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Situational Awareness and Workload Management in Aviation: A Case Analysis of the Crash of American Airlines Flight 965

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Objectives: The objective of this study was to examine the impact of workload management (WM) on situational awareness (SA) and determine factors leading to poor workload management in flight operations by analyzing the crash of American Airlines Flight 965.

Background: Approximately 85 percent of aviation accident reports mentioned the loss of SA. This necessitates examining factors contributing to the loss of SA to improve aviation safety.

Methods: An analysis of the data and information synthesis was done qualitatively to arrive at results, conclusions, and recommendations.

Results: The analysis of the crash revealed that inadequate equipment, ineffective communication, automation mismanagement, improper coordination and planning, and assumption could result in the loss of SA.

Conclusion: The conclusion showed (1) Inadequate equipment can contribute to ineffective WM and increase the chances of loss of SA, (2) maintaining SA has more to do with effective WM because poor WM prevents flight crews from accomplishing critical safety functions and divert their attention to irrelevant activities, (3) A lack of effective communication threatens flight safety and SA. It causes assumptions, which may eventually lead to poor WM,

Recommendations: (a) implementation of space-based radar services in regions without radar services, (b) timely repair of inoperative navigational equipment, and (c) having a standalone training for preparation, planning, and vigilance behavior to help the crew actively master the techniques of anticipating contingencies and actions that can lead to a high workload situation.

Application: Potential applications of this case study include ensuring effective WM to ensure SA in flight operations.

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Introduction

Situational awareness (SA) is an essential aspect of flight deck management and has become an increasingly salient factor contributing to flight safety and operational performance (Salas & Dietz, 2011). It is a vital component of safe and effective operations in the flight deck, maintenance tasks, and the air traffic management spectrum (Kanki, Anca, & Chidester, 2019). Problems with situational awareness were found to be the leading causal factor in a review of military aviation mishaps (Hartel, Smith, & Prince, 1991), and statistics of aviation accidents reveal that approximately 85 percent of accident and incident reports included a mention of the loss of SA (Skybrary, 2016). In a review of about 200 accidents in aviation, poor SA was identified as the main causal factor (Stanton, Chambers, & Piggott, 2001).

The loss of SA often leads to controlled flight into terrain (CFIT), which accounts for more fatalities than other accident categories (Kelly & Efthymiou, 2019). One of the accidents recorded in the aviation industry due to loss of SA was the crash of American Airlines Flight 965. The flight crashed into terrain during the approach phase of the flight. The flight crewmembers were well trained and experienced but lost SA regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids.

Several factors often trigger the loss of situational awareness (Kanki, Anca, & Chidester, 2019). However, ineffective workload management (WM) remains one of the profound factors leading to the loss of SA in flight operations (Wickens, 2002). This necessitates examining factors contributing to ineffective WM and their impacts on SA using American Airlines Flight 965 as a case study.

Intent

Several CFIT accidents occurred due to the loss of SA, and research revealed that CFIT accounted for a considerable number of fatalities compared to other accident categories (Kelly & Efthymiou, 2019). One of the CFIT accidents ever recorded in the aviation industry is the crash of American Airlines Flight 965. The lack of situational awareness regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids served as the precursor to the crash, killing hundreds of passengers and flight crewmembers. (Aeronautica Civil of the Republic of Colombia (ACRC), 1995). Investigations revealed that WM directly impacts SA, and in most cases, ineffective WM contributes to factors leading to loss of SA and CFIT (Kanki, Anca, & Chidester, 2019). Therefore, this research aimed to analyze the crash of American Airlines Flight 965 and examine the impact of WM on the flight crew's SA and factors contributing to ineffective WM in flight operations.

Research Questions

- What factors contributed to the loss of SA of the crew of American Airlines Flight 965 regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids?
- How does poor WM set the stage for aircraft accidents?

Literature Themes

SA is critical to flight safety, especially threat and error management (TEM) (Kanki, Anca, & Chidester, 2019). It begins with developing mental toughness, being physically fit, thinking ahead of the airplane, having a good scanning technique, and having the ability to deal with unknown situations (Kanki, Anca, & Chidester, 2019). Various Investigations revealed that one of the most critical factors for achieving successful performance in flight operations is high levels of SA (Endsley, 1999). In addition, the National Aeronautics and Space Administration (NASA) identified SA as one of the seven major areas targeted for human error reduction in its Aviation (Endsley & Garland, 2000).

SA is essential in maintaining safe control of an aircraft and adequate awareness of system status to track the development of events as they gradually unfold (Stanton, Chambers, and Piggott, 2001). Tracking the development of these events hinges on the aeronautical decision-making of the flight crewmembers, and research revealed that decisions and actions are likely to be negatively influenced when SA is impaired; therefore, acquiring and maintaining a high level of SA in flight operations is critical to enhancing safety. (Nguyen, Lim, Nguyen, Gordon-Brown, & Nahavandi, 2019).

An essential element of SA is knowing the current state of the aircraft flight path and energy state and projecting that into the future (Kanki, Anca, & Chidester, 2019). It requires pilots to actively monitor the aircraft's flight path by scanning the flight instruments and comprehending their meanings (Kanki, Anca, & Chidester, 2019). Endsley (2019) supported this notion by saying that the three main concepts involved in SA are: perception of elements in the environment, comprehension of the current situation, and project of future status. Perception of elements in the environment requires using our senses of vision, hearing, and touch to gather information to understand the current situation (Endsley, 2019). Comprehension of this current situation is based on using existing knowledge and experience to analyze the information gathered to project future status by thinking ahead of the situation (Endsley, 2019). Therefore, to increase SA, one must acquire all pertinent information, process it, and decide what to do with it (Kanki, Anca, & Chidester, 2019).

Kanki, Anca, & Chidester (2019) stated three ways by which SA can be improved: (1) monitoring of the aircraft flight path, (2) effective WM, and (3) managing flight deck automation. Of these three, WM is the most profound element enhancing situational awareness due to its direct impact on aircraft flight path monitoring and automation management, and it has gained considerable prominence in many complex multitasking domains, especially in aviation due to its effects on flight safety (Iani & Wickens, 2005). For example, research on accident analysis showed that 60 to 90 percent of aviation accidents occurred in flight tasks with high mental workload intensity and stress levels (Endsley, 2019). The essence of WM in flight operations is to get the crew ahead of the airplane and perform all critical tasks before flight crewmembers become overwhelmed (Wickens, 2002).

Flight crewmembers can become tasks saturated if tasks are not executed promptly, and any form of delay can lead to a high workload situation (Kanki, Anca, & Chidester, 2019). A high workload negatively affects crew performance by making the crew dwell on a particular task and delaying other critical tasks (Kanki, Anca, & Chidester, 2019). This situation often leads to a lack of adequate monitoring and a series of errors such as error omission and error of commission (Guastello, 2014). High workload often results in poor WM and is proven to have detrimental effects on flight safety since it can make the crew dwell on a particular task, delay other critical tasks, and set the stage for an accident (Kanki, Anca, & Chidester, 2019).

Workload management and situational awareness are essential components of flight safety (Kanki, Anca, & Chidester, 2019). They determine how threats and errors would be managed effectively in flight (Kanki, Anca, & Chidester, 2019). Pilots who work hard to effectively manage workload enhance situational awareness and minimize risk to the barest level, thereby enhancing safety. On the other hand, pilots who neglect effective workload management are prone to losing situational awareness (Kanki, Anca, & Chidester, 2019).

Methodology

This study used a case study analysis qualitative approach to analyze the impact of WM on SA and factors contributing to the crew's ineffective WM in flight operations because it fits the research questions properly and offers an adequate way to construct the required knowledge, and the data were derived from the analyses of the crash of American Airlines flight 965 because post-accident and incident analyses are for educational purposes to understand factors contributing to aircraft accidents. The data were collected from the report generated by the Aeronautical Civil of The Republic of Colombia and the air crash investigation video.

The qualitative research method used the taxonomy of the precondition for unsafe acts of human factors analysis classification system (HFACS) to analyze the crash of American Airlines flight 965 to determine the impact of WM on SA. The analysis begins with a summary of the crash, followed by a step-by-step analysis using the precondition for unsafe acts of human factors analysis classification system (HFACS).

Summary of American Airline flight 965 crash

American Airlines Flight 965 crashed into a mountainous terrain during descent from cruise altitude in visual meteorological conditions (VMC). The flight was uneventful from the departure to the approach segment. Prior to the descent from the cruise flight, the crew planned to land on runway zero one (01). The captain, who was the pilot monitoring, radioed the approach controller of their intention to descent to flight level two zero zero (FL200). The request was granted, and he was further told to proceed to Cali VOR for the approach, maintain flight level one five thousand (FL150), and report Tulua VOR. The captain entered Cali waypoint into the flight management computer (FMC), believing they were cleared direct to Cali. This attempt erased all the waypoints in the FMC, including Tulua. After a few minutes, the controller asked if the crew would accept a straight-in approach into runway one niner (19) due to the calm wind. The captain responded, “yes sir” and requested a lower altitude. The controller cleared the flight for the VOR DME runway one nine, Rozo one arrival, and asked them to report Tulua VOR 21 miles at 5000 feet due to the absence of radar to track their flight path. Once the crew realized that they would be flying to Rozo waypoint, the captain punched ‘R’ into the FMC to generate all waypoints starting with ‘R’. The captain did not realize Rozo waypoint was not on top of the list but went ahead to execute the first waypoint on top of the list. This led to the flight veering off on a new and deadly course and also descending (ACRC, 1995).

Figure 1: American Airlines Flight 965 Flight Track. Image from Mayday television series (Mayday, 2005)

While on the deadly course, the crewmembers were busy studying charts but realized that they were on the wrong path after a couple of minutes. The crew decided to find their way back to Rozo waypoint without realizing there were mountains between them and their next waypoint. After a couple of minutes, the ground proximity warning system came up, alerting them of the potential controlled flight into terrain. Unfortunately, the crew's attempt to recover from the impending danger was unsuccessful (ACRC, 1995).

Upon investigation, the Aeronautica Civil of The Republic of Colombia report stated that the probable causes of this accident were:

- The flight crew's failure to adequately plan and execute the approach to runway 19 at SKCL and their inadequate use of automation.
- Failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach.
- The lack of situational awareness of the flight crew regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids.
- Failure of the flight crew to revert to basic radio navigation at the time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight (ACRC, 1995).

Figure 2: The crash site of the American Airline Flight 965 (Fact Not Fiction Films, 2006)

Analysis

The human factors analysis classification system (HFACS) framework describes the conditions responsible for an accident by separating human errors into four categories: (1) organizational influences, (2) unsafe supervision, (3) preconditions for unsafe acts, (4) unsafe acts. (Small, 2020). These categories are then broken down into subcategories, as seen in figure 3. Since this research intended to analyze the crash of American Airlines Flight 965 and examine the impact of workload management on the flight crew's situational awareness and determine factors that contributed to ineffective workload management, this analysis will only focus on preconditions for unsafe.

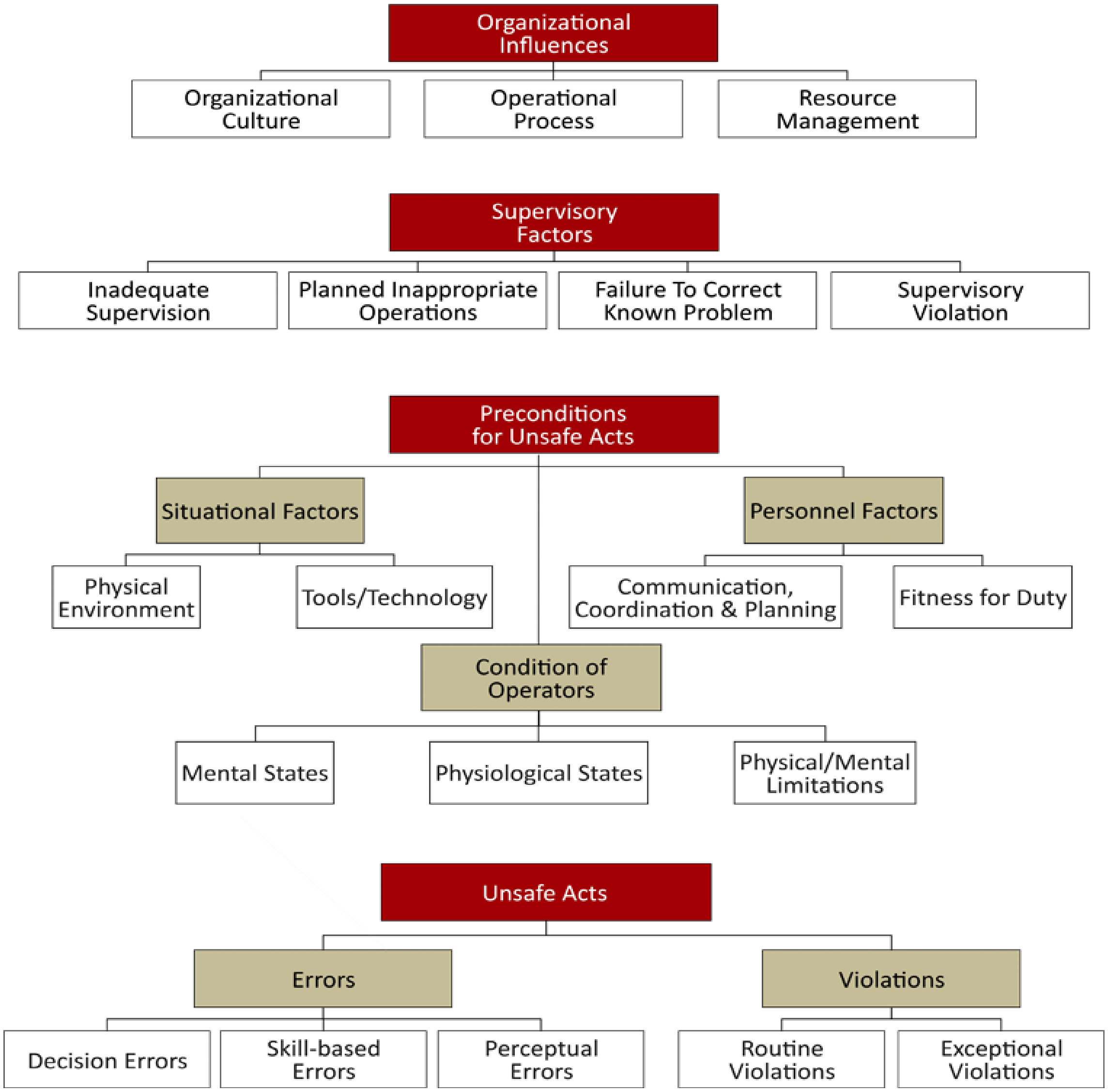

Figure 3. HFACS model developed by Wiegmann and Shappell (2009).

Preconditions for unsafe acts: This is the third level of human error under the classification of HFACS, and it's subdivided into three other factors: situational factors, personnel factors, and conditions of operators (Small, 2020). Situational factors can also be referred to as environmental factors such as physical environment and tools or technology (Small, 2020). Personnel factors comprise communication, coordination, and planning issues that affect performance, while the condition of operators comprises factors affecting mental states, physiological states, and physical or mental limitations (Small, 2020).

Situational Factor

Situational factors comprise the technological environment and physical environment (Small, 2020). Both contributed to the preconditions for unsafe acts that led to American Airlines Flight 965 mishap. The physical environment includes both operational settings such as weather, altitude, terrain, and the ambient environment such as heat, vibration, lighting, toxins, and other environmental factors (Wiegmann & Shappell, 2001). One of the physical environmental factors that contributed to the ineffective WM and a lack of joint effort of the crew and air traffic controller to bring the flight to safety was the absence of radar services. A few days before the flight, insurgency opposed to the Columbia government blew up the radar installation, so the controller had no way of knowing where an aircraft was until the crew reported their position (Air Crash Investigation, 2015). Effective WM is a joint effort between those who directly impact flight safety as stipulated in the goals of crew resources management, especially between air traffic controllers and flight crew as air traffic controllers provide timely and safety-related information for the safety of flight. Radar services also enable air traffic controllers to quickly and effectively identify and resolve potentially hazardous situations and enhance flight crew WM. The absence of this service prevented the controller from seeing the flight when it veered toward a deadly course (ACRC, 1995).

The technological environment encompasses a variety of issues, including the design of equipment and control, display or interface, checklist layouts, tasks factors, and automation (Wiegmann & Shappell, 2001). For example, technological issues in terms of automation display and identification of navaids played out when position reporting was necessary. Flight crews are required to make position reports when operating in a non-radar environment to enhance SA between the crew and air traffic controllers. However, the crew of American Airlines Flight 965 failed to make the required position report due to a series of automation mismanagement, which eventually led to the loss of SA regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids (ACRC, 1995).

Personnel Factors

Personnel factors under the precondition for unsafe of HFACS comprise issues of communication, coordination, and planning that impact performance (Wiegmann & Shappell, 2001). A lack of effective communication was one of the personnel factors that led to ineffective WM and loss of SA of the crash of American Airlines Flight 965. The controller cleared the flight to Cali and asked them to report Tulua. Instead, the captain reprogrammed the FMC to fly directly to Cali based on the assumption that they were asked to fly directly to Cali. This action led to the auto-delete of all the waypoints in the FMC, including Tulua, their reporting point, and could not identify it. At that point, the workload began to increase gradually (ACRC, 1995).

Improper coordination and planning were noticed during the unexpected event change due to the crew's decision to land on runway 19. This decision did not afford the crew enough time to safely and adequately set up the approach. The crew needed to execute immediate descent, locate the approach chart for runway 19, enter the route in the FMC, brief the approach and fly the airplane. While setting up for Rozo 1 arrival, the crew were confused because they had no time to study the arrival chart, identify the fixes and mentally fly the airplane. The captain was in search of Tulua waypoint that got deleted when attempting to fly direct to Cali. The crew became confused and asked the controller if they could fly directly to Rozo. With the approval to fly direct to Rozo, the controller expected the crew to report Tulua. At that point, a series of errors began to unfold. Errors of commission stemmed from the assumption that the closest waypoint usually appears on top of the list in the FMC. The captain punched the letter ‘R’ in the FMC in anticipation of navigating to Rozo waypoint but selected the first waypoint. Unknown to the captain, Rozo waypoint was not on top of the list. This made the flight turn towards a deadly course. Due to a high workload situation, the captain failed to ask the first officer to confirm the selected waypoint before executing the command, and the first officer was also busy flying the airplane and had no time to reconfirm the captain's input into the FMC (ACRC, 1995).

Condition of Operators

The condition of operators includes mental states, physiological states, and physical or mental performance that affect flight crew performance (Wiegmann & Shappell, 2001). The performance of the crew was impaired due to the unexpected change of events. They lost the ability to immediately recognize errors, which affected task management efficiency. As the flight veered toward a deadly course, the crew failed to monitor the system's operations to ensure they maintained SA but was busy studying charts. This is because the unexpected change of events increased the workload and, as a result, prevented the crew from properly briefing the approach and fixing a series of errors that led to the accident (ACRC, 1995)

Results

The crash analysis revealed that the absence of radar services, ineffective communication, automation mismanagement, improper coordination and planning, and assumption led to the loss of SA regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids. These are a series of events that, if not efficiently managed, could lead to a loss of situational awareness in flight operations due to the fact that they are likely to serve as precursors to errors of commission and omission. Equipment and resources are essential in ensuring flight crewmembers bring flights to safety. The absence of essential equipment increases flight crews' physical and mental workload and may prevent effective coordination and planning, therefore making flight crew susceptible to a loss of situational awareness.

The crash of American Airlines flight 965 confirmed that poor workload management could lead to a high workload situation and eventually set the stage for aircraft accidents due to the likelihood of improper coordination and planning and a series of errors that could stem from increased mental workload, thereby preventing flight crews from adhering to safety-related functions to ensure the safety of flight. In addition, an unexpected change of events could lead to ineffective WM and eventually set the stage for an accident due to the probability of losing situational awareness. Therefore, maintaining SA is hugely dependent on effective WM.

Discussion

There's a direct relationship between workload management and situational awareness because factors inhibiting effective workload management often affect situational awareness. For example, as workload increases, situational awareness decreases. This is why pilots should ensure workload is effectively managed in flight operations. In addition, one of the factors that are likely to impact workload management negatively, according to the case study of American Airlines flight 965, is inadequate equipment or equipment failure, such as navigation equipment.

Navigation devices in the national airspace are essential in ensuring flight safety. For this reason, inoperative navigational devices are reported in the notice to airmen (NOTAM) to ensure pilots are aware of the factors that can impact flight safety and plan accordingly. This is because equipment failure or malfunction can increase the flight crew's workload and an increase in workload demands additional mental resources to manage flight-related activities.

As mental workload increases, the tendency for errors also increases. In flight operations with automation in use, the pilot could make a deadly mistake as the mental workload increases, like in the case of American Airlines Flight 965. This is because automation is a double-edged sword; effective use of it could enhance safety, and ineffective use could be deadly, especially when the crews fail to monitor system operation effectively, perhaps through ineffective workload management or complacency.

Improper planning and coordination are unprofessional acts that could make flight crews susceptible to a series of errors leading to effective workload management and, eventually, loss of situational awareness. This is because ineffective workload management takes away attention from pertinent functions in flight, such as radio communication. When flight crews become distracted with other flight-related functions and unable to pay attention to radio communication, assumptions may set in, making flight crews act contrary to air traffic control instructions, thereby losing situational awareness.

Recommendations

Regions without radar services should be encouraged to implement a space-based radar system. Space-based radar systems give access to any part of the globe, thereby enhancing air traffic control operations to provide timely and accurate guidance to aircraft within the national airspace system (NAS). Implementing a space-based radar system will increase air traffic control SA and enhance crew resource management.

Timely repair of inoperative navigational equipment should be a priority in the aviation industry, as inoperative equipment can pose a danger to flight safety. Therefore, airport management should be encouraged to ensure adequate pieces of equipment that will enhance safety are provided and any inoperative equipment is repaired as soon as possible.

Since ineffective WM may result in the loss of SA, a focused approach should be used in teaching WM in the flight training environment. This can be standalone training for preparation, planning, and vigilance behavior. Even though preparation, planning, and vigilance behavior are part of the training pilots receive, a standalone training will ensure the crew actively masters the techniques of anticipating contingencies and actions that can lead to poor WM, thereby preventing loss of SA. In addition, this training will instill in pilots the ability to constantly be ahead of the airplane and identify potential hazards in flight. The training can be conducted in the classroom and the simulator. The classroom phase will incorporate aeronautical decision-making (ADM) and risk management (RM) into preparation, planning, and vigilance behavior. This way, the crew will master the act of preparing mentally for any eventuality that can occur in flight. The simulator portion of the training will incorporate a series of abnormalities and distractions that can lead to poor WM in order for pilots to master the techniques of dealing with and preventing such situations.

Conclusions

Inadequate equipment can contribute to ineffective WM and increase the chances of loss of SA. This is because adequate equipment is an essential resource in flight operations to ensure flight safety. One of crew resource management's (CRM) goals in aviation is the effective use of all available resources, including information, equipment, and people, to achieve safe and efficient flight operations (Powell & Hill, 2006). When equipment (onboard, ground, or satellitebased) becomes inoperative or unavailable, flight crews' workload increases as other necessary steps must be taken to compensate for the inoperative or unavailable equipment. For example, operating in a non-radar environment demands additional workloads of reporting positions. Therefore, the failure of the crews to take necessary steps to compensate for the lack of equipment is an act of ineffective WM and may result in loss of SA.

Maintaining SA has more to do with effective WM because poor WM can prevent the flight crew from accomplishing critical safety functions and divert their attention to irrelevant activities, which may eventually lead to the inability to monitor the aircraft's flight path actively. Poor WM can result from delaying critical tasks, resulting in a high workload and affecting the crew's ability to manage all available resources to ensure SA. From the analyses of American Airlines Flight 965, an unexpected event change can lead to a high workload and stressful situation that can lead to the loss of SA.

A lack of effective communication is a threat to flight safety and SA. It causes assumptions, which may eventually lead to poor SA. When assumption sets in, flight crews may be prone to taking unnecessary and unsafe actions that may lead to loss of SA. The crash of American Airlines flight 965 also revealed that a lack of effective communication could precipitate errors of commission and omission, thereby resulting in a high workload situation.

In-flight stress and fatigue are often a product of high workload situations and can serve as precursors to factors leading to the loss of SA. Stress and fatigue impair decision-making, tunnel attention, induce errors, and reduce flight crew concentration on critical safety functions that can enhance SA. In addition, when the stress level increases, the crew tends to make mistakes capable of affecting the regular sequence of WM.

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