helping ensure that the pilot stays sufficiently engaged to detect an anomalous situation where the automated response to the checklist items could be inadequate. This participant explained,

> In terms of the loss of cognitive knowledge or skill, because of how the information is presented, watching the schematic as the checklist is done, there is little threat that the pilot will become less proficient. An alternative way is for the pilot to execute the steps in the checklist instead of the automation. In this way, the pilot's knowledge and skills to do this task will not degrade.

Pilots: Example 3. Another Example of the Loss of Situational Awareness. This example, provided by another pilot, further emphasizes the concern with losing situational awareness because of reliance on automation to detect problems. The importance of not only individual situational awareness but also team situation awareness was emphasized by this participant. To illustrate this concern, this pilot recalled the following accident,

> The crew crossed the Pacific in the middle of the night from Hong Kong. There were three pilots, including the internal relief officer. They were descending into Anchorage, and it was clear and beautiful. As they began the descent, the pilot who was taking his relief break was late getting back to the flight deck. At the top of the descent, they were all in the cockpit, but the internal relief pilot goes back to clean up. He came back to the jump seat 2 minutes outside the final approach fix, 10 miles out, and missed the crew briefing. They were flying an instrument approach. Since the ILS was out, they were flying an RNAV approach. The internal relief pilot hops into the seat and asks, "Did you edit the RNP?" The captain—the pilot monitoring—said "no." They went heads down, banging on the FMC to make this simple administrative step take place but had trouble finding the right keystroke. They were flying with the autopilot and autothrottle on. The pilot flying shifted his attention to the captain who was fighting with the FMC, instructing the captain on what to do. No one was looking outside. They crossed the final approach fix 600 feet low. ATC didn't see what was happening at first. The third guy—his eyes were on the captain at the FMC too. Nobody was monitoring the airplane. It's poor crew management. If they had just looked out the window, they could have climbed up 200 feet and landed.

According to this participant, the likelihood that a crew will be reliant on the automation during final approach and fixate on other task demands in the next 5 years is very high, and the potential impacts to safety also are very high (see Table A11).

Table A11. Inadequate Teamwork—Attention Focused on Landing Automation Without Maintaining Broader Situation Awareness

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge was or could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.					X
If such an incident occurs, it could have a significant impact on efficiency.			X		

As a result of this accident, the airline that this pilot works for started providing additional training focusing on these issues with automation. This airline trains pilots to not only maintain their technical knowledge and skill but also recognize when their situational awareness is decreasing. The participant stated,

> We haven't broken the code on how to teach that, but it helps to train them on relevant situations to help them recognize a scenario where it could happen. We use slides in class to talk about things that have happened on the line, including all the holes in the cheese.

The participant indicated that the airline also trains pilots in simulations that contain "gotcha" scenarios, saying,

> Since they know something will go wrong, we'll try to distract them and bring in the threats that lined up in order to re-create a situation so that the minor errors can snowball. This is especially important with scenarios like flying a nonprecision approach, which they don't use often. We have to teach them to not be reliant because, even though it's rare, you can have 3–4 things line up at once, and you need to detect this early.

The participant indicated that the airline provides training in several forms, including bulletins, classroom presentations and discussion, and simulator runs. He further indicated the need for support from management to emphasize the importance of taking such training seriously.

In addition to training, the participant mentioned several other key mitigation strategies:

- Implementing a good reporting system that is really used so that problems can be detected. The participant noted,

  > Even when an accident does not occur, crews need to report issues that have arisen, but they do not always disclose the root cause. To get at the root cause, there needs to be protection when something is disclosed, and every crew member has to have buy-in to report because an accident could happen to them.

- Designing and updating procedures as necessary because "as soon as a procedure is deemed foolproof, someone will find a way to make it less so."
- Providing safety nets, which should include the human monitoring the automation and the situation. The participant stressed,

  > The pilot monitoring is the biggest defense. He needs to be engaged. The pilot monitoring is going to save the day. He's the most effective tool because he's not as task loaded. The challenge is how to keep the human engaged in monitoring the automation.

- Requiring pilots to fly the airplane using lower levels of automation to maintain their knowledge and skills. The participant said,

  > We encourage pilots to fly approaches on lower levels of automation on a beautiful day to avoid having their skills atrophy. They have to do it, or they will get worse and worse. You have to turn off the automation to realize your cross-check has atrophied. You discover that, because the automation works so well, you stop looking at the airspeed to the left of the altitude indicator. The pilot misses it because it's always okay. Or you focus on the altitude and don't notice the heading is off. It comes at a little expense, but if you don't do it you are setting yourself up for failure.

According to the participant, the effectiveness of these responses to mitigate the problem with training and experience is very high (see Table A12), with modifying procedures being only slightly less effective.

Table A12. Effectiveness of Mitigation Strategies to Improve Teamwork Concerned with Attention Focused on Automation Without Maintaining Broader Situation Awareness

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Training on automation issues in several forms					X

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Visible buy-in for safety and training from the top down					X
Implementing a good reporting system					X
Modifying procedures[a]				X	
Providing safety nets					X
Requiring pilots to practice flying the airplane using some other functionality (e.g., "manual" control)					X

[a]The participant cautioned, however, that the use of procedures does not always have the desired effect. It can produce an unanticipated side effect, in which pilots lose situational awareness of the big picture because they are focused on a detailed process. This concern, therefore, needs to be emphasized in training.

A.2.3. Controllers' Failure to Act as the Primary "Agent" to Detect Problems

This controller indicated that introduction of the user request evaluation tool (URET) reduced the level of engagement needed by ATCs and had an effect on their level of active engagement. He indicated, "Before URET, the controllers had to think in three dimensions. Because URET provided alerts for potential conflicts, the critical thinking that controllers had to work hard at was reduced. It took away some of the thinking process."

As an illustration of how this could be important, this participant described one particular problem with URET. There was a way to turn off the alert for a specific airplane for the entire ARTCC. This feature was useful for fighters, where ATCs would want to turn off nuisance alerts while the airplane was maneuvering at a low altitude. However, ATCs sometimes would forget to turn the alerts back on for this airplane when it reentered high-altitude airspace, where ATCs would need to be monitoring and controlling the airplane. *If ATCs forgot to turn the alerts back on, they might miss the detection of a potential conflict because they were relying on URET to alert them,* and because their skill in detecting the potential conflict on their own without URET had degraded because of their diminished use of these skills.

A.3. Reduced Attentiveness and Preparation to Recognize and Deal with Automation Degradations or Failures

Examples of this impact concern the potential for the user to monitor for degradations or failures of the automation less attentively. Similar to the previous impact, this impact focuses on decreased attentiveness of the user in focusing on the automation displays and the operational environment. This impact differs, however, in that it focuses on the case where the technology has degraded or failed and, as a result, does not present an alarm or response at all, presents an inappropriate recommendation, or performs an inappropriate action. An important special case emphasized in the interviews focused on sensor failures.

This impact was highlighted in the following examples provided by dispatchers, controllers, pilots, doctors and nuclear power expert.

A.3.1. Dispatchers' Failure to Detect a System Degradation

Dispatchers: Example 1. Failure to Detect an Automation Failure. An example of this concern was provided dispatchers. This example shows a case where trust in automation could result in a delayed response to detect a problem with automation. One dispatcher provided the following example:

> ACARS [aircraft communications addressing and reporting system] messages exchanged between the dispatcher and [the] flight crew can contain critical information. In general, this digital communication is reliable, creating the expectation that, if a message has been sent, it has been received. The airline does not require an acknowledgment when such a message has been received because there are times when these messages are transmitted [when] the task load is very high, and the policy decision has been made that adding "acknowledgement" as an extra task is not worth the trade-off.

In this case, the dispatcher cannot wait for an alarm as there is none. As a result, the dispatcher must be monitoring the message stream across time to assess whether the absence of expected messages indicates that the communication channel may have failed. If the last ACARS message was received from the flight crew with a greater than normal delay (i.e., the dispatcher has not seen any message in the stream for a while), the dispatcher should then determine whether there is a communication problem. However, because, overall, ACARS is reliable, the dispatcher may become inattentive in monitoring for an indication of such a problem.

This dispatcher indicated that, in terms of severity, some ACARS messages involve the transmission of safety-critical or operationally important information that impacts efficiency. As an illustration, in reports of communication breakdowns for one particular airline, such a communication problem resulted in a failure to transmit important weather notifications, reports of holding, reports of diversions, No-Radio messages, fuel concerns, and medical emergencies. In one instance, a flight was en route to Las Vegas, Nevada, and had 1 hour of fuel on board when wind shear was reported on approach. This flight was diverted to Bullhead City, Arizona but had to declare a fuel emergency because the airplane only had enough fuel for

45 minutes of flying time. The airplane could not reach dispatch through ACARS, so they had to get diversion permission from ATC without prior input from the dispatcher. Dispatch did not even know an emergency was declared until the airplane landed at this unapproved airport.

According to the participant, the likelihood of the missed or late detection of an ACARS message as a result of lost communication occurring in the next 5 years is very high, and the potential negative impacts on safety or efficiency also could be very high (see Table A13).

Table A13. Risks for Undetected or Late Detection of the Loss of ACARS Communications

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]		X			X
If such an incident occurs, it could have a significant impact on efficiency.					X

[a]The participant clarified, "The risk to safety is a '2' if the loss of communication occurs when the weather is good, but it is a '5' if the loss of communication occurs when the weather is bad."

This example highlights several complementary mitigation strategies that were implemented by the airline:

- Performance monitoring to reactively detect and plan for how, in the future, to deal with classes of problems that occurred in the past. There was universal agreement from interview participants that performance monitoring plays a critical role in reducing the likelihood that reliance on automation could result in a serious incident. This airline actively monitors FOQA and Aviation Safety Action Program reports as well as other formal reports provided by pilots, dispatchers, and maintenance staff. After reviewing these data, if a concern is identified, the person involved is interviewed, and the ATC tape is reviewed. These data are used for early identification of potential issues associated with the use of automation and to guide the initiation of responses to potential issues.
- Use of proactive actions to reduce the impact if a problem arises. For instance, some pilots run their landing numbers as soon as they take off in case there is a problem with ACARS later.
- New policy for backup methods. The former policy for communications was ACARS, then radio, then air link. However, pilots and dispatchers must be on the right frequency to use

radios. Thus, the decision was made to shift the communication policy to ACARS, then air link, then radio to make communications more reliable.

In addition, this airline designed a program to make use of the results of performance monitoring. The review of this program resulted in several actions:

- Send out notices to dispatchers of potential concerns in an online publication.
- Conduct a review of the contributing hardware and software issues, which led to retiring old communication management units and changing out antennas and corroded wires.
- Suggest changes in procedures and training. For example, if the policy does not require an acknowledgment, individuals should be trained to always request acknowledgment of messages that are safety critical.

According to the participants, the effectiveness of these responses to mitigate the problem varies, with performance monitoring, sending out notices to dispatchers, and fixing hardware/software problems more likely to be effective than the other responses (see Table A14).

Table A14. Effectiveness of Mitigation Strategies for Undetected or Late Detection of the Loss of ACARS Communications

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Performance monitoring					X
Using proactive actions			X		
Improving the policy for backup methods				X	
Sending out notices to dispatchers			X		
Fixing hardware/software problems					X
Changing procedures			X		
Changing initial or recurrent training				X	

Another dispatcher provided a second example of this concern highlighting the challenge that can arise when the person needs to detect a situation where the automation ceases to provide important information. In this case, the dispatcher noted that there are times when dispatchers may not notice a breakdown in the communication of alerts from National Weather Service

(NWS) advisories, which could result in delayed or less than optimal responses to important missed information.

The participant explained that some dispatchers may become too reliant solely on their traffic situation displays to alert them to weather advisories. These displays can be set up to alert the dispatcher of any flights operating through icing, thunderstorms, or other significant meteorological information. However, these alerts are created based on NWS data. Consequently, if there is breakdown in communication with NWS, such advisories and alerts are not being communicated.

According to this participant, there have been occasions where NWS has not been sending advisories for as long as an hour. Dispatchers who are too reliant on their traffic situation displays to alert them may not detect that they are not receiving important weather information because they are not cross-checking the information provided by the traffic situation display with other sources of weather information. In short, if the dispatcher focuses too much on one display, he/she can miss important information that requires an action.

Dispatchers: *Example* 2. Failure to Detect an Automation Failure. Another dispatcher provided a second example of the challenges of dealing with the lack of an alert, or because of a failure to attend to an alert due to competing tasks. This participant discussed flights that may need to be redispatched while airborne because of a change in fuel requirements. The concern is that the dispatcher can miss such an alert because his/her attention is on other displays or tasks or because the automation fails to provide the alert when it is supposed to.

According to this participant, the likelihood of a missed redispatch alert occurring in the next 5 years is very high, and the potential negative impacts on safety and efficiency also are very high (see Table A15).

Table A15. Risks for Missed Redispatch Alert

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]					X
If such an incident occurs, it could have a significant impact on efficiency.[b]					X

[a]Although there could be a serious safety problem, which is why this is rated 5, the chances are slim that it would reach this level of serious safety threat. [b]This participant noted: "If you have to divert the flight because of a fuel shortage, this has a significant impact [on efficiency]."

The participant suggested the following two strategies to help resolve this problem:

- Provide a manual backup to the redispatch alarm. The participant said, "Tell the dispatcher on a worksheet how many hours out he needs to do the redispatch, so he is more likely to do it even if the technology fails."
- Use the pilot as a safety net. The participant explained, "The pilots should also be monitoring [for a redispatch] and should send a message to the dispatcher saying, 'We didn't get redispatch yet. What is going on?'"

According to the participant, however, the effectiveness of these strategies to mitigate the problem may only be somewhat effective (see Table A16).

Table A16. Effectiveness of Mitigation Strategies for Missed Redispatch Alert

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Provide a manual backup to the redispatch alarm.			X		
Use the pilot as a safety net.			X		

A.3.2. Controllers' Failure to Detect Potential Loss of Separation

Other examples were provided where controllers can learn to be reliant on aircraft automation, resulting in a delayed response if ATC has not been attentively monitoring the situation. Another example, provided by a controller, illustrates the case where ATCs may become reliant on the airplane's automation to fly the modeled trajectory for area navigation (RNAV) approaches resulting in the controller not paying attention his/her own automation indicating a potential loss of separation. The controller stated,

> Controllers tend to get reliant. They get used to a certain amount of separation between arrivals after they say "descend via." That's normally all you have to tell the pilot and then the next contact is with approach control to hand them off. If the controller is not paying attention to speeds, though, [the airplanes] get too close. It can be too late to use speed to separate. You have to vector the plane off and back on [the RNAV route]. You can have other aircraft piling up behind it and that becomes an issue. You might have to turn everyone on a nice string of pearls. Everyone has to turn off.

According to the participant, the likelihood of a late detection of such an undesirable reduction in separation while on RNAV approach occurring in the next 5 years is high, and the potential negative impacts on efficiency also could be high (see Table A17).

Table A17. Risks for Late Detection of Reduction in Separation While on RNAV Approach

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]			X		
If such an incident occurs, it could have a significant impact on efficiency.[b]					X

[a]The participant explained, "Any time the controller has to bust somebody out of the line, it's taking his attention away from other conflicts in the airspace." [b]The participant clarified, "When it's allowed to go too far, it's a 5. If it's caught early, if the controller is alert and watching, it would be a 1–2. If the controller is getting lackadaisical, relying on the pilots complying, it can get challenging."

This participant proposed several mitigation strategies that he felt would be equally effective (see Table A18):

- Monitoring and support from a supervisor or a D-side controller. The participant noted, "It can be extremely useful to have a supervisor watching, but it depends on having a supervisor who is experienced. On a swing shift, you may have a D-side only who isn't certified." Having another person serve as a backup monitor can ensure that a potential loss of separation is caught early enough.
- Managing time on position. The participant stated,

  > The front-line controller needs to be engaged. So does the FLM [front line manager], but he is responsible for several positions. If the controller is on for 4 hours instead of 2 [hours], you can't expect the same level of effectiveness. The second level managers, the OMs, are responsible to ensure that the front lines are not burned out by 4–5 hours at a time.

- Training ATCs to maintain vigilance.

Table A18. Effectiveness of Mitigation Strategies for Late Detection of Reduction in Separation While on Area Navigation Approach

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Monitoring and support from supervisor or a D-side controller.					X
Managing time on position.					X
More training for ATCs.					X

A.3.3. Pilots' Failure to Detect Input Error

One of the pilots pointed out yet another dimension of the impact of a lack of attentiveness because of reliance on the automation. The point of this example was that a lack of engagement resulting from reliance on the automation can result in problems when the pilot makes a slip or mistake while making an input and does not detect it. This pilot discussed scenarios where the initial problem is an operator input error rather than an automation failure. The consequences from reliance on automation remain the same, however, with delayed and less than optimal performance of necessary tasks.

For example, a pilot input error such as entering a wrong altitude or putting the airplane in the wrong mode could cause an airspeed control or heading control problem. If the pilot is not adequately cross-checking the responses made by the automation based on his/her inputs, and the pilot inputs are incorrect, an error can go undetected.

Interestingly, this participant noted that pilots of airplanes with less reliable automation, such as the MD88, are less likely to have these types of errors because they are more engaged with monitoring the airplane's automation. The pilot explained,

> We track automation errors. The MD88 has the worst automation at the airline. It's old technology and isn't always reliable. But we see the lowest level of automation errors [made by the pilots] with that fleet because pilots don't trust the automation. They stay fully engaged because they know it will let them down.

The participant noted, however, that pilots of airplanes with very reliable automation are more likely to make errors that are detected too slowly, such as altitude errors. Because they trust the automation and assume that they have input the correct information, they do not check the automation's responses. The pilot stated,

> One of the things we struggle with is that the automation has been so good that the pilots trust it almost to a fault. They need to monitor it because errors can be introduced through programming errors [pilot errors]. Most of the time the problem is because the pilot entered something wrong and didn't notice it.

According to this participant, the likelihood that a pilot will fail to detect an input error in the next 5 years is very high, but various safety nets help to avoid accidents even when this occurs (see Table A19). The pilot clarified,

> The seriousness is all over the map. Generally, it's pretty benign; 99% of the time there's nothing there. Also, there's a bunch of other safeguards, old-fashioned eyes, the controller, and there's the TCAS [traffic alert and collision avoidance system]. All of these other safety nets help ensure that an accident won't happen.

Table A19. Pilot Does Not Detect Impact of an Input Error

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.			X		
If such an incident occurs, it could have a significant impact on efficiency.	X				

In response to the problem in this example, the airline has highlighted this issue in its policies, procedures, training, and evaluation, and has taken the following steps:

- Changed the policy so that any time a change is made by a pilot to the flight annunciator, the pilot must verbally acknowledge the change and what has taken place. The intent of this new policy is to reduce the chances that any pilot programming errors will be caught by "making pilot monitoring an active skill rather than a passive one."
- Trained pilots to help ensure that they actively monitor to detect errors. In this training, pilot monitoring is emphasized as a core crew resource management skill.
- Trained pilots to understand the automation and not just how to use it. Pilots must be able to explain to trainers exactly what will happen in a simulation before they press the button.

- Added a series of evaluation modules in pilot training that are focused on monitoring performance. Instructor pilots in the simulator and on the line riding in the jump seat are looking at this and assessing the pilot's skills in monitoring.
- Made a policy that pilots should practice manually flying the airplane under the appropriate conditions. This policy is intended to be put in place during benign conditions (i.e., daytime visual approaches), not situations where there is low visibility or the weather is bad.
- Made a policy that when the automation is doing something it is not expected to do, the pilot should downgrade to increased manual control or use some other functionality to perform the task. If automation continues to behave in an expected manner, the pilot should continue to further reduce the use of the automation.

The participant said these responses to mitigate the problem can be very effective (see Table A20).

Table A20. Effectiveness of Mitigation Strategies When the Pilot Does Not Detect Impact of an Input Error

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Policy change that requires verbal acknowledgement of pilot programming.					X
Training to ensure active monitoring.					X
Training to ensure understanding of automation.					X
Performance evaluation of monitoring skills.					X
Policy that pilots should practice flying manually under appropriate conditions.					X
Policy that pilots should transition to decreasing levels of automation when automation is not responding correctly.[a]					X

[a]This participant stated, "The importance of maintaining their knowledge and manual flying proficiency cannot be overstated. A programming error or aircraft malfunction can require a transition to manual flight. At the extreme, consider the Air France accident. When the autopilot kicked off and all automation stopped working, the pilots had to manually fly the aircraft. They were not up to the task. We've had a series of similar incidents in the A330s where we lost the airspeed indicator and the autopilot turned off, most likely due to a pilot-static problem. These were nonevents because we train our pilots that, when they don't know what is going on, they should rely on manual flying. They are taught to stabilize the aircraft, stabilize the situation first, and then figure out what is happening and where to go."

A.3.4. Doctors' Failure to Cross-Check Sensors

One of the doctors emphasized the importance of training individuals to cross-check the data provided by monitors that measure the same underlying physiological condition of the patient. This doctor stated,

> There's a tendency to have an unwavering belief in what one monitor is telling you. Monitoring of an arterial catheter to monitor whether blood is flowing is an example. If you use a blood pressure cuff on the same arm with the arterial catheter, the catheter will trigger an alarm indicating that the heart isn't beating. You need blood flowing through the capillaries in the finger to indicate that the heart hasn't stopped. But every time the blood pressure cuff is inflated, you lose the blood pressure and the catheter sets off a very strong asystolic alarm. But if you cross check with the other monitors, you can see that the heart could not have stopped. The cardiograph still looks fine, the display from the pulse oximeter looks good. You need to cross check your monitors, but nobody teaches the residents that.

A.3.5. Nuclear Power Operators' Failure to Cross-check Sensors

The nuclear power plant expert further emphasized the importance of designing the software to make similar cross-checks and discussed the issues that arise when there is a sensor degradation or failure. The nuclear power plan expert explained,

> Sensors can drift. They can start to fail so the information to the control system and the operator shows a deviation from what it should be. Is it the sensor or is something wrong with the plant? An example is a high temperature in the reactor telling the control system it needs to do something. The operators are trained to believe the instruments as a first step. If a sensor is degraded and the temperature isn't actually going up at the rate the sensor is indicating, the automated system may be reacting.

According to this participant, checks for sensor validity is one of the safeguards. This participant noted,

> There are multiple sensors and the system is designed to see if it is getting different readings from different sensors. You could have one sensor showing a high reactor temperature but the other readings that ought to be changing aren't. If there are four sensors and one is out of whack, the system won't use this input, but it still shows it to the operator with a color code or symbol around it to say: Don't trust this sensor.

However, if multiple sensors give faulty readings, the operators are faced with an ambiguity. In this case, according to the participant,

> If something isn't flagged as a faulty sensor and the values don't reach the emergency procedures stage, the operator and the automation can be dealing with misinformation. If the level of automation is higher, the automation might turn on a few of those feedwater pumps, doing more by itself. That's when things can get out of hand, with the operators playing catch-up to make sure this is want we should be doing.

According to the participant, the likelihood of the operator facing ambiguity about the validity of sensors occurring in the United States in the next 5 years may or may not happen. However, if this situation does occur, the potential negative impacts on safety and efficiency are strong (see Table A21).

Table A21. Risks for Ambiguity About the Validity of Sensor Information

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.			X		
If such an incident occurs, it could have a significant impact on safety.				X	
If such an incident occurs, it could have a significant impact on efficiency.[a]				X	

[a]The participant explained, "You would have to shut down the plant until the NRC gave approval to start operations again."

To address this problem, this participant noted that several mitigation strategies have been employed or proposed:

- In an emergency situation, stop diagnosing and keep the plant within its operational envelope. The participant said, "In an emergency, they're not responding to individual alarms."
- When automation is not working as expected, reduce the level of automation. The participant explained,

> There's a functional hierarchy, with functions that control specific pumps and valves. The operator can take control of more of these functional systems. If

conditions in the plant trigger emergency procedures, the operators think harder about turning off the automation, because it could be turning off a safety system. They can significantly deviate from procedures.

- Check for sensor validity. To do this, design redundancies for the sensors and monitor for and respond to inconsistencies, including flagging of inconsistent data.
- Supplement the operational system with a disturbance analysis system that acts as a decision support tool.
- Provide more training, especially on complex failures. The participant noted,

> Training is absolutely important. However, in an ideal world, [operators] should have a lot more. They are trained on lots of things, with priority on normal operations. The training is effective 99% of the time but not on complex failures. They do get training on responses to emergencies, but that training uses input from the probability risk assessments to decide what to train on. The cases tend to be simpler, not multiple failures. They train on the events they are most likely to see. It's the multiple failures that get them and they don't really train on them. And the automation becomes a black box.

- Provide training to better understand the automation. The participant stated,

> They need to understand the automation and what can go wrong. They need to know how it can fail and what they'll see in the control room. They get little of that. I'm not aware of operators getting enough training on the ways in which automation can fail. This would be a great enhancement in the training.

- Use a multiple person crew. The participant said,

> When the whole crew is involved, that's a good mitigation strategy. You need a three-person crew because each person has a different awareness. Because of the different perspectives, you increase the opportunity to detect that the operation is degrading and respond effectively. You need good crew coordination to take advantage of this. Crew resource management training for the whole crew is valuable [because] the introduction of advanced automation can have a huge effect on crew interactions.

According to this participant, the effectiveness of these responses to mitigate the problem varies, with keeping the focus on safety rather than diagnosis, enhancing training to better understand automation, and using a multiple person crew being more likely to be effective than the other strategies (see Table A22). Note that this participant indicated that to "Reduce the level of automation" could be undesirable if the automation was functioning correctly when the operator thought it was not, but would be highly desirable if the automation was functioning incorrectly.

Table A22. Effectiveness of Mitigation Strategies for Ambiguity About the Validity of Sensor Information

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Stop diagnosis and focus on plant safety.				X	
Reduce the level of automation.	X				X
Check for sensor validity.			X		
Supplement the operational system with a disturbance analysis system.				X	
Provide more training, especially on complex failures.		X			
Provide training to better understand the automation.				X	
Use a multiple person crew.				X	

A.4. Alarm Fatigue, False Alarms, and Ignoring Alarms

Examples of this impact emphasizes the effect on human performance of automation that generates numerous alerts, potentially leading to alarm fatigue or suppression of alarms. These numerous alerts may be the result of false alarms resulting from the setting of extremely tight alarm limits by the manufacturer. This contributing factor was noted by both doctors with one stating, "When inducing general anesthesia, the manufacturer has set the alarm limits extremely tightly. As a result, alarms are chiming almost constantly. There's a cacophony of alarms." This impact was further demonstrated in the following examples provided by controllers, naval officer, and dispatchers.

A.4.1. Controllers' Missed Alert Due to False Alarms

These examples provided by controllers show a case where false alarms can lead to a failure to attend to a valid alert. In the first example, new automation was introduced to calculate the wake turbulence separation requirements on final approach. The automation displays the separation requirements in miles and turns yellow if the ATC needs to make an adjustment to the aircraft in 2 minutes and red if he/she needs to make an adjustment immediately. According to this participant, the automation worked well and helped ATCs with spacing, especially with the new separation standards that also were introduced.

However, this participant noted that sometimes the automation would malfunction and would give the ATC the wrong separation distance. One problem with the automation was false alarms. The controller explained,

> We'd have a flight on a downwind leg, using standard 3-mile separation. The plane would start to turn on final and the automation would kick in, giving an alert that we needed 5 miles. By the time the turn was done, the separation would be more than 5 miles, but the automation didn't know that. We'd get a ton of false alarms—nuisance alerts. Then you wouldn't notice when there was a legitimate alert. It's like the boy who cried wolf.

In this case, controllers may become desensitized to the alert, leading to a longer response time to attend to an alert or to completely missing an alert.

This participant also noted another example with reliance on the automation, resulting in the detection of a problem later than desired. The participant clarified,

> You'd have one plane on final and another on the downwind leg. The plane on final slows from 180 knots to 110 knots, but you don't notice it. You turn the downwind in, which is flying at 210 knots, overtaking the lead aircraft at 100 knots. You've got 15 seconds to deal with that.

According to the participant, the likelihood of a failure to attend a wake turbulence alert in a timely manner occurring in the next 5 years would be very high, and the potential negative impacts on safety and efficiency also would be very high (see Table A23).

Table A23. Risks for Failure to Attend to a Wake Turbulence Separation Alert in a Timely Manner

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge could be a contributor is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.				X	
If such an incident occurs, it could have a significant impact on efficiency.		X			

This participant suggested that better training on automation for ATCs to mitigate the effects of such problems with alerts would likely be effective. The participant also indicated that, when new automation is put in place, the contractors downplay any shortcomings of the automation. Shortcomings might be mentioned but would not be emphasized or used in training scenarios. This participant stated, "They need to emphasize the shortcomings so [that] we know what to expect. Forewarned is forearmed. Tell me how it works and when it doesn't."

A second example provided by a controller about false alerts dealt with the Minimum Safe Altitude Warning (MSAW) automation. The MSAW alerted controllers when an airplane gets too close to the terrain by flashing and providing an audible alert. However, it would provide a lot of false alerts because the automation was not designed to consider pilot intent during descents. One controller stated,

> It would look at the rate of descent, 9,000 feet coming down at 2,000 feet per minute. The software didn't understand the pilot's intent to level off. There were so many false alarms that when a flag was legitimate, you'd miss it. About 1 in 25 alerts were legitimate. Because of the large number of false alarms, controllers would sometimes miss the alert and respond later than they would have if they had noted it.

An implied concern with this example is attention management, such that experience with the automation may influence the likelihood that a valid alert will be noted in a timely manner.

A.4.2. Naval Officers' Suppression of Valid Alarms

The example provided by the naval officer demonstrate a case where valid alarms may get suppressed during busy times. In this example, the naval officer emphasized another variation on delay in responding to an alert or in failing to respond to it at all. This included a discussion of the contributions of task saturation and distractions to ignoring an alert. The naval officer described the following scenario,

> If there's an indication of an engine problem, you need to know if it's a sensor failure or a physical failure. You need to determine all the possible causes. And it's time sensitive. An example is a bearing failure. There was a kid on the console who saw an indication of a high bearing temperature inside an engine. The icon came on and he kept silencing it. … There were three things he was supposed to be doing at that time, so he was distracted, double tasked. … He wasn't paying attention to what it said and eventually it went away. He thought the problem had been solved, but the sensor had burned out and the bearing wasn't getting lubrication. There was a clog somewhere. The bearing eventually failed. When

> that happens, metal goes flying and gets ingested into the engine. The metal debris in the oil is scarring surfaces and destroying the engine. Since the engine is built into the ship as you build it, if this happens you have to cut a hole in the ship in dry dock. That's a several month operation. … I've seen that happen with a gas turbine engine on a destroyer too. The sailor either ignores the alert or is unaware of what he's seeing and thinks: If I can just get the light out, I'm okay. It's a problem with a lack of supervision, a lackadaisical attitude and training. The captain and chief engineer were relieved of duty because of that.

According to this participant: "The same thing has happened on the bridge. The ship got off track. The sailor silenced a navigational alarm a dozen times. There was a casualty."

This participant indicated that there is a moderate likelihood of a sailor failing to respond appropriately to an alarm occurring in the next five years with the result being a system failure. However, if such an incident does occur, the potential negative impacts to safety and efficiency would be strong (see Table A24).

Table A24. Risks for Failure to Respond Appropriately to an Alarm Resulting in a System Failure

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident in which the degradation of cognitive skills and knowledge could be a contributor is likely to occur within the next 5 years.			X		
If such an incident occurs, it could have a significant impact on safety.				X	
If such an incident occurs, it could have a significant impact on efficiency.[a]				X	

[a]The participant clarified, "It's a big deal to lose a warship."

The participant provided the following strategies to mitigate this problem and indicated that all strategies would be effective (see Table A25):

- Training, including "tons of repeated drills." This participant emphasized, "That includes training on teamwork. You could have a supervisor and three people in a room. They all need to be trained the same and understand the watch concept for that team, the standard way of doing it."
- Good interface design. The participant stated, "It should be telling you what's wrong and the immediate controlling action."

- Procedures, which "need to be developed by the operators and engineers, people who understand what to do and in what order."

Table A25. Effectiveness of Mitigation Strategies for Failure to Respond Appropriately to an Alarm Resulting in a System Failure

The following mitigation strategies are likely to be effective:	1 Strongly disagree	2	3	4	5 Strongly agree
Training					X
Good interface design					X
Procedures					X

A.4.3. Dispatchers' Missed Alerts Because of Too Many Alerts

One dispatcher provided another example that further highlights the effect on the user of automation when the automation provides a large number of unfiltered or unprioritized alerts. This dispatcher described the following scenario,

> We have software that alerts you of certain problems, flights that are late, crews that are close to illegal duty time remaining, major disconnects. The weakness is that there are so many alerts in there that I may not look at it for 30 minutes because most of them are not important for me. … This includes messages about flights that were fueled more than 1,000 pounds above the flight release, indicating that you need to check to see if the plane could be overweight. Another alert indicates whether you've been shorted on your fuel. Another indicates that you have two flight plans out there for a flight, and you need to cancel one of them. You can have 50–100 messages on the screen, where 2 of them might be important and need action in the next 15 minutes. Because not very many are important, and you've got calls and other work to do, you might not look at the screen for 15 minutes, and then you have to find the important one. So, you might not get to an important alert in a timely fashion.

According to this participant, the likelihood of this scenario (i.e., information overload due to a large number of undifferentiated alerts) occurring in the next 5 years is "guaranteed to occur," and the potential negative impacts on efficiency are very high (see Table A26).

Table A26. Risks of Alarm Fatigue as a Result of Information Overload

	1 Strongly disagree	2	3	4	5 Strongly agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.[a]	X				
If such an incident occurs, it could have a significant impact on efficiency.					X

[a]The low rating regarding the impact on safety is based on an assumption that, if the dispatcher doesn't detect the problem, someone else will at some point during the flight when it is still possible to safely deal with the situation.

To mitigate this scenario, this participant suggested that changes need to be made to the software so that the most important alerts get the dispatcher's attention.

A.5. Automation-Induced Effects on Team Situational Awareness and Teamwork

Examples of this impact emphasize the effects that the capabilities and implicit demand characteristics embedded in automation can have on the extent and effectiveness of a team's situational awareness and teamwork skills. This impact was clarified in the following examples provided by a doctor and a nuclear power expert.

A.5.1. Doctors' Loss of Team Situational Awareness

One example provided by a doctor demonstrated a case where automation led to loss of shared situational awareness among team members because it reduced the level of communication between team members. This doctor noted,

> Electronic medical records work well for billing, but they are the bane of many people's existence. A busy resident may look at the previous electronic notes and cut and paste them to get his notes done faster. It's easy to fall into that realm instead of modifying the notes to provide new details. Or he may just check off something like: Broken right upper extremity; splint applied; follow up in two weeks, without explaining in more depth the structures injured. That detail can be important when another doctor reviews that information.

A.5.2. Nuclear Power Operators' Loss of Teamwork Skills

Another example provided by a nuclear power expert demonstrated a case where automation led to a reduction in interaction among team members because it changed the roles and responsibilities of team members. This nuclear power expert noted,

> In the early designs of nuclear power plants, the automation made it very much a one-man operation. It was no longer a highly interactive crew activity. The supervisor might want to know a valve position, but the amount of interaction was way reduced. The roles and responsibilities of the human crew members were changed. Crews felt their interactions and work as a crew were greatly depreciated. And the introduction of computerized aids required a change in the CONOPS. The operator might be asked for some information, but without knowing the context of where the computer was in a procedure. Self-checking eroded away. … In the newer systems, they built in stopping points to coordinate with each other and were given more specific communication and diagnosis roles than they used to have.

A.5.3. System Design to Provide Safety Nets through Pre-coordinated Responses

Management support and contingency planning is needed in order to ensure that, as necessary, safety nets are introduced to make the system more robust or resilient to failures of the human-automation team. The following example was provided by a physician and illustrates such pre-coordination as one example of a safety net,

> I see reports about free-standing surgical centers where they have a complication and have to ship the patient off to the university hospital. These centers provide a high level of efficiency, but when things go wrong, the model can really break down for the patient. In a fully staffed hospital, you have people with all the various skill sets. That provides a safety net. Without that, if something goes awry, it can really go awry. In the best case, these centers will have an effective transfer relationship with a hospital that can provide a higher level of care, allowing an expeditious transfer of the patient. That's not always the case.

According to the participant, the likelihood of a facility having inadequate safety net to ensure access to personnel with needed backup skills and knowledge occurring in the next 5 years is very strong, and the potential negative impacts on safety and efficiency also are strong (see Table 27).

Table A27. Risks for Inadequate Safety Net Providing Access to Personnel with Needed Backup Skills

	1 Strongly Disagree	2	3	4	5 Strongly Agree
This type of incident is likely to occur within the next 5 years.					X
If such an incident occurs, it could have a significant impact on safety.*					X
If such an incident occurs, it could have a significant impact on efficiency.**				X	

* The participant noted, "This has happened and will continue to do so."
** The participant clarified, "It would depend on the incident. It depends on the procedure and whether the patient can be transferred quickly to the other facility. Something even as benign as a polyp being removed, with a bad reaction, can lead from something that is normally innocuous to patient mortality."

To mitigate this problem, the participant recommended to the following strategies:

- Learn from past incidents. The participant remarked,

> Best practices have to evolve. In medicine, it depends on what you do after those incidents to make it better. There has to be a willingness to accept that their performance was a problem instead of wiping their hands [because] they had transferred the patient. You need to make the process better so it never happens again. Locally, you need a debrief and then a root cause analysis to get an outside perspective to make the system better. Globally, there are doctors who write about what they have done based on personal experience in order to become better.

- Learn from a mentor. The participant explained,

> It is incredibly effective to have a sage, a mentor. Having an ally like that is very valuable. A doctor needs a surgical coach above him in the surgical ranks who can say, "Don't make the same mistake I did." Even in late or mid-career, I'm still learning from an old sage who will say, "Come and watch me on this case."

According to the participant, the effectiveness of these responses to mitigate the problem are strong or very strong (see Table 28), with learning from a mentor expected to be slightly more effective.

Table A28. Effectiveness of Mitigation Strategies for Inadequate Safety Net Providing Access to Personnel with Needed Backup Skills

The following mitigation strategies are likely to be effective:	1 Strongly Disagree	2	3	4	5 Strongly Agree
Learn from past incidents.				X	
Learn from a mentor.					X