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Crew Resource Management in Helicopter Air Ambulance Operations: A Literature Review

Crystal Rowley
Michelle R. Bryant

Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

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16. Abstract

INTRODUCTION: Crew resource management (CRM) training has evolved from an aviation-specific practice to a much broader-scoped practice involving other industries with team oriented objectives. Combined objective industries such as helicopter air ambulance (HAA) operations have the unique requirement to combine ground (dispatch) and air (flight crew) with traditional medical and aviation operations in ad hoc situations adding another dimension to the CRM implementation process. Despite the requirements for such training in HAA operations, evidence suggests that CRM training does not reach all team members equally. Thus, there are gaps in the current research both in theory and practice.

METHODS: Using a systematic computer query, 224 citations and 58 representative articles published from 1972 to 2015 were included in this review study. The results of the review are separated into five areas: (1) the definition of CRM and a description of implementation strategies across different industry types, (2) a description of CRM training approaches, (3) an overview of the role CRM has played in aviation and healthcare, (4) the role of dispatch and communication centers regarding CRM in HAA operations, and (5) the gaps that that exist in training and implementation strategies in CRM as they relate to HAA operations. The gaps were prioritized based on the estimated risk to HAA operations from lowest to highest.

RESULTS: The first priority was to develop a research plan to address pilots' risk-based decision making processes. The second and third priorities were to develop a research plan to identify gaps in medical personnel's knowledge regarding HAA operations, including their responsibilities in flight, and to determine whether these gaps play a role in the successful implementation of CRM principles. The fourth and fifth priorities were to develop a research plan to identify gaps in supporting personnel's (i.e., dispatch, communication centers, etc.) knowledge regarding HAA operations and to determine whether these gaps play a role in the successful implementation of CRM principles.

DISCUSSION: Relevant CRM research from industries such as medical units, military units, and ground operations will be discussed. Cognitive and social skills associated with CRM as well as behavioral markers (e.g., communication, teamwork, and decision making) will also be shared and discussed.

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INTRODUCTION

On August 26th, 2011 a Eurocopter AS 350 B2 helicopter was dispatched to a hospital for medical transport of a patient to another hospital (NTSB/AAR-13/02). During patient pick-up, the pilot informed the company's EMS communication center that he did not have enough fuel to complete the second leg of the mission. While en route to refuel, the helicopter ran out of fuel and crashed, resulting in the death of the pilot, flight nurse, flight paramedic, and patient on board. As a result of this incident, the NTSB recommended that the company revise procedures such that pilots are no longer solely responsible for non-routine operation decisions and, instead, are required to consult with the operation control center (OCC) for approval to accept, decline, or continue a mission when confronted with elevated risk situations (NTSB/A-13-015). This investigation highlighted the need to establish better communication procedures and practices directly related to Crew Resource Management principles specific to helicopter air ambulance (HAA) operations.

The incident described above is not the first time CRM has been identified as a primary contributing factor of an HAA incident. As far back as June of 1998, a Helicopter Accident Analysis Team was constructed of government and industry helicopter experts to analyze 34 fatal helicopter accidents occurring between 1988 and 1992 from NTSB accident dockets (Table 1).

Table 1.
HAAT (1998) CRM Principles Attributed to 34 Fatal HAA Accidents

CRM Cause Associated with Accident	Number of Accidents Associated	Percentage of Accidents Associated with CRM Cause
Communication		
Coordination with Ground Personnel	3	9%
Coordination with ATC	2	6%
Coordination with Other Pilots	3	9%
Judgment/Decision Making		
Sense of Urgency Led to Risk Taking	10	29%
Diverted Attention/Distraction	7	21%
Flight Profile Unsafe for Conditions	17	50%
Poor CRM	6	18%
Perceptual Judgment Errors	7	21%
Procedural Errors	14	41%
Pilot Control/Vehicle Handling Deficiencies	8	24%
Use of Unauthorized Equipment	1	3%
Situation Awareness		
Aircraft Position and Hazards	12	35%
Aircraft State	5	15%
Local and En Route Weather	8	24%

In addition, an NTSB special investigation report (NTSB/SIR-06/01) found that between January of 2002 and January of 2005, 55 HAA accidents occurred in the United States. These accidents resulted in 54 fatalities and 18 serious injuries, resulting in an increase in accidents from 3.53 accidents per 100,000 flight hours between 1992 and 2001 to 4.56 accidents per 100,000 flight hours between 1997 and 2001 (NTSB/SIR-06/01).

The number of HAA operations with critical or fatal outcomes rose steadily until 2008. To date, 2008 remains the single highest year of fatal helicopter accidents (Table 2; NTSB, 2009). In response to these accidents and the NTSB's recommendations (NTSB, 2009), the Federal Aviation Administration (FAA) issued the HAA, Commercial Helicopter, and Part 91 Helicopter Operations rule (79 FR 9931) in 2014. This rule requires that all certificate holders have training in aeronautical decision making (ADM) and risk management, crew resource management and risk management as well as risk mitigation (79 FR 9931).

Table 2.
Number of Fatal Helicopter Accidents by Year and Resulting Fatalities

Year	Accidents	Fatalities
2006	3	5
2007	2	7
2008	8	29

Between 2009 and 2014, the FAA focused on operational concerns with helicopter operations besides CRM (e.g., night operations, responding to inadvertent flight into deteriorating weather conditions; FAA, 2014). However, due to an increase in Helicopter Air Ambulance accidents (GAO, Aviation Safety, 2009) and NTSB recommendations, the FAA consolidated their HAA operations safety scope to require stricter flight rules and procedures, as well as improved communications and training and additional on-board safety equipment (79 FR 9931). In 2014, the FAA issued a fact sheet outlining safety measures that have been implemented for HAA operations (FAA, 2014) including commentary on the final rule (79 FR 9931) published February 21, 2014, requiring stricter safety procedures and equipment on board.

Specific to CRM requirements, the FAA's Advisory Circular (AC) 135-14B, Helicopter Air Ambulance Operations, recommends combined CRM training between air and ground crews to build "effective integration and coordination during routine flight operations as well as including issues such as the use of medical personnel to supplement flightcrew, as appropriate during emergency operations" (FAA, 2015). Two types of training, Air Medical Resource Management (AMRM) training and Judgment and Decision-making training, are outlined in sections 4-10 and 4-11 in the AC. General training focused on safety culture and shared training are both included in AMRM training. According to the AC, shared training "provides a common language and understanding to enable appropriate safety communication, responsibility and authority, within both HAA operators and medical organizations (and others as appropriate)" (AC 135-14B). Section 4-11, Judgment and Decision-making Training, includes sections on topics that should be included, risk analysis, decision-making, management personnel involvement, as well as

human factors that potentially affect HAA operations (AC 135-14B). This guidance makes up the bulk of the prescribed recommendations from the FAA to the operators. However, there are no guidance materials that specifically identify the knowledge gaps that may exist between medical crew knowledge and pilot knowledge while performing these operations.

Given the inception of the new rule in 2014, the FAA is now examining the effectiveness of Crew Resource Management training for HAA Operations. Therefore, in response to a request jointly made by the Flight Standards Division of the FAA (AFS-800) and the Air Transportation Division (AFS-200), this report summarizes the literature regarding Helicopter Crew Resource Management for Part 91 and Part 135 Operators including HAA Operations. This review will cover five broad areas:

1. Define CRM and implementation strategies across different industry types.
2. Describe CRM training approaches.
3. Provide an overview of the role CRM has played in both the healthcare and aviation industries.
4. Describe the role of dispatch and communication centers with regard to CRM in HAA operations.
5. Identify gaps that that exist in CRM in HAA operations.

WHAT IS CRM?

Crew Resource Management was identified as a means to train teams to work together. Specifically, it has been utilized to coordinate flight crews and to allow for cross-checking and back-up (FSF ALAR Briefing Note 2.2, 2009). Additionally, CRM has been implicated as a foundational element of both flight crew performance and interactions with automated systems across multiple domains. When flight crews and automation work together as a unit, the resources needed to achieve successful and safe flights are utilized efficiently (Kanki & Helmreich, 2010). Similarly, when crew members are trained to work together as a unit, flight safety is enhanced (Orasanu, 2010).

CRM curriculum was introduced to achieve increased performance capabilities by utilizing team resources most effectively. Studies found that by emphasizing the cognitive and social skills required to manage team-oriented activities (such as flying aircraft), as opposed to the technical knowledge associated with performing the task (Royal Aeronautical Society, 1999), better team performance was possible (Helmreich, 1991). The premise of CRM stresses that strengthening communication skill between team members allows technical skills to be seamlessly integrated into an operation for an efficient use of resources with a greater chance of successful outcomes.

Skills Associated With CRM

Previous work has identified specific CRM components and their associated behavioral markers. The two fundamental CRM component groups are cognitive skills (e.g., decision making, situation awareness, and workload management), and social skills (e.g., leadership and

teamwork; Flin & Martin, 2001). These categories are used fairly consistently throughout the literature (Table 3). For example, the Royal Aeronautical Society (1999) identified both cognitive and social skills as keystones to CRM in aviation. However, there are some differences in labeling among research studies, airlines, and fleets. This suggests a lack of uniformity in labeling skills versus behavioral markers. For example, the Airbus Flight Operations Briefing Notes (June, 2004) identifies 11 CRM skills including assertiveness, inquiry/advocacy, and time management. Similarly, the Flight Safety Foundation released a CRM Briefing Note (2009) identifying complacency/overconfidence, inadequate proactive flight management, and inadequate preparedness in addition to the 11 identified by Airbus in 2004. Though they are identified in these sources at a more fine-grained level, these skills do generally fall into either a cognitive or social skill (Table 3).

Table 3.

Similarities in CRM Categories Across References

Study	Cognitive	Social
Royal Aeronautical Society, 1999	Situational Awareness Planning and Decision Making	Communications Teamwork
Airbus Flight Operations Briefing Notes, 2004 FSF ALAR Briefing Note 2.2, Oct 2009	Inquiry and Advocacy Procedures Time Management Error Management Risk Management Decision Making Spatial Disorientation	Leadership Teamwork Assertiveness Interruptions/Distractions Complacency/Overconfidence Inadequate anticipation Inadequate preparedness Personal Factors Absence of trained instructors and check airmen for CRM evaluations
ICAO-CAP 720 (Formerly, ICAO Digest No. 2), Aug 2002 (CAA, 2002)	Situation Awareness Problem Solving Decision Making Judgment Stress Management Critique	Leadership/Followership Social Skills (i.e., listening, conflict resolution, and mediating).
Joint Aviation Authorities, JAR-OPS 3 Commercial Air Transport (Helicopters), July 2007 (Weaver et al., 2010;Morey et al., 2002; Haller et al., 2008)	Error Prevention and Detection Stress, Stress Management, Fatigue and Vigilance Information Acquisition Situation Awareness Workload Management Decision Making	Communication Co-ordination inside and outside the Cockpit Leadership Team Behavior
History of CRM, (FAA TV, 2012)	Setting Priorities Workload Management	Communications

Behavioral Markers

Due to the diversity of literature sources and reporting methods, labeling behavioral markers that apply across the spectrum of CRM research has proved challenging. However, the most basic behavioral markers have been identified from the literature including communication, teamwork, and decision making (Helmreich, 1997). Subcategories of behavioral markers tend to vary based on organizational need, choice of measurement, and reporting method. When examining the lists contained in Table 3, the category "other" must be added to the behavioral markers identified to account for subcategories under the cognitive and social umbrellas (Figure 1). However, other behavioral markers have been examined and found to be important indicators of performance. For example, Drury, Dorrian, Ferguson, and Thomas (2013) examined the heightened emotional activity (HEA) of 27 short-haul and long-haul pilots by measuring five HEA behavior markers: confusion, disagreement, stress, frustration, and unease. They found that pilots were able to identify when they were experiencing HEA reliably and validly throughout the task. They concluded that these behavioral markers were indicators of HEA for pilots, and they were aware of such HEA when performing tasks. While these findings suggest that pilots are aware of their HEA, the authors did not provide evidence to suggest that these HEA impaired performance. Nor did they identify whether there were potential differences in performance for those pilots who may not be aware of their HEA.

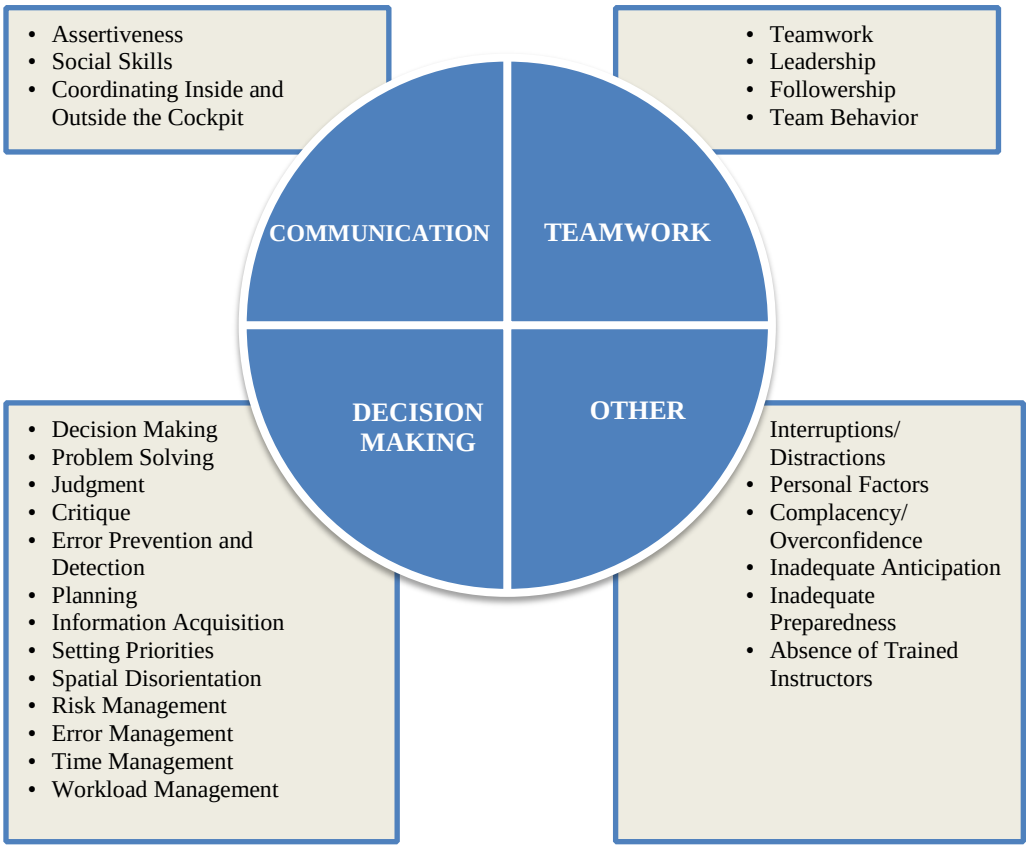

Figure 1. Subcategories of Behavioral Markers Including Cognitive and Social Umbrella

Flin and Martin (2001) were concerned with the current implementation of CRM training including validity and reliability of such measures. One difference that study had from the Drury et al. (2013) study was that assessments were made of others, rather than a rating of one's own behavior. This key difference means that while it may be possible for pilots to reliably and validly rate their own HEA depending on the operation type, workload, and stress level, it may not be possible to do the same for a team member. In addition, HEA is not considered to be a tenant of CRM, per se. Rather, it seems HEA may be more likely to have an effect on the behavioral markers of CRM. This distinction makes it even more important that measurement of performance be included in future studies of CRM. In fact, Flin and Martin (2001) suggested that if researchers provided more detail about the events and scenarios employed, it may be possible to reduce technical and non-technical behaviors associated with behavioral markers into a more condensed assessment.

An FAA Advisory Circular (AC 120-51E Appendix 1), lists crew performance marker clusters. Behavioral markers are identified in three categories. Section 1, Communications Processes and Decision Behavior Cluster, includes behavioral markers for briefings (i.e. [2] The briefing is interactive and emphasizes the importance of questions, critique, and the offering of information). There are also behavioral markers related to inquiry, advocacy, and insertion, which, according to the authors, "relate to crewmembers promoting the course of action that they feel is best, even when it involves conflict with others." Section 2, Team Building and Maintenance Cluster, includes markers for leadership/followership and concern for tasks, as well as markers that concern social relationships and group climate, such as crewmembers' ability to remain calm under stressful conditions. Section 3, Workload Management and Situational Awareness Cluster, focuses on preparation, planning and vigilance, as well as workload distribution and avoiding distractions.

More recent approaches to the study and implementation of CRM have consolidated the behavior markers depicted in Figure 1 with events and scenarios relevant to particular operations into a threat and error management model (TEM; Helmreich, 1998; Musson & Helmrich, 2004). Specific to aviation most CRM programs currently use TEM as a foundation for CRM training (Helmreich, Klinect, & Wilhelm, 1999). This model allows for prediction and prevention of error through the identification of threats present in an operational environment, as well as possible errors that may increase the risk of those threats (Chidester, 2016). Viewing aviation through the lens of TEM with CRM as an overlay has allowed for qualitative as well as practical improvements in flight safety (Huerta, 2014).

PHASES OF CRM

From the literature, CRM effectiveness was typically measured by examining one or more of four adoption phases: Implementation, Trial Period, Ending Period, and After-Action Period. For each adoption phase, studies gleaned best practices for a successful CRM program. These phases have been identified in previous works from the perspective of developing a measurement instrument for behavioral markers (Flin & Martin, 2001): scale development, scale trialing, training of assessors, and system evaluation. Each phase of adoption allows team members to

familiarize themselves with CRM concepts and time to culturally adjust to maximize acceptance of the CRM program. In the following sections, each phase is defined and supporting literature was reviewed.

Implementation

The goal of the implementation phase is to create a CRM program, teach the principles of the program, and then implement the program into the work environment. Several studies examined the implementation phase in order to determine what processes were required to ensure successful adoption. For example, a study conducted by Kemper, van Dyck, Wagoner, Wouda, and de Bruijne (2014) focused on the implementation of CRM in three intensive care units (ICUs) of a hospital facility. Those personnel who were responsible for implementing the program were interviewed regarding the choices, rationales, and consequences that played a role in their approach. Personnel identified problems with communication, structural time allotted to the training phase, and a clear vision for implementation as obstacles to successful implementation. By addressing each of these problems, personnel across three different ICUs successfully launched several CRM initiatives, each using an implementation strategy tailored to their needs. This outcome highlighted how CRM training courses can be implemented in a way that best fits an organization and produces successful outcomes.

In a study conducted by Cahill, McDonald, and Losa (2014), current implementation practices across five European airlines were assessed. The researchers used three process mapping phases: (1) preflight, (2) flight execution, and (3) postflight, to identify areas in need of improved training. A process map is an account of a task from beginning to end and has the ability to visualize the process of that task. In this study, the operational flight process from start to finish was mapped by five different European airline personnel in a workshop setting. Researchers found that the process models held by workshop participants were focused mainly on the flight crew rather than the team as a whole (air traffic control, dispatch, and crew). As such, Cahill et al. proposed a new integrated model that focused on operational tasks of all team members. These results emphasize the need for a team focus during the implementation phase of a new CRM program that integrates the tasks of all members of a team. Such a focus should identify specific roles and responsibilities for individuals as well as the group as a whole to ensure a collective understanding of the team's responsibilities (Cahill et al., 2014).

Recommendations. The two studies above represent two perspectives on the implementation phase of CRM programs: the mind-set and planning perspective, and the program model perspective. The mind-set and planning perspective describes the planning necessary for those personnel tasked with implementing the program within an organization. Six best practices were identified by Kemper, et al. (2014):

1. Identify and solve problems.
2. Seek advice from other implementation experts.
3. Formulate end goals and evaluate them.
4. Start directly after the CRM training.

5. Schedule enough time in advance/planning for the implementation phase.
6. Be aware that CRM can easily lose momentum.

The program model perspective describes the model by which a CRM program is developed for an organization. For example, does the CRM program focus on defining and understanding CRM practices? Does the CRM program identify the specific roles of the team and how their actions uniquely contribute to operational success? From this perspective, the following best practices were identified:

1. Identify the specific roles of each individual expected to participate in the CRM process throughout the operation.
2. Use explicit examples of good CRM practices when implementing a CRM program.

Trial Period

The trial period for CRM is defined as the period in which the program is in its first weeks following personnel training and implementation or when the CRM program is tested on smaller sample of the environment in which it is to be adopted. Trial period studies are an important part of the CRM phases because they can collect critical information ahead of a major implementation of CRM training. Findings from these studies shape the adoption, integration, and outcomes of each organization, which may utilize resources and tools offered to improve CRM in their industry.

Young-Xu, Fore, Metcalf, Payne, Neily, and Sculli (2013) conducted a preliminary study to assess the degree to which the Boise VA Medical Center could improve both communication and situational awareness within nursing units. Prior to the study, it was identified that unclear protocols led to personnel failing to call in a specialist when patients met criteria for specialist attention. Since checklists have been shown increase performance by decreasing slips and lapses in procedures (Reason, 2008), Young-Xu et al. (2013) created a "read and do" checklist to attempt to decrease the overall failure-to-rescue events within their smaller, 18-bed step-down intensive care unit. Findings showed that correct specialist calls were increased significantly from before the training (4%) to after the training (22%) with the use of the checklists. This trial-period study showed how read-and-do checklists may improve outcomes in a larger nursing setting. The use of such trial-period studies emphasizes the ability to test CRM programs before widespread use is recommended.

Other studies have focused on a trial period for determining training delivery type. For example, Clay-Williams, Greenfield, Stone, and Braithwaite (2014), evaluated the learning of participants in a modular-based CRM program (provided over the course of weeks or months) yields similar results to traditional all-day seminar environments. Participants were allowed to choose their module based on their perceived learning needs. Learners were provided a baseline attitude survey five minutes prior to workshops they attended, as well as a questionnaire to examine reactions to the training and to assess behaviors in the workplace within 15 minutes of attending each workshop. Results indicated that the workshop content and format were beneficial and met the needs of participants. While the authors did not conclude that these findings should

be interpreted as generalizable to the wider population, this study represents one way researchers are utilizing the trial-period phase to determine best needs for an organization or process. By "testing out" these ideas, the CRM program becomes more robust and is more likely to meet the objectives and outcomes desired by an organization.

Recommendations. The two studies referenced above represent two approaches that can be taken to the trial-period phase. The following recommendations were identified:

1. Identify a subset of your population that accurately represents the broader body of team members.
2. When implementing the trial-period phase of new CRM program, plan to measure the desired outcomes in the field once training is complete.

Ending Period

The ending-period phase is defined as the time at which an organization assesses the impact that CRM training has had on operations. This phase could be seen as a post-test follow up measure of performance once CRM training has completed. It is different from the trial period because it is assumed that the CRM program implemented is one that has had success in other organizations across the industry and possibly in other industries as well. It is unique from the after-action period, as it represents the general differences in performance from either implementing a different CRM program to replace an existing CRM program, or implementing a CRM program for the first time in the organization.

Sweeney, Warren, Gardner, Rojek, and Lindquist (2014) examined the effectiveness of a new CRM program through measurement of participants' perceptions of quality of communication before and after the training program. Researchers found that by measuring the perceptions staff held before and after the study, they were able to assess the changes of these perceptions once training was complete. However, they point out that these measures were subjective and not followed up with objective measures (e.g., improved performance).

Sandahl, et al. (2013) examined the start-to-finish results of a two-year case study involving CRM training. Their findings from the ending-period phase showed that without continuous organizational accommodations (e.g., debriefing and feedback), the positive communication increases found throughout the study would not continue. They also found that if resources were strained, positive CRM outcomes could not be sustained. Similarly, Morgan et al. (2015) found that by assessing ending-period outcomes they were able to identify increased teamwork ability but no change for performance-based outcomes. This distinction is important because it demonstrated that successful CRM adoption and outcomes cannot be used as a proxy for performance improvement.

Recommendations. The studies referenced above represent different approaches for measuring the ending-period phase. As such, the following recommendations were identified:

1. Plan to measure the outcomes of CRM adoption once training is complete.
2. Plan to measure performance apart from CRM skills.

3. Training phases of the CRM program should mirror operational constraints of the environment in which it will be implemented.

After-Action Period

The After-Action period is defined as the time at which an organization assesses the current CRM training effectiveness by examining the outcomes of operations and practices within the organization. These assessments can be done by examining accidents and mishaps, reports made by crew members, surveying personnel, and other methods. Crew Resource Management training programs should be constantly revised and updated as new information is compiled. Therefore, in the after-action period, it is essential that information gleaned during this time is analyzed in such a way as to identify gaps that exist in the current training so that improvements can be made. For example, in 2003, the Flight Safety Foundation summarized the final NTSB report on accident no. NYC99FA140 regarding an air ambulance crash in 1999. Based on their findings, a combination of weather and failed CRM incidents contributed to the crash. In response, the company made changes to their CRM training program to integrate line-oriented simulations to determine which crewmembers should receive additional training prior to flying. This example highlights how organizations can examine their CRM training programs internally or utilize external sources to assist with modifying the training program.

In the medical field, O'Dea, O'Connor and Keogh (2014) sought to discover whether CRM in acute care domains would be beneficial. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), the authors examined 20 articles that met their standards for inclusion in a meta-analysis. Findings showed that CRM training participant reactions were highly positive with regard to training, and they believed it was relevant to improving teamwork as well as patient safety. The authors found an effect on participants' knowledge of CRM, an effect on attitudes of CRM training, and an effect on behaviors related to good CRM practices. Though this study did not directly associate CRM training with better performance, their measurement of attitudes and behaviors are a benchmark for how these variables should be examined during the after-action period for any CRM training program.

Recommendations. The studies referenced above represent different approaches for measuring the After-Action phase. As such, the following recommendations were identified:

1. Organizations may utilize both internal and external reviewers to determine the broad implications and outcomes of CRM training within their company.
2. Measurement of employee's perception of CRM effectiveness is an important consideration in assessing the broad impact of a CRM training program.

Summary

The four core phases of CRM within an organization are Implementation, Trial Period, Ending Period, and After-Action Period. The purposes of each phase vary by the point in which they should be applied (i.e., development, adoption, and review) to ensure effectiveness of a CRM program within an organization as well as across the industry for which it was intended.

Each phase represents a critical point at which the CRM program should be assessed. Following the best practices and recommendations outlined by the literature reviewed above provides a foundation for successful CRM programs.

Table 4.
The Four Core Phases of CRM.

Phases	Definition	Recommendations
Implementation	Create a CRM program, teach the principles of the program, then implement the program into the work environment.	• Assess the current safety culture. • Identify and solve problems. • Seek advice from other implementation experts. • Formulate end goals and evaluate them. • Start directly after the CRM training. • Schedule enough time in advance/planning for the implementation phase. • Be aware that CRM can easily lose momentum. • Identify the specific roles of each individual expected to participate in the CRM process throughout the operation. • Use explicit examples of good CRM practices when implementing a CRM program.
Trial Period	The first weeks following personnel training and implementation or when the CRM program is tested on smaller sample of the environment in which it is to be adopted.	• Identify a subset of your population that accurately represents the broader body of team members. • When implementing the trial-period phase of new CRM program, plan to measure the desired outcomes in the field once training is complete.

Ending Period	When an organization assesses the impact that CRM training has had on operations as compared to before CRM training was established.	• Plan to measure the outcomes of CRM adoption once training is complete. • Plan to measure performance apart from CRM skills. • Training phases of the CRM program should mirror operational constraints of the environment in which it will be implemented.
After-Action Period	When an organization assesses the broad CRM training program effectiveness by examining the outcomes of operations and practices within the organization.	• Organizations may utilize both internal and external reviewers to determine the broad implications and outcomes of CRM training within their company. • Measurement of employees' perception of CRM effectiveness is an important consideration in assessing the broad impact of a CRM training program.

CRM TRAINING METHODS

Training courses vary within the industry based on several factors including aircrew, aircraft type, financial restraints, company culture, and course developer type (i.e., psychological basis or systems designs basis). In addition, training has been conducted using both classroom-based training courses and scenario based training courses with "real-world" assessments for both medical and aviation domains. In many cases, CRM training is implemented through a combination of classroom and simulation training. The medical literature suggests that some form of simulation should be woven into CRM courses to improve understanding of the principles in real time. The merits of whether these simulations should be traditionally simulated (that is, a predetermined fictitious scenario in a dedicated training space) or if training should occur "in-situ" (i.e., a predetermined fictitious scenario within the environment in which the team actually works) have been debated (Rall, Stricker, Reddersen, Dieckmann, & Conrad, 2006). Nevertheless, evidence shows the use of simulation-based CRM training provided improved feedback, ability to integrate the curriculum, varied difficulty levels of the simulation, captured clinical variation, and individualized outcomes, all resulting in more valuable learning experiences for the participants (Issenberg, McGaghie, Petrusa, Gordon, & Scalese, 2005). Pietsch and Lischke (2014) identified simulator training as a valid method of providing coordinated CRM training for mountain rescue teams in Germany even when considering the ad hoc nature of team assembly. The authors noted

"…the combined use of helicopters and qualified emergency medical care personnel offers substantial evidence to support the meaningfulness of intensive cooperation between mountain rescue and air rescue teams" (Pietch & Lischke, 2014).

While simulation has enhanced the training (Foushee, 1984), the verdict is still out on whether simulation training alone is the best route. Several studies have focused on simulation vs. real world training methods. Droogh, Kruger, Ligtenberg, and Zijlstra (2012) examined 10 intensivists and 10 ICU nurses as part of a mobile ICU (MICU) to determine whether training with a patient simulator would be a feasible alternative to traditional training methods for providing CRM training. Participants reported that the training is useful and that they were more confident in their skills after participating in the training (2012).

A study conducted by Hänsel et al. (2012) examined the effectiveness of a 1.5-day CRM course on situational awareness among final-year medical students' performance in sepsis-resuscitation. The authors were concerned about the prevalence (62%–88%) of human error in critical incidents in anesthesia and aviation identified in Arnstein's Catalogue of Human Error (British Journal of Anaesthesia, 1997). Participants in the experimental conditions were trained using either (1) a CRM seminar course with no patient simulator or (2) with only the patient simulator. Results concluded that there was no difference in performance between experimental and the control group suggesting that simulator training was no better than a seminar based CRM training.

Similarly, Clay-Williams, McIntosh, Kerridge, and Braithwaite (2013) were interested in whether simulation-based CRM training would be as effective as traditional classroom-based training. The randomized controlled trial included a total of 157 doctors, nurses, and midwives who were randomized into four groups including a control group, classroom training only, simulation training only, and classroom training followed by simulation training. The results concluded there was no statistical significance in performance and attitudes for participants in the simulation training-only group as compared to the combined simulation-classroom and classroom-only groups.

Another review compared 12 studies regarding the effectiveness of simulation-based CRM versus other educational methods (Fung et al., 2015). The authors were interested in whether current research validated simulation-based CRM training as an acceptable alternative to any other education intervention. With the exception of one study (Shapiro et al., 2004), all of the studies reported significant improvement outcomes related to simulation-based CRM training. However, the authors point out that several limitations, including financial and risk of bias, should be considered (Fung et al., 2015).

While research has not found negative outcomes of CRM, there have been many where there was no difference in performance (e.g., Morgan et al., 2015). However, many of these same

studies did not measure performance, had no pre-test comparison, and other similar issues. Specific areas in which CRM has shown positive outcomes are outlined in Table 5.

Table 5.
Specific areas in which CRM has shown positive outcomes.

Area of Improvement	Studies
Aeronautical decision-making	Orasanu, 2010
Team decision-making	Mosier, 1991; Orasanu, & Salas, 1993; Cannon-Bowers & Salas, 1998
Conflict resolution	Blake and Mouton, 1964; Dowd, 2010
Coping with internal/external pressures	Helmreich, 2010

BACKGROUND ON CRM

CRM in Healthcare

Since 1994, the medical community has made strides to reduce the number and frequency of errors (Schenkel, 2008). Through this push for safer medical practices, the use of CRM training became progressively advanced in theory (see Helmreich & Foushee, 2010 for review) it also became more aggressively applied within medical operations (see Musson, 2009 for review). The medical community has shared both knowledge and experience regarding challenges and best practices with implementing CRM into the daily operation of aviation (Baker, Gustafson, Beaubien, Salas, & Barach, 2005). One example of a recent study that examined CRM issues identified deficiencies in medicine with frontline nursing in surgical and emergency room activities (Sculli, Fore, Neily, Mills, & Sine, 2011). Findings showed that by targeting leadership behaviors associated with CRM skills such as coordinated care and mutual respect (i.e., communication), overall perceptions of safety were improved. These perceptions have been found to be critical in the mitigation of errors (Helmreich, 1991). In a similar study (Young-Xu, Fore, Metcalf, Payne, Neily, & Sculli, 2013), a "read-and-do-checklist" was implemented after the Institute of Medicine (2000) advised the medical community to implement such procedures as have been used in aviation to enhanced operational safety in high stress situations. This checklist was provided to personnel with the purpose of improving failure-to-rescue rates in their 18-bed cardiac step-down unit. Upon implementation of the checklist, the unit's failure-to-rescue rates decreased from 25% before intervention to 12% after intervention. These findings are not unique throughout the CRM medical literature. Studies have found that implementing CRM techniques reduced observed errors (Morey et al., 2002), reduced length intensive care unit stays (Pronovost, 2003), improved perceptions of teamwork climate (Sexton, 2006), and reduced adverse labor and delivery outcomes (Mann, Marcus, & Sachs, 2006).

As CRM gained traction in the aviation industry, other industries such as nursing and intensive care units have adopted CRM processes into their fields. For example, Sexton, Thomas, and Helmreich (2000) found in a study that compared 1,033 medical personnel to over

30,000 aviation personnel found similarities in error reporting and hierarchical structure issues across domain. Sculli et al. (2011) also examined the use of CRM in aviation and drew similarities between high stress aviation situations that pilots face versus frontline nurses, who are generally the first on scene to treat and triage patients. Sculli et al. (2011) suggested implementing CRM systems at the frontline of occupations like these may help to alleviate threats to performance.

CRM in Aviation

Industry operations. The aviation community began implementing CRM when a series of aviation accidents were accredited with failures of CRM principles such as situational awareness (Florida Everglades crash, 1972, NTSB AAR-73-14). Shortly thereafter, in 1979, NASA held an industrial workshop deemed to be the foundation of CRM awareness and CRM principles. Psychologists, flight surgeons, academics, and airline pilots shared their experiences and knowledge regarding aviation and working toward managing the systems and workload more efficiently (Cooper, White, & Lauber, 1980). Smith (1979) examined crew behavior during a simulated emergency procedure. These findings revealed that certain crewmembers became overwhelmed by tasks necessary to address the emergency. By measuring workload, vigilance and decision-making in this study, Smith's finding became the pinnacle for understanding group processes and CRM implementation needs within aviation. Since this time, human factors models have been introduced to the aviation industry with the purpose of improving communication both within flight crews and between flight and ground crews (Civil Aviation Authority, CAP 719, 2002). Since these findings were published, the FAA has released three Advisory Circulars (ACs; Dispatch Resources Management Training [DRMT] 121-32A; Crew Resource Management Training [CRMT] 120-51E, Air Medical Resource Management [AMRM] 00-64; and Helicopter Air Ambulance Operations [HAAO] 135-14B) in which CRM implementation requirements in various aviation operations are outlined.

Dispatch and Communication Centers

Cumulatively, the role of CRM in the aviation and medical field has been studied extensively. What has not been studied with as much depth is the unique role that off-site team members play in the HAA operation. Studies have examined how air traffic controllers (ATCs) may benefit from CRM training (Moon, Yoo, & Choi, 2011), as well as how flight crews on board aircraft benefit from CRM (Wagener & Ison, 2014). Likewise, differences between CRM training for pilots versus flight nurses versus dispatch may vary widely depending on vocabulary, task requirements, expectations, and resources/capabilities of each entity. As the HAAO AC states, it is important to provide teams with "shared training [that] provides a common language and understanding." The following papers reviewed the role of dispatches and communication centers in the CRM process, specifically where those roles had influence over HAA operations.

Very little literature examines CRM as it applies to dispatch teams. Crew resource management is focused on the entire team and how it interacts during crisis; however, the focus has mainly been in the cockpit, neglecting the importance of effective dispatch. Grannan,

Bastian, and McLay examined military dispatchers who were tasked with locating HAA air assets to respond to casualty situations (2015). To assist the dispatchers, Grannan et al. (2015) developed a binary linear programming (BLP) model to optimally choose among two different types of air assets. Grannan et al. introduced the BLP model that optimally locates two classes of air assets and assigns to casualty locations, such as military treatment facilities (MTF), using a dispatch preference list. The list is essentially an ordered ranking for each location. The BLP also balances workload and enforces contiguity among first assigned locations for air assets.

The FAA has identified the aircraft dispatcher as an integral part of flight operations which can positively influence safety (FAA, AC 121-32A, pg. 5). Advisory Circular 121-32A, *Dispatch Resource Management Training*, was published in 2005 in order to integrate CRM with dispatch operations to form a formal dispatch resource management (DRM) training curriculum. According to the AC, DRM focuses on areas such as situational awareness and team building and optimizes communication between the various airline operations groups to form a cohesive team. DRM consists of three components: "initial indoctrination/awareness, recurrent practice and feedback, and continual reinforcement" (FAA, 2005). The FAA notes that most problems within flight and dispatch operations are the results of poor group decision-making, communication problems, inadequate leadership, and poor task/resource management (pg. 4). The focus of DRM training is to transition from the traditional focus on "how-to" operations to incorporate solid group relations between air and ground operations. While this AC provides guidance on the purpose and scope of dispatch CRM, there are still gaps that exist within HAA operations. For example, the composition of the dispatch team varies depending on number of aircraft and operation type. Dispatch teams can also be comprised of traditional communications centers who fall under FAA regulatory authority but may also be comprised of personnel who act on behalf of the air operator for certain duties (e.g., flight planning, deconfliction procedures). Currently, the FAA has no approach for identifying or assisting those dispatchers who perform duties outside of regulatory oversight.

Gaps Specific to HAA

Given the body of research that currently exists on CRM within both the medical and aviation field, this literature review identified only the key pillars of the concept. The focus of this research was placed on identifying where possible gaps may exist between the current understanding of CRM knowledge, the implementation of that knowledge, and the effectiveness of the principles in HAA operations. From this perspective, we were able to glean three areas of concern: the "mission mindset" issue, flight crew CRM, and dispatch CRM.

The "Mission Mindset." As previously indicated in Table 1, it has been shown that 10 of 34 accidents investigated from 1988 to 1994 were associated with a "mission mindset" (HAAT, 1998; e.g., a sense of urgency leading to risk-taking). Indeed, the structure of HAA operations lends itself to this mindset in several ways. First, the very nature of HAA operations is such that a patient is transported in one of a two ways: either from one hospital to another (hospital to hospital transfer), or from the scene of an incident/accident to a hospital (scene-call). A hospital to hospital transfer generally occurs when a patient is transferred to a receiving hospital because

the sending hospital does not have adequate resources to meet the needs of a patient. When a scene-call occurs, the helicopter meets first responders and emergency response teams at a scene to transport a patient to a hospital after an accident/incident (e.g., skiing, hiking, car accident, etc). In both of these scenarios, a patient is moved via helicopter because time to transport is shortened both by providing a more direct route and because traffic encounters are greatly reduced (i.e., ground transport). Research has shown that in situations where time is a factor, stress becomes increased (Keinan, 1988).

When stress is increased, cognitive resources are reduced such that decision-making behaviors are impaired resulting in less risk-based consideration. It is common for pilots to experience reduced situational awareness, decreased decision-making capability, and diminished communication abilities in times of stress (Hancock & Desmond, 2001). Therefore, it is not surprising that a pilot's perception of an HAA operation may be focused on "the mission" resulting in reduced risk assessment and thus risky behaviors. For example, the scenario described at the beginning of this paper cited an incident in which the pilot informed the company's EMS communication center that he did not have enough fuel to complete the second leg of the mission during patient pickup. While it is difficult to determine whether the "mission mindset" was primarily responsible for the subsequent fatal accident, it is clear that ensuring the aircraft has enough fuel to complete the operation is a necessary step in a pilot's pre-flight checklist. This example highlights how the actions of a pilot may be influenced by perceptions of urgency and how this may contribute to greater risk taking.

Crew CRM. The composite crew of an HAA varies dependent on patient needs. Typically, a crew consists of the pilot in control (PIC) and two medical crew members. The medical crew members can be made up of a flight nurse, flight paramedic, and/or a specialty nurse. When it is necessary to use large equipment to sustain the life of a patient, the crew can be comprised of just the PIC and one medical crew member. The variation of these crew characteristics introduces risk to scenarios where medical crew members are relied upon to assist with take-off and landing protocols. Indeed, the extent to which the crew members are trained in principles specific to aviation, flight, and CRM is unreported within the literature. The AMRM AC guidance suggests that medical crews be trained in accordance with the company's needs and identifies topics to be covered with expected outcomes of the training. However, the appropriate level of overlap needed to bridge the possible knowledge gap between medical personnel and the PIC of the operation is not addressed. The ambiguity of this guidance works in favor of industry, as it allows for companies to individualize their training to best meet the needs of their unique structure. However, due to just how unique the structure of HAA operations is, it is possible that the medical crews are not experiencing domain-specific training in aviation that will improve their performance as flight crew or ensure flight safety. Incomplete training for medical crew and ground crew could lead to the transfer of inaccurate information and potentially increase risk to the operation. For example, medical crew using night-vision goggles without proper training can exacerbate the overall risk of the operation by the creation of new hazards. In addition, the CRMT AC highlights that having a shared vocabulary between crew members is an essential part

of successful implementation of CRM principles. It is currently unclear if these common vocabularies are being obtained by HAA operation crew members or if the training they experience was created with such an objective in mind. Furthermore, the lack of uniformity with which CRM training has been conducted between the aviation industry and the health care industry makes HAA especially susceptible to risk. For example, the finding that most CRM training programs implemented in the aviation industry are based in a TEM approach (Heilmrich, Klinect & Wilhelm, 1999) is not a finding true of the health care industry. Differences such as these present risk in HAA operations because PIC and health care crew may not have a shared understanding of TEM practices or responsibilities. To this end, more research is needed to determine what, if any, knowledge gaps may exist between medical crew and the PIC, the extent to which these gaps may be closed, and if there are current training programs that address these issues successfully.

Dispatch. Similar to the identified gap regarding medical crew knowledge and PIC knowledge, also unclear is the degree to which dispatch knowledge of flight-related tasks plays a role in successful CRM implementation. For example, it is important to know what the credentials of and training requirements are for current dispatch personnel. Each of these criteria should be addressed based on the task requirements of the dispatch personnel and what effect his has on flight safety. Additionally, it is important to know if there are existing training programs that address these issues successfully. Determining if there are current CRM related flight safety issues that dispatchers face while augmenting HAA operations would assist with enhancing training programs that currently exist while mitigating risks.

Finally, with regard to both crew and dispatch gaps in the literature, one of the most glaring issues is the unknown quality and content provided by training programs across the industry. That is, to what degree do these training programs address the behavioral markers identified as the pillars of CRM? How has this training been implemented by organizations? What measureable changes have come about since the implementation of such programs? What perceptions do flight crews hold of the importance of CRM? Are those perceptions reinforced or challenged by training curriculum provided by their organizations? Each of these questions addresses some aspect of the overall quality of the CRM training programs and ultimately determines if knowledge will be transferred from training into field operations. Identifying components of successful CRM programs and how they impact flight safety within the flight crew team as well as those in augmenting roles is a natural next step to enhancing the safety of HAA operations with regard to current CRM concerns.

Recommended Next Steps

The following steps are recommended as a process for beginning to measure the impact of FAA published CRM guidance and rules in HAA operations. These recommendations address the current gaps identified from the literature review while assessing the current status of CRM training programs across the industry.

- Develop a plan of research that assesses pilots' risk-based decision making processes while engaged in HAA operations.
    - Assess stress experienced by pilots while conducting operations.
    - Assess risk assessment by pilots while conducting operations.
- Develop a plan of research that assesses the gaps that exist in medical personnel's knowledge of aviation and flight safety amid medical responsibilities while involved in HAA operations.
- Determine whether gaps in medical personnel's responsibilities and knowledge of aviation and flight safety play a role in the successful implementation of CRM principles.
- Develop a plan of research that assesses the gaps that exist between supporting personnel (i.e., dispatch, communication centers, etc.) responsibilities and knowledge of aviation and flight safety amid dispatch responsibilities while augmenting HAA operations.
- Determine whether gaps in supporting personnel's responsibilities and knowledge of aviation and flight safety play a role in the successful implementation of CRM principles.
- Develop a plan to assess the organizational safety culture and its ability to embrace CRM principles.

CONCLUSION

HAA accidents are rising (NTSB/SIR-06/01) and have typically been associated with CRM-related issues (79 FR 9931). It is the FAA's responsibility to address these challenges by assessing the previously established rules and guidance by measuring industry practices of implementation. Following up published rules and guidance with measurement ensures a commitment to the safety of the National Airspace System by continuing to monitor progress toward our safety goals. From this review, it is clear that CRM principles are alive and well in the aviation and medical communities. However, it is unclear how well those behavioral markers are taught, trained, and then transferred to the operational environment. The assessment of such issues meets a research need that would gauge the effectiveness of current CRM guidance and rules within HAA operations while providing feedback and resources to industry regarding their current CRM training programs.

REFERENCES

Airbus. (2004). *Flight operations briefing notes: Human performance CRM aspects in incidents/accidents*. Retrieved from http://www.skybrary.aero/bookshelf/books/171.pdf

Arnstein, F. (1997). Catalogue of human error. *British Journal of Anaesthesia*, *79*, 645–656.

Baker, D., Gustafson, S., Beaubien, J., Salas, E., & Barach, P. (2005). Medical teamwork and patient safety: The evidence-based relation. *Agency for Healthcare Research and Quality*, Rockville, MD. Retrieved from http://archive.ahrq.gov/research/findings/final-reports/medteam/index.html

Cahil, J., McDonald, N., & Losa, G. (2014). A sociotechnical model of the flight crew task. *Human Factors, 56*(8), 1337–1363.

Cannon-Bowers, J. A., & Salas, E. (1998). Individual and team decision making under stress: Theoretical underpinnings. In J. A. Cannon-Bowers & E. Salas (Eds.), *Making decisions under stress: Implications for individual and team training*. (17–38). Washington, DC: APA Press.

Clay-Williams, R., Greenfield, D., Stone, J., & Braithwaite, J. (2014). On a wing and a prayer: An assessment of modularized crew resource management training for health care professionals. *Journal of Continuing Education in the Health Professions*, *34*(1), 56–67.

Clay-Williams, R., McIntosh, C., Kerridge, R., & Braithwaite, J. (2013). Classroom and simulation team training: A randomized controlled trial. *International Journal for Quality in Health Care*, *25*(3), 314–321.

Chidester, T. (2016). Creating a culture of safety. In K.J. Ruskin, M.P. Stigler, & S.H.

Rosenbaum, Quality and Safety in Anesthesia and Perioperative Care. London: Oxford University Press.

Civil Aviation Authority. (2002). CAP 719 – Fundamental human factors concepts. *Previously ICAO Digest No. 1.* Retrieved from http://publicapps.caa.co.uk/docs/33/CAP719.PDF

Civil Aviation Authority. (2002). CAP 720 – Flight crew training: Cockpit resource management (CRM) and line-oriented flight training (LOFT). *Previously ICAO Digest No. 2.* Retrieved from http://www.skybrary.aero/bookshelf/books/890.pdf

Cooper, G. E., White, M. D., & Lauber, J. K. (1980). *Resource management on the flightdeck: Proceedings of a NASA/industry workshop*. Moffett Field, Calif: NASA - Ames Research Center; 1980. NASA Conference Publication No. CP-2120.

Droogh, J. M., Kruger, H. L., Ligtenberg, J. J., & Zijlstra, J. G. (2012). Simulator-based crew resource management training for inter-hospital transfer of critically ill patients by a mobile ICU. *The Joint Commission Journal on Quality and Patient Safety*, *38*(12), 554–559.

Drury, D.A., Dorrian, J., Ferguson, S.A., & Thomas, M.J.W. (2013). Detection of heightened emotional activity in commercial airline crews: A reliability study. *Aviation Psychology and Applied Human Factors*, *3*(2), 83–91.

FAA TV. (2012, April 5). *The History of CRM* [Video file]. Retrieved from https://www.faa.gov/tv/?mediaId=447

Federal Aviation Administration. (2004) *Advisory circular: Crew resource management training* (AC No. 120-51E, Appendix 1). Retrieved from http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC120-51e.pdf

Federal Aviation Administration. (2005). *Advisory circular: Dispatch resource management training* (AC No. 121-32A). Retrieved from http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_121-32a.pdf

Federal Aviation Administration. (2014). *FAA Initiatives to Improve Helicopter Air Ambulance Safety* [Fact sheet]. Retrieved from http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=15794

Federal Aviation Administration. (2015). *Advisory circular: Helicopter air ambulance operation* (AC No. 135-14B). Retrieved from http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/1027108

Federal Register (2014). Helicopter air ambulance, commercial helicopter, and Part 91 helicopter operations. Final Rule [RIN 2120-AJ53] by FAA, 02/21/2014. Retrieved from https://www.federalregister.gov/articles/2014/02/21/2014-03689/helicopter-air-ambulance-commercial-helicopter-and-part-91-helicopter-operations

Flin, R., & Martin, L. (2001). Behavioral markers for crew resource management: A review of current practice. *The International Journal of Aviation Psychology*, *11*(1), 95–118.

Flight Safety Foundation. (2009). *FSF ALAR briefing note 2.2: Crew resource management.* Retrieved from http://www.skybrary.aero/bookshelf/books/851.pdf

Foushee, H. C. (1984). Dyads and triads at 35,000 feet: Factors affecting group processes and aircrew performance. *American Psychologist, 39*(8), 885–893.

Fung, L., Boet, S., Bould, M.D., Qosa, H., Perrier, L., Tricco, A.,…& Reeves, S. (2015). Impact of crisis resource management simulation-based training for inter-professional and interdisciplinary teams: A systematic review. *Journal of Inter-professional Care, 29*(3) 1–12.

Grannan, B.C., Bastian, N.D., & McLay, L.A. (2015). A maximum expected covering problem for locating and dispatching two classes of military medical evacuation air assets. *Optimization Letters*, *9*(8), 1511–1531.

Haller, G., Garnerin, P., Morales, M., Pfister, R., Berner, M., Irion, O.,…& Kern, C. (2008). Effect of crew resource management training in a multidisciplinary obstetrical setting. *International Journal for Quality in Health Care, 20*(4), 254–263.

Hancock, P. A., & Desmond, P. A. (2001). Stress, workload and fatigue. Erlbaum, Mahwah, NJ.

Hänsel, M., Winkelmann, A.M., Hardt, F., Gijselaers, W., Hacker, W., Stiehl, M.,…& Müller, M.P. (2012). Impact of simulator training and crew resource management training on final-year medical students' performance in sepsis resuscitation: A randomized trial. *Minerva Anestesiologica*, *78*(8), 901–909.

Helmreich, R. L. (1991). Outcomes of crew resource management training, *The International Journal of Aviation Psychology, 1*(4), 287–300.

Helmreich, R. L. (1997). Managing human error in aviation. *Scientific American, 276*(5), 62–67.

Helmreich, R. L. (1998). Error management as organisational strategy. *Proceedings of the IATA Human Factors Seminar* (pp. 1-7). Bangkok, Thailand: International Air Transport Association.

Helmreich, R.L., Klinect, J.R., & Wilhelm, J.A. (1999). Models of threat, error, and CRM in flight operations. In *Proceedings of the Tenth International Symposium on Aviation Psychology*. Columbus, OH: The Ohio State University.

Helmreich, R. L., Merritt, A. C., & Wilhelm, J. A. (1999). The evolution of crew resource management training in commercial aviation. *International Journal Of Aviation Psychology, 9*(1), 19.

Helmreich, R.L., & Foushee, H.C. (2010). Why crew resource management? Empirical and theoretical bases of human factors training in aviation. In, E. Wiener, B. Kanki, & R. Helmreich (Eds.), *Cockpit resource management* (3–45). San Diego, CA: Academic Press.

Helicopter Accident Analysis Team (HAAT). (1998). *The final report of the Helicopter Accident Analysis Team*. Retrieved from http://www.ihst.org/portals/54/industry_reports/HAAT-FinalReport.pdf

Issenberg, S.B., Mcgaghie, W., Petrusa, E., Gordon, D., & Scalese, R. (2005). Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review. *Medical Teacher, 27*(1), 10–28.

Joint Aviation Authorities. (2007). *JAR-OPS 3: Commercial Air Transportation (Helicopters).* Englewood, CO: Global Engineering Documents.

Kanki, B., & Helmreich, R. (2010). *Why CRM? Empirical and theoretical bases of human factors training.* In, Kanki, B., Helmreich, R., & Anca, J. (Eds.), Crew resource management. Academic Press. Oxford, UK.

Keinan, G. (1988). Training for dangerous task performance: The effects of expectations and feedback. *Journal of Applied Social Psychology, 18*(4), 355–373.

Kemper, P.F., van Dyck, C., Wagner, C., & de Bruijne, M. (2014). Implementation of crew resource management: A qualitative study in 3 intensive care units. *Journal of Patient Safety, 00*(00), 1–9.

Kemper, P.E., van Dyck, C., Wagner, C., Wouda, L., & de Bruijne, M. (2014). Barriers and facilitators for taking action after classroom-based crew resource management training at three ICUs. *Joint Commission Journal on Quality and Patient Safety, 40*(7), 311–318.

Mann, S., Marcus, R., & Sachs, B. (2006). Lessons from the cockpit: How team training can reduce errors on L&D. *Contemporary OB/GYN*, *51*(1), 34.

Meurling, L., Hedman, L., Sandahl, C., Felländer-Tsai, L., & Wallin, C.J. (2013). Systematic simulation-based team training in a Swedish intensive care unit: A diverse response among critical care professions. *BMJ Quality & Safety*, *22*(6), 485–494.

Moon, W. C., Yoo, K. E., & Choi, Y. C. (2011). Air traffic volume and air traffic control human errors. *Journal of Transportation Technologies*, *1*, 47–53.

Morey, J., Simon, R., Jay, G., Wears, R., Salisbury, M., Dukes, K., & Berns, S. (2002). Error reduction and performance improvement in the emergency department through formal teamwork training; Evaluation results of the MedTeams project. *Health Services Research Journal*, *37*(6), 1153–1581.

Morgan, L., Pickering, S.P., Hadi, M., Robertson, E., New, S., Griffin, D., Collins, G., Rivero-Arias, O., Catchpole, K., & McCulloch, P. (2015). A combined teamwork training and work standardization intervention in operating theatres: Controlled interrupted time series study. *BMJ Quality & Safety*, *24*(2), 111–119.

Mosier, K. (1991). *Expert decision-making strategies.* Paper presented at International Symposium on Aviation Psychology: 6th, April 29–May 2, 1991: Columbus, OH.

Musson, D. (2009). Putting behavioural markers to work: Developing and evaluating safety training in healthcare settings. In, Flin, R., & Mitchell, L. (Eds.), *Safer surgery: Analysing behaviour in the operating theatr*e. Ashgate. Farnham, UK.

National Transportation Safety Board. (1972). *Eastern Air Lines, Inc., L-1011, N310EA, Miami, Florida, December 29, 1972*. Aircraft Accident Report AAR-73-14. Washington, DC: NTSB.

National Transportation Safety Board. (2006). *Aviation special investigation report: Special Investigation Report on Emergency Medical Services Operations*. NTSB/SIR-06/01. Washington, DC: NTSB.

National Transportation Safety Board (2009). *Four safety recommendation letters concerning helicopter emergency medical services*. Public Meeting of September 1, 2009. Retrieved from http://www.ntsb.gov/news/events/Pages/109.aspx

National Transportation Safety Board. (2013). *Crash following loss of engine power due to fuel exhaustion, Air Methods Corporation, Eurocopter AS350 B2, N352LN, Near Mosby, Missouri, August 26, 2011*. Aircraft Accident Report AAR-13/02. Washington, DC: NTSB.

National Transportation Safety Board. (2015). *Safety Recommendation A-13-015*. Washington, DC: NTSB. Retrieved from http://www.ntsb.gov/investigations/AccidentReports/_layouts/ntsb.recsearch/Recommendation.aspx?Rec=A-13-015

O'Dea, A., O'Connor, P., & Keogh, I. (2014). A meta-analysis of the effectiveness of crew resource management training in acute care domains. *Postgraduate Medical Journal, 90*(1070), 699–708.

Orasanu, J., & Salas, E. (1993). Team decision making in complex environments. In, Klein, G., Orasanu, J., Calderwood, R., & Zsambok, C. E. (Eds.), *Decision making in action: Models and methods* (327–345). Norwood, NJ: Ablex.

Orasanu, J. M. (2010). Flight crew decision-making. In, Kanki, B., Helmreich, R., & Anca, J. (Eds.), *Crew resource management*. Academic Press. Oxford, UK.

Pietsch, U., & Lischke, V. (2014). Medical simulation training of helicopter-supported mountain rescue situations. *AirRescue, 4,* 16–19.

Pronovost, P., Berenholtz, S., Dorman, T., Lipsett, P., Simmonds, T., & Haraden, C. (2003). Improving communication in the ICU using daily goals. *Journal of Critical Care, 18*(2), 71–75.

Rall, M., Reddersen, S., Stricker, E., Zieger, J., Dieckmann, P., & Conrad, G. (2006). Evaluation of a mobile "in-situ" simulation training course for teams (paramedics and doctors) in wing-based emergency air rescue and intensive care using subjective pre-post competency ratings. *Simulation in Healthcare, 1*(2), 140.

Reason, J. (2008). *The human contribution: Unsafe acts, accidents and heroic recoveries.* Burlington, VT: Ashgate.

Royal Aeronautical Society. (2009). *Crew Resource Management: A paper by the CRM standing group of the Royal Aeronautical Society*. Retrieved from http://www.skybrary.aero/bookshelf/books/232.pdf

Salas, E., DiazGranados, D., Klein, C., Burke, C. S., Stagl, K. C., Goodwin, G. F., & Halpin, S. M. (2008). Does team training improve team performance? A meta–analysis. *Human Factors, 50*(6), 903–933. doi:10.1518/001872008X375009

Sandahl, C., Gustafsson, H., Wallin, C., Meurling, L., Øvretveit, J., Brommels, M., & Hansson, J. (2013). Simulation team training for improved teamwork in an intensive care unit. *International Journal of Health Care Quality Assurance, 26*(2), 174 – 188.

Schenkel, S. (2000). Promoting patient safety and preventing medical error in emergency departments. *Academic Emergency Medicine*, *7*(11), 1204–1222.

Sculli, G., Fore, A., Neily, J. Mills, P., & Sine, D. (2011). The case for training veterans administration frontline nurses in crew resource management. *Journal of Nursing Administration, 41*(12), 524–530.

Sexton, J. B., Makary, M., Tersigni, A., Pryor, D., Hendrich, A., Thomas, E.,…& Pronovost, P. (2006). Teamwork in the operating room: Frontline perspectives among hospitals and operating room personnel. *Anesthesiology, 105,* 877–884.

Sexton, J. B., Thomas, E. J., & Helmreich, R. L. (2000). Error, stress, and teamwork in medicine and aviation: Cross sectional surveys. *BMJ, 320*, 745–749.

Shapiro, M. J., Morey, J. C., Small, S. D., Langford, V., Kaylor, C., J., Jagminas, L.,… Jay, G.D. (2004). Simulation based teamwork training for emergency department staff: Does it improve clinical team performance when added to an existing didactic teamwork curriculum? *Quality & Safety in Health Care, 13*, 417–421.

Smith, R. (1979). *NASA technical memorandum 78482: A simulator study of the interaction of pilot workload with errors, vigilance, and decisions*. NASA Ames Research Center, Moffett Field, CA.

Sweeney, L., Warren, O., Gardner, L., Rojek, A., & Lindquist, D. G. (2014). A simulation-based training program improves emergency department staff communication. *American Journal of Medical Quality, 29*(2), 115–123.

U.S. Government Accountability Office. (2009). *Testimony before the subcommittee on aviation, committee on transportation and infrastructure, house of representatives: Aviation safety – Potential strategies to address air ambulance safety concerns* (Publication No. GAO-090627T). Retrieved from http://www.gao.gov/new.items/d09627t.pdf

Wagener, F., & Ison, D. (2014). Crew resource management application in commercial aviation. *Journal of Aviation Technology and Engineering*, *3*(2), 2–13.

Weaver, S., Rosen, M., DiazGranados, D., Lazzara, E., Lyons, R., Salas, …& King, H. (2010). Does teamwork improve performance in the operating room? A multi-level evaluation. *The Joint Commission Journal on Quality and Patient Safety, 36*(3), 133–142.

Yang, J.H., Cowden, B.T., Kennedy, Q., Schramm, H., & Sullivan, J. (2013). Pilot perception and confidence of location during a simulated helicopter navigation task. *Aviation Space Environment Medicine, 84*(9), 952–960.

Young-Xu, Y., Fore, A.M., Metcalf, A., Payne, K., Neily, J., & Sculli, G.L. (2013). Using crew resource management and a 'read-and-do checklist' to reduce failure-to-rescue events on a step-down unit. *The American Journal of Nursing*, *113*(9), 51–57.