CREW RESOURCE MANAGEMENT AND MISSION PERFORMANCE DURING MH-53J COMBAT MISSION TRAINING

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ABSTRACT

Empirical research is confirming that crew resource management (CRM) should be an integral part of tactical aircrew training. This study evaluated the link between CRM and mission performance for 16 MH-53J rotorcraft aircrews during preparation and execution of a complex combat scenario in a networked training simulation. A strong correlation of .84 was obtained between CRM and mission performance. All CRM categories (e.g., mission evaluation, risk management, situation awareness) were highly correlated with mission performance; however, the categories were differentially predictive of mission performance in the various mission phases (communication was the best predictor in mission preparation, task management in infil/exfil, tactics employment in low-level). This study extends the findings of earlier research with MC-130P aircrews, where comparable CRM-mission performance correlations were obtained. Despite differences in the missions, flight profiles, and capabilities of the two aircraft, a number of key CRM behaviors emerged as common across the two weapon systems. As an example, the best crews in both aircraft immediately identified threats while enroute and classified them as "planned" or "unplanned." There were also some notable differences between the two weapon systems. One example is that the nature of communication among the crewmembers differed, with the MH-53J crews exhibiting more general, crew-wide interaction, while communication within the larger MC-130P crew centered around pairs of crewmembers communicating specific information at specific times. A major implication of this body of research is that a core behavior-based tactical CRM curriculum can be tailored to reflect the tactics and unique demands of each individual weapon system. The networked training mission afforded an excellent opportunity to observe important coordination and communication activities within the larger tactical team context. The results underscore the importance of broader team coordination and the need to formally train these team skills.

ABOUT THE AUTHORS

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INTRODUCTION

This paper describes a study that examined the relationship between crew resource management (CRM) and tactical mission performance during a networked simulated mission conducted as part of MH-53J simulator refresher training. The work was performed at the 58th Special Operations Wing (58 SOW) at Kirtland AFB, NM, by the Warfighter Training Research Division of the Air Force Research Laboratory (AFRL). The objectives of this study were to: (a) determine whether CRM proficiency is predictive of tactical mission performance for the MH-53J; (b) identify key CRM behaviors and elements of mission performance that characterize effective MH-53J aircrews; and (c) determine to what degree and in what fashion the MH-53J CRM-mission performance relationship differs from that for fixed-wing weapon systems. Identifying, specific CRM behaviors and mission performance elements is critical for developing a behavior-based CRM program for tactical aircrew training. It is also necessary to determine the extent to which effective CRM differs from one platform to another, and thus to what degree a tactical training CRM curriculum must be tailored to meet the unique needs of a specific weapon system.

CRM in Tactical Weapon Systems

Over the last 20 years, CRM has been emphasized in both civil and military aircrew training (Prince & Salas, 1993). Considerable effort has been spent in identifying the relevant components of CRM and developing CRM training programs (Salas, Prince, Bowers, Stout, Oser, and Cannon-Bowers, 1999; Spiker, Tourville, Silverman, & Nullmeyer, 1996). A behavior-based and data-driven approach has begun to pay major dividends for military tactical aircrew training. Specific CRM behaviors relevant to an individual weapon system are identified, measured, and correlated with mission performance (Spiker, Silverman, Tourville, & Nullmeyer, 1998). When identified at this detailed, measurable level, CRM behaviors have been shown to consistently predict mission performance.

In a study with MC-130P aircrews, AFRL researchers at Kirtland AFB found a strong, positive correlation between CRM behaviors and mission performance (Silverman, Spiker, Tourville, and Nullmeyer, 1997a). The behaviorally-based approach to CRM taken in the MC-130P study has now been applied to two other weapon systems—the MH-53J and the C-5 (Spiker, Tourville, Bragger, Dowdy, & Nullmeyer; 1999). These studies utilized a similar methodology to that employed by Povenmire, Rockway, Bunecke, and Patton (1989), who found a direct relationship between CRM and mission performance in B-52 aircrews. Thornton, Kaempf, Zeller, and McAnulty (1992) also demonstrated correlations between aspects of CRM-related communication and objective performance measures in the UH-60 Army helicopter.

Crews who receive mission-specific CRM training, focusing on key skills and behaviors, should evidence improved mission performance. A new Air Force Instruction (AFI) 11-290, "Cockpit/Crew Resource Management Training Program" (1998), has taken steps to ensure these concepts and approach are incorporated into USAF training operations. The AFI stipulates that "CRM knowledge and skill objectives will be tailored to fit the unique characteristics of each primary mission" (AFI 11-290, 1998, p. 5).

MH-53J Mission Operations

The MH-53J Pave Low III is a modified heavy-lift, twin-engine, air refuelable helicopter. The MH-53J can penetrate enemy territory at low altitude under the cover of darkness and/or adverse weather. The primary mission of the MH-53J is to search, locate, deliver, and recover personnel and equipment in all environments. Insertion/extraction (known as infiltration/exfiltration or infil/exfil) is the most important mission of the Pave Low, and is the mission tasking in the observed training scenario. The crew for the MH-53J consists of two pilots, the aircraft commander (AC) and copilot (CP), two flight engineers (FEs), and two gunner-scanners. The pilots and one FE sit in the cockpit. The other crewmembers are "back-seaters" and operate the guns; they also serve as scanners, and act as an extra set of "eyes" to the pilot, augmenting the limited out-the-window view. (For further discussion of MH-53J capabilities and mission, see Spiker & Nullmeyer, 1995.)

Rotorcraft CRM

Helicopter tactical missions present some unique challenges. The rotorcraft mission will be contrasted with that of tactical fixed-wing aircraft, specifically the MC-130P, and implications for CRM will be discussed. Helicopter crews fly at very low altitudes (100' and lower), which imposes very high workload for navigation and electronic warfare. Terrain and threat avoidance, flight path control, and object avoidance become critical factors. Additionally, rotorcraft missions are intimately linked with ground operations and must account for many additional factors in their mission planning. The MH-53J weapon system mission is extremely busy and crews are task-saturated from beginning to end.

As a result of the high workload imposed by navigating at low altitudes, the two pilots in a helicopter have distinctly different roles and must work cooperatively. The pilot flying (usually the AC in our study) must maintain situational awareness outside of the cockpit at all times to fly the aircraft and clear obstacles. The pilot not flying must maintain awareness of the aircraft's ground track, providing verbal directions to the pilot flying about heading, altitude, airspeed, flight path, and relevant terrain features (Hart, 1988), as well as keeping track of threat locations and capabilities and operating the radios. In short, the second pilot is a critical and active crewmember for the helicopter mission. His primary function is not just to back up the other pilot.

The size and composition of the MC-130P and MH-53J crews are also very different. The MC-130P has a much larger and more specialized crew. In addition to two pilots and an FE, there are two navigators, one of whom is also an electronic warfare specialist, and a communications specialist. In the MH-53J, the pilots and FEs must shoulder a larger burden during planning and individual crewmembers do not have the luxury of specializing and focusing on only one aspect of the mission. The Pave Low cockpit crew must be aware of each other's duties, and continuously cross-check each other throughout the mission.

The MH-53J operates in extremely stressful, lethal, dynamic environments, while flying very low and operating under high-workload conditions. This reduces the time the crew has to respond to unexpected events and requires anticipating and preplanning responses to all potential outcomes. Mission planning becomes an even greater factor. In a study with UH-60s, Thornton et al. (1992) found that navigation accuracy was related to quality of planning. Crews who performed well also anticipated upcoming terrain cues and events, and prioritized tasks. Anecdotal reports also suggested that crews who used the available flight time *during the mission* to review their plan performed better on an instrument approach.

These unique aspects of conducting a rotorcraft tactical mission should be reflected in the specific CRM behaviors observed with the MH-53J and in the detailed pattern of results—which aspects of CRM are the best mission performance predictors and which mission phases show the strongest CRM-mission performance relationship? Mission planning should be crucial as well as ongoing mission evaluation. Factors relating to interaction within the team environment should also prove to be an important determinant of effective rotorcraft CRM.

METHOD

Participants

Sixteen active-duty MH-53J aircrews were observed as they participated in a mission-oriented simulator training (MOST) scenario during their week-long annual refresher training at the 58 SOW. The MH-53J weapon system trainer (WST) does not have stations for the gunner/scanners, thus they are not included in refresher training or in this study. The training crew consisted of the AC, CP, and FE. A second FE in some cases participated in the training by observing from a seat in the back of the simulator, and sometimes swapped with the first FE in the middle of the mission. In all cases, only the FE in the front seat was rated by the observers. In the majority of the crews, both pilots were qualified ACs. These crews decided which pilot would act as the AC. There was no restriction on which pilot flew which portion or how much of the mission, so the two pilots often switched off and flew different mission phases. An instructor was present in the WST throughout the training mission.

WST and Networked Training Environment

The MH-53J WST is a motion-based, six–degree–of–freedom, high–fidelity representation of the MH-53J cockpit stations for the AC, CP, and one FE. The cockpit instruments and out-the-window displays are night vision goggle (NVG)–compatible. Instructor stations located at the rear of the WST allow control and monitoring. One of the most important and unique features of this simulation environment is its full electronic warfare simulation capability.

This training session is a networked simulation. Multiple team players prepare for and fly the mission together (Spiker, Tourville, & Nullmeyer, 1997). The MH-53J WST is networked with an MC-130P WST and an HH-60G WST. Additionally, an aerial gunner/ scanner simulator, a head-mounted virtual reality training device, can be networked to support "backenders" for either the MH-53J or HH-60G (Silverman, Spiker, & Nullmeyer, 1996). The network is controlled by a training director, and live role players (e.g., airborne command, control, and communication [ABCCC], ground assault team commander, downed fighter pilot, transload aircraft) communicate with all participants. The scenario is controlled through the training observation center (TOC). It is a multi-media auditorium, where observers can simultaneously view the out-the-window scenes (simulated NVG) and cockpit video from the three WSTs, and a map display showing the various players and simulated threats. All communications can be monitored from the TOC, as well as intercom transmissions in the MH-53J. Data collection for this study occurred in the TOC.

Mission Scenario

MH-53J crews are tasked to fly an NVG low-level route as formation lead with the HH-60G. They fly to a pre-planned air refueling point, conduct refueling operations with the MC-130P, and then penetrate deep into hostile territory to a POW compound where they insert a Special Forces team. The MH-53J provides air cover and fire support while the team secures the compound; it then extracts the team and POWs. After leaving the compound, they fly to a transload site to transfer and evacuate the POWs. Along the way, the MH-53J encounters numerous threats, poor visibility, difficult terrain, numerous malfunctions, enemy fire, and severe aircraft damage. Because of damage and malfunctions, the crew must abandon and destroy the aircraft at the transload airfield. For purposes of the analysis, the mission has been divided into five mission phases: (a) Mission Preparation (MP), (b) Low-Level (LL), (c) Air Refueling (AR), (d) Infil/Exfil (IE), and (e) Recovery and Transload (TL).

In the scenario, the HH-60G flies as formation wingman to the MH-53J, performs a simultaneous refueling, and assists the MH-53J on the infil/exfil. Immediately following the exfil, the HH-60G is given a search–and–rescue tasking to pick up a downed pilot. The MC-130P refuels the helicopters and then crosses into enemy territory to airdrop a reconnaissance-reception team at the transload airfield.

Data Collection Instruments

Separate instruments were used to collect CRM and mission performance data.

CRM Worksheet. The MH-53J CRM instrument is organized around the five mission phases. For each phase, the worksheet is divided into seven CRM categories, with three specific, observable elements per category. Six of the CRM categories were taken from AFI 11-290 (1998): situation awareness (SA); crew coordination/flight integrity (CC); command, control, and communication (C3); risk management/decision making (RM); task management (TM); and mission evaluation (ME). A seventh category, tactics employment (TE), was added to address the specific tactical nature of the MH-53J mission. Table 1 gives the definitions of the CRM categories.

The elements under each CRM category are specific questions, tailored to the MH-53J tactical mission. Figure 1 shows the three CRM elements comprising the TM category in the IE phase. The space in the right-hand column is for the observer to describe specific behaviors and make any other comments associated with that CRM element. The observer assigns a 1 to 5–point rating (1 = needs improvement, 2 = adequate, 3 = standard, 4 = very good, 5 = outstanding) for each crewmember and for the crew as a whole in each category. Overall ratings are assigned for each crew

Table 1. CRM Category Definitions

CRM Category	Core Definition
Situational Awareness (SA)	Knowledge and skill objectives to prevent the loss of SA, skills for recognizing the loss of SA, and techniques for recovering from the loss of SA
Crew Coordination/ Flight Integrity (CC)	Knowledge and skill objectives covering impact on aircrew performance of command authority, leadership, responsibility, assertiveness, conflict resolution, hazardous attitudes, behavioral styles, legitimate avenues of dissent, and team-building
Command-Control-Communication (C3)	Knowledge of errors, cultural influences, barriers (rank, age, experience, position). Skills encompass listening, feedback, precision and efficiency of communication with all members and agencies (i.e., crewmembers, wingmen, weather, ATC, intelligence)
Risk Management/ Decision Making (RM)	Includes risk assessment, the risk management process, tools, breakdowns in judgment and discipline, problem-solving, evaluation of hazards, and control measures
Task Management (TM)	Includes establishing priorities, overload, underload, complacency, management of automation, available resources, checklist discipline, and standard operating procedures
Mission Evaluation (ME)	Includes pre-mission analysis and planning; briefings; ongoing mission evaluation, and post mission debrief; specific tools and techniques to be used in operational and training missions
Tactics Employment (TE)	Includes those analytic activities designed to avoid or minimize threat detection or exposure, and to successfully complete complex mission events and multiple objectives using sound tactical management procedures.

Task Management (TM)	AC 1 2 3 4 5	CP 1 2 3 4 5	FE 1 2 3 4 5	Overall Crew 1 2 3 4 5
Is a ***task distribution*** process for executing the planned IE profile communicated & acknowledged by CMs? (e.g., Tasks are evenly distributed and prioritized; CMs assume unique or nonstandard responsibilities during the IE.)	Y N			
Do CMs employ a particular ***method of working together*** to fly the IE profile? (e.g., They cross-check each other's efforts, divide the workload based on functional area, use personal execution checklists, cheat sheets, guides, etc.)	Y N			
Does the crew work to ***ensure the (timely) completion*** of their required tactical ***procedures*** **during the IE phase**? (e.g., in-flight checklists or procedural items are accelerated.)	Y N			

Figure 1. CRM Worksheet, Task Management Segment, Infil/Exfil Phase.

position for the seven different CRM categories; crew CRM ratings are assigned for each CRM category and each mission phase. Finally, a single overall crew CRM rating is determined.

Mission Performance. A six-page instrument was developed for use by a separate observer to rate mission performance and provide the rationale for the ratings. Specific, ratable mission performance elements were included for each phase; there are 5-7 elements for each phase, for a total of 31 mission performance elements. One of the elements from the LL phase is depicted in Figure 2. Some of the elements (e.g., aircraft handling, checklist proficiency, external communication) appear in several mission phases; others (e.g., fuel plan, navigation accuracy) appear in only one phase. These elements were identified through detailed front-end analysis, and were customized for the MH-53J mission and the specific mission phase. The observer rates each element; these ratings then are aggregated into mission phase ratings, and finally into an overall mission rating. Mission performance is rated at the crew-level only; no mission performance ratings were provided on individual crewmembers. A 5-point rating scale (1 = poor, 2 = marginal, 3 = standard, 4 = very good, 5 = exceptional) is used throughout. Very specific behavioral anchors provided a structure for the ratings of each mission performance element. These anchors illustrate characteristics of a "typical" 1, 2, 3, 4, or 5 rating. They allow for the collection of much more objective, reliable rating data.

Instrument Validation. A detailed front-end analysis was performed to develop the two rating instruments. This included extensive discussions with instructors and other subject-matter experts (SMEs), observations of multiple training sessions, and trial runs followed by iterative revision of the instruments. Item reliability was assessed by having two observers (in addition to the two primary observers) independently rate multiple sessions. One person rated CRM using the CRM worksheet; the other rated mission performance with that instrument. Both of these raters were SMEs. The CRM rater was a retired USAF Special Operations helicopter pilot and wing commander; the mission performance rater was a fixed-wing navigator and instructor.

Interrater reliability for both the CRM instrument and the mission performance instrument was quite high. For the overall mission performance ratings, based upon seven observed training missions, the correlation between the two independent raters was .98. Interrater reliability for the CRM worksheet was .97 when actual simulation sessions were rated (N = 3), and .85 when videotaped sessions were included (N = 6). Correlations for both instruments exceeded .80, generally considered the benchmark for acceptable interrater reliability (Cronbach, 1990).

Low Level					1	2	3	4	5	not observed
Threat Avoidance – *avoidance of LOC & population, terrain masking, identification, reaction, minimize time exposure*					1	2	3	4	5	not observed
Instructor Intervention					1	2	3	4	5	
1 = little or no consideration of threats, too much time exposure to multiple threats, mission success compromised	2 = some use of terrain to mask threats; no response to new threats; LOCs crossed; pop. centers flown over; too much time exposure	3 = route based on known threats & terrain; some avoidance of LOCs, pop. centers, new threats	4 = threat capabilities considered to determine terrain masking, minimal threat exposure	5 = excellent route following and replanning based on new threats, minimal threat exposure, avoided LOCs & pop. centers						
Rationale:										

Figure 2. Sample Performance Element from the MH-53J Mission Performance Rating Instrument.

Procedure

The primary CRM data collector was an experienced MC-130P instructor navigator. The primary mission performance data were collected independently by a second researcher using the mission performance instrument. The two observers did not discuss the mission or their ratings during the mission or afterwards until each had finalized his or her ratings. The results presented in the remainder of this paper reflect the ratings of these two primary data collectors only.

Instructors, the training director, and role players were aware of the study and agreed not to intervene or alter their typical activities because of our presence. Although the instructors attempted to maintain some degree of consistency across simulation sessions, there was a great deal of variability in weather, threats, malfunctions, etc. encountered by the different crews, as is typical of refresher training.

Each data collection session began with the mission briefing followed by an MP session. Trainees were told that the observers were "conducting training research for AFRL," with no explicit mention of CRM. This explanation invariably sufficed. After asking each crewmember for his overall flight and MH-53J experience and whether he had participated in the same scenario before, the two observers sat unobtrusively in the back of the room and observed the crews perform their MP activities. The two researchers observed the MP period and any crew briefings immediately prior to the simulation. During the simulation session, the observers sat in the TOC where they could observe the out-the-window scenes and listen to all radio communications as well as intercom transmissions in the MH-53J. Following the 4-hr simulator session, the observers accompanied the crew and instructor to a briefing room to observe their debrief session.

Statistical Testing Considerations

Rating data from both the primary CRM data collector and the primary mission performance data collector were summarized and subjected to statistical tests of significance. The main statistical analyses reported in the results section are based on Pearson product moment correlations. All tests use the crew as the unit of analysis, with 14 degrees of freedom (df = N-2, N = 16). The 16 crews observed for this study comprise 16% of the total population of approximately 100 MH-53J crews. Because this is a substantial proportion of the relatively small total population, we can use a finite population correction coefficient (Winkler & Hays, 1975). The correction coefficient decreases the observed sample variance, resulting in lower critical t values required to achieve significance. In this instance, the critical t values have been reduced by 10%, reflecting a 1.1 finite-population multiplier.

Since the initial test of overall CRM and mission performance is purely *a priori*, it was two-tailed, adjusted only for the finite population. Following the initial test of our primary hypothesis, we further explored the data to investigate which CRM variables (e.g., mission phase or CRM category) were good predictors of mission performance. Conducting numerous exploratory statistical tests inflates the experiment-wise alpha level, increasing the probability of a Type-I error. To correct for this, a Bonferroni adjustment was applied, dividing the desired experiment-wise (EW) alpha level by the number of tests performed (Harris, 1994). Since we planned to test approximately 50 correlations for statistical significance, a nominal alpha level of .001 was adopted to achieve an experiment-wise alpha level of .05 (.05/50 = .001). Accounting for both the finite population correction and the Bonferroni adjustment, our correlations must reach a critical r value of .67 to achieve statistical significance at the $p_{EW} < .05$ level. These exploratory tests are one-tailed. Given the initial positive overall correlation of CRM and mission performance, our hypothesis is that the variables will be related in a positive fashion (higher CRM should equate with better mission performance).

RESULTS

Overall CRM-Mission Performance Correlations

Pearson product moment correlations were calculated between the ratings of crew-level CRM and mission performance. Overall CRM and overall mission performance showed a very strong, statistically significant positive correlation (r = .84, df = 14, p < .001, 2-tailed test). This correlation is comparable to that found in the MC-130P study (r = .86). Figure 3 depicts the relationship between overall CRM and tactical mission performance for the 16 crews we observed. The dashed lines bisecting the two rating scales reflect the basic level of behavior expected (neither notably strong nor weak) for CRM and mission performance. As illustrated in the scatterplot, the vast majority of the crews fall in either the upper right quadrant (good CRM and good mission performance) or the lower left (poor CRM and poor mission performance). Only three fall in the other two quadrants.

Confirming our primary hypothesis in this fashion gives us "permission" to probe the data further for more specific relations in the data structure (Harris, 1994).

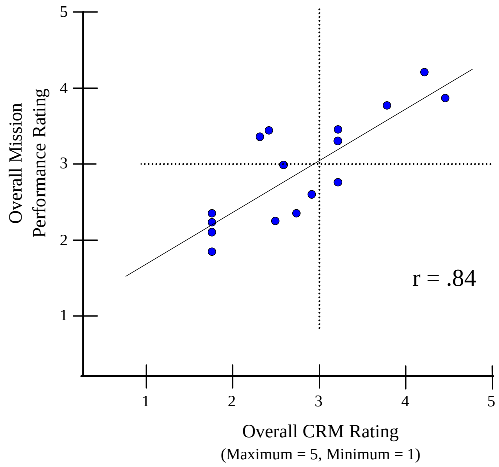

Figure 3. Scatterplot of Overall CRM and Mission Performance Ratings

Correlations were calculated for phase-specific CRM and overall mission performance in each mission phase (MP, LL, AR, IE, and TL). CRM was positively correlated with overall mission performance for all phases of the mission; the correlations were significant with the exception of LL (r = .60) and AR (r = .54). The highest CRM-mission performance correlation was found in the TL phase (r = .84), followed by IE (r = .80), and MP (r = .74). AR in the MH-53J is a "textbook" operation, requiring individual skills such as aircraft handling and fuel management. AR tends to be highly constrained in this networked simulation, with little room for creativity. LL combines the period prior to the AR with the more difficult terrain-following flight through hostile territory. It is therefore a less well-defined phase, and there are no discrete events to be accomplished during the LL period. Events in the TL phase are the least predictable for the crew, and thus the final phase requires creative problem-solving and good CRM. IE is a very workload-intensive phase, where all crewmembers must work closely with each other and with the larger tactical team. MP provides the greatest opportunity for interaction and information sharing, and because there is less time pressure, crews can engage in extensive CRM activities.

Mission Preparation

In the earlier MC-130P study, a strong relationship was found between the quality of mission planning and subsequent performance during mission execution (Spiker et al., 1998). The quality of MP was a powerful determinant for the MH-53J, even though crews had limited time for MP and were simply reviewing a prepared packet with a pre-planned, "canned" mission. MP CRM significantly predicted subsequent performance during *mission execution* (the final four phases of the mission) (r= .69, $p_{EW} < .05$). An even better predictor of mission execution performance was the *time spent planning the mission* (r = .76, $p_{EW} < .05$). The three best crews, who consistently obtained higher CRM and mission performance ratings, spent 3-4.5 hr preparing for the mission. MP time for other crews ranged from 10 min-2.5 hr. This objective, independent measure of MP serves to validate the CRM ratings.

Crew Position and CRM

Although we know that crew-level CRM is important to mission performance, there is no indication in the crew-level ratings of the relative importance of individual crewmember CRM. To make this determination, correlations were calculated between CRM ratings for the three crew positions and overall crew mission performance. The strongest correlation was for the CP (r = .86), followed by the AC (r = .78), with FE CRM producing consistently lower correlations (r = .49). The higher correlations with the CP's CRM mirror the results of the earlier MC-130P study (Silverman, Spiker, Tourville, & Nullmeyer, 1997b), except that the left navigator (not a crew position in the MH-53J) played a significant role in the MC-130P as well. In a parallel study with C-5 crews, Spiker et al. (1999), found that CRM was more strongly associated with crew mission performance for the FE than for either of the pilots. A possible explanation of the finding in the present study is that there is more variability in the capabilities of the CPs among MH-53J crews (the CPs ranged from a brand-new mission qualification graduate to a squadron commander), and "strong" CPs added significantly to the CRM capabilities of the crew. As discussed earlier, in helicopters, the pilot-not-flying (usually the CP) plays a critical role, navigating and scanning the instruments.

The relative strength of the CRM-mission performance correlation across crew positions was maintained throughout all phases with the exception of IE. During IE, the AC's CRM took precedence over the CP's. The IE phase was high-workload and required very precise timing, handling, and crew/team coordination; in most cases, the AC became very directive during this phase, with other crewmembers feeding him information.

Leadership

An important observation from the MC-130P study (Spiker et al., 1998) was that the most successful crews all had a strong leader who "weaves all crewmembers into a cohesive unit." Traditional interpretations of CRM have focused more on creating an atmosphere of information sharing, rather than on leadership per se (Ginnett, 1993). In the current study, we generated a 5-

point “leadership index” for each crew (1 = no leader much of the time; 2 = no leader or weak/default in 3/5 phases, or other CMs do not defer to leader; 3 = leader in 3/5 phases, 4 = leader in 4-5 phases, perhaps not commanding, can be different crewmembers; 5 = appropriate leader throughout, no question). This leadership index produced a significant, strong positive correlation with overall crew CRM ($r = .72$, $p_{EW} < .05$). The three most effective crews all had a very strong leader. The five least effective crews had no leader. In six of the eight crews that had a leader, it was the AC. In one crew, the FE served as a default leader; in another the CP leader was a squadron commander. The remaining eight crews had no clear leader.

Relative Contributions of CRM Components

Table 2 depicts the correlations of the seven CRM category ratings with mission performance. The row of Table 2 labeled “Overall” presents the correlations between the seven individual CRM category ratings and overall mission performance ratings (across all mission phases). All seven categories produced positive, statistically significant correlations with overall mission performance. The individual CRM category that produced the strongest correlation with overall mission performance was ME, and the weakest (but still significant) was TM. Interestingly, C3, which did not correlate with mission performance in the MC-130P study, was highly correlated in this study.

The bottom five rows of Table 2 present the correlations between the CRM category ratings for each mission phase and mission performance for that phase. While ME was most strongly correlated with overall mission performance, it was not the most influential category in any of the individual phases. C3 was most highly correlated with MP performance, TE in LL and AR, TM in IE, and SA in TL. Although many of the CRM categories are highly correlated with mission phase performance, the relative influence of the CRM categories varies across mission phases. It is clear from Table 2 that different CRM categories vary in relative importance, and which category takes precedence depends on the specific mission phase. To determine the specific aspects of CRM that are important in each mission phase, it is necessary to examine the individual CRM behaviors that crews exhibited during that phase (see the section entitled “Key CRM Behaviors”).

Characteristics of Good Mission Performance

The correlations presented in the preceding sections establish a positive, statistically significant relationship between CRM and mission performance. We will now focus on patterns within the mission performance ratings to better understand the aspects of mission performance that characterize the most effective crews. The mission performance data were analyzed to determine which specific performance elements were most predictive of overall mission performance ratings. Correlations were calculated between the individual mission performance element ratings in each mission phase and overall mission performance. If the correlation for a given element exceeded the critical r value ($r = .67$), that performance element was considered “predictive.” This method was used for descriptive purposes only and is not considered an inferential test of statistical significance. Table 3 lists the predictive performance elements for each mission phase. The first column lists the mission phases. Performance elements that were strongly correlated with overall mission performance are listed in the second column, with the most highly correlated elements listed first. If an element did not achieve the $r = .67$ critical value, it is not included in Table 3. Not surprisingly, given the consistently low correlations in the AR phase, no individual elements were highly correlated for AR.

Having determined the important mission performance elements, we then examined the comment data from the crews who received the highest ratings for those elements. The third column in Table 3 summarizes the positive aspects of mission performance for the best crews. Note that this is a composite of several crews’ mission performance (see Thompson, in preparation).

Table 2. CRM Categories Correlated with Mission Performance

Mission Phase	CRM Categories						
	ME	TM	SA	CC	C3	RM	TE
Overall	.87*	.68*	.85*	.81*	.78*	.81*	.76*
MP	.84*	.61	.80*	.73*	.85*	.84*	.83*
LL	.43	.68*	.50	.47	.58	.62	.71*
AR	.48	.34	.49	.46	.49	.24	.51
IE	.68*	.74*	.62	.66	.62	.67*	.66
TL	.74*	.47	.77*	.66	.56	.69*	.59

*$p_{EW} < .05$, $p_{NOM} < .001$, critical $r = .67$; Bonferroni adjustment assuming 50 tests; one-tailed tests

Table 3. Predictive Mission Performance Elements and Descriptions of Effective MH-53J Crews

Phase	Predictive Mission Performance Elements	Description of Top Crews' Mission Performance
MP	Tactics Plan	Detailed plan (comm, bullseye, threats, SEAD requests, infil/exfil, transload). Detailed examination of maps, imagery, FRAG. Printed new maps, individualized FRAG. Coordinated tactics with HH-60G.
	Flight Plan	Detailed review of threats, terrain, weather, timing. Checked waypoints, revised route plan, custom map.
	Preplanning	Previewed materials, requested additional materials. Extensive discussion, all crewmembers participated.
	Contingency Plan	Extensive what-iffing, coordinated with other team members. Created back-up plans, supplemented plans.
LL	Threat Avoidance	Flew low altitude, used terrain masking, altered flight path to avoid known threats. Avoided roads, wires, population centers. Coordinated with –60 when threat detected. No unnecessary intercom chatter.
AR	None	
IE	Event Accomplishment	Accomp. infil, fire support, exfil quickly and effectively, minimal threat exposure. No instructor assistance
	Exfil LZ Profile	Chose LZ & approach to meet tactical demands. Fast response to call for exfil, minimal time on ground.
	Threat Avoidance	Took out towers, avoided known threats, wires, pop centers. Stayed low, reacted quickly to ground fire.
	Aircraft Handling	Steady, accurate approach, hover, circling, landing, and exit.
TL	Egress Response	Decision to destroy aircraft made quickly. Detailed plan for transload, egress, and aircraft destruction.
	Threat Avoidance	Flew planned route, stayed low. Avoided threats, wires, pop. centers. Responded to ground fire and threats.
	Damage Response	Identified and assessed malfunctions, damage, and injuries, and responded quickly and appropriately.

Examination of Table 3 provides some interesting insights into how the successful crews performed. First, some of the elements traditionally associated with good mission performance are conspicuous in their absence. Formal briefings and checklists did not correlate highly with mission performance. External communication was also fairly low in the list of predictive mission performance elements. This, surprisingly, is not a result of consistently high mission performance ratings across all crews. Most crews (including some of the higher rated crews) did not provide formal briefings, and many did not complete checklists as cleanly as one might expect or prefer to see. More informal aspects of discussion, coordination, and attention to detail are embedded within the important mission performance elements. This underscores some of the differences between this type of tactical mission and the traditional commercial airline environment. The MH-53J tactical environment is very fluid and requires fast and creative responses rather than specific procedures.

Elements that were most predictive of overall mission performance ratings were threat avoidance, tactical planning, and IE event accomplishment. These are the most challenging aspects of the MH-53J mission, and thus become the discriminators between good and average or poor mission performance. The best crews did extensive and very detailed tactical and route planning, and coordinated more details with other members of the their tactical team. They were "ahead" of the aircraft throughout the flight, and were able to call upon backup plans they had generated during mission preparation.

Key CRM Behaviors

Finally, we analyzed the CRM behaviors exhibited by the most successful crews. A content analysis was performed on the comments made by the observer for each data element in the CRM worksheet, for the crews demonstrating the best CRM. The top three crews were selected, as they received high CRM ratings across all mission phases; comments were also included from crews who received high CRM ratings in individual mission phases. CRM behaviors were extracted from these best crews for the seven CRM categories in each of the five mission phases, focusing on the CRM categories that were significantly correlated with each mission phase (see Table 2). Table 4 summarizes the notable CRM behaviors identified in the content analysis. Space prevents a comprehensive listing of the CRM behaviors. For a detailed listing, see Thompson (in preparation).

As we found in the MC-130P study, there are identifiable, concrete CRM behaviors that characterize the most effective MH-53J crews. One of the most distinguishing aspects of the best crews was that they interacted more with the tactical team as a whole. Better crews did their mission planning in conjunction with other tactical team members (HH-60G and MC-130P crews, Intel, ground assault team commander), and there was extensive coordination regarding dissimilar tactical capabilities of the different aircraft and practices between the MH-53J Special Operations and HH-60 Search and Rescue aircrews. During mission execution, the same theme of acting in the broader "team" context is carried through. Crewmembers were aware of the

Table 4. Sample CRM Behaviors Exhibited by Top MH-53J Crews

CRM Cat.	CRM Behaviors—Mission Preparation
ME	Create extra charts and maps, individualized mission execution plan
TM	All crew members develop macro plan; individuals perform position-specific duties
SA	Prioritize infil as #1, develop other requirements to meet primary objective
CC	Obvious leader, usually the AC, in most cases -53 leader is also team leader
C3	Include all team members, extensive coordination of dissimilar procedures
RM	Extensive what-iffing of every detail from beginning to end; each step chair-flown to identify problems, options, alternatives
TE	Coordinate with -60 and -130 about aircraft tactical capabilities and mission requirements
	CRM Behaviors—Mission Execution
ME	Review/brief planned profile/expected series of events prior to starting each phase; continuous systems advisories by FE, SA advisories by CP
TM	Task distribution established at mission brief, execute as planned; efficient use of slow periods (status reports, checklists, replanning, updates, etc.)
SA	Aware of other operations/comm traffic, utilize relevant information; AC verbalizes "big picture" overview
CC	Clearly defined leader, but with active full-crew participation
C3	Disciplined interphone communications; coordinate with outside tactical team members
RM	Identify and verbalize risks; minimize impact of actions on mission accomplishment
TE	Running evaluation of expected threats vs. current indications; query HH-60 about threat indications; use HH-60 for fire support

"big picture," monitored other aspects of the mission, coordinated actions with team members as appropriate, and utilized team assets to ensure mission success.

CONCLUSIONS

This study supports the notion that there is a strong, positive relationship between CRM and tactical mission performance. Taken together with other studies on different weapon systems (Povenmire et al., 1989; Silverman et al., 1997a; Spiker et al., 1999), this study provides confirming evidence that: (a) CRM is intimately linked with mission performance; and (b) there are identifiable, specific CRM skills and behaviors that represent "good" CRM for any given weapon system. Presumably, the specific CRM behaviors can be taught as part of tactical training, and, if included in the curriculum, should lead to improved mission performance. One practical issue concerns delineating CRM behaviors that are common across weapons systems from those unique to the MH-53J. Table 5 presents some of the commonalties and differences between the most effective MH-53J and the MC-130P crews (Spiker et al., 1998, Thompson, in preparation). This list is by no means exhaustive, but illustrates some noteworthy themes.

There are many similarities between CRM behaviors in top performing crews across the two weapon systems. The differences tend to be one of degree in the relative importance of some aspect, rather than a clear differentiation between desirable behavior in the two weapon systems. This might tempt one to conclude that identical tactical CRM training could be employed for the two weapon systems. The fallacy of this assumption is that it disregards not only differences such as those pointed out in Table 5, but also the details of how these concepts are implemented in different weapon systems.

Table 5. Sample Comparisons between CRM in the MC-130 and MH-53J

Similarities	
Created additional maps and charts	
Clearly defined leader	
Consideration of the "big picture"	
Larger "team" perspective	
Tactical planning, coordination with team members	
Duties specifically allocated to individual crewmembers	
Extensive "what-iffing"/backup planning	
Detailed threat analysis	
Running evaluation of threats as planned vs. new	
Focused on mission, little socializing	
Disciplined intercom and radio communications	
No intercom chatter during mission execution	
Differences	
MH-53J	**MC-130P**
Conservative plans with aggressive options	Very aggressive plans
AC as leader	AC or Left Nav as leader
Whole-crew discussions including in flight	Focus on specific info sharing between pairs
Comm significant mission performance predictor	Comm not significantly correlated with performance
Often no formal brief, but detailed discussions	Quality of formal briefings important

As an example, an effective CRM behavior for the MH-53J is, "CP coordinates with scanners to set up guns and use the ramp for special forces team egress/ingress." By the time that comment gets distilled to a level where it would be included in Table 5, it might read, "Coordinates with other team members." While that characterization is not wrong, it loses much of its true content and applicability. This is a problem with training "soft" skills. We end up trying to teach general interpersonal communication skills, rather than the context-specific application of what and when information needs to be communicated to whom.

While one generic CRM course will not meet the needs of all (or even one) individual weapon systems, there is indeed a great deal of commonality between the CRM skills needed in the various weapons systems. A CRM curriculum can be developed for one of these weapons systems, based on a combination of: (a) general principles of CRM; (b) common threads identified across all of the weapon systems evaluated; and finally (c) application of very specific CRM skills identified as relevant to that weapon system and mission. This curriculum can then be used as a prototype and tailored to reflect the tactics and crew composition of other weapon systems. It is not necessary to start over every time a tactical CRM course is developed for a different platform. However, it is important to follow a behavior-based, data-driven approach to tailor the core curriculum to meet the needs of each different aircraft.

A revised "tactical" CRM curriculum for mission qualification training is currently under development for the MC-130P (Tourville, Thompson, Spiker, & Nullmeyer, 1999). That curriculum will eventually be modified for the MH-53J, based upon the data collected in this study, combined with a detailed evaluation of the applicability of the content to the MH-53J. While it is not necessary to collect as much, or as detailed, data on each new weapon system as we have in this study, it is imperative that a comparable approach be applied for identifying key applicable CRM behaviors that predict mission performance in the weapon system of interest.

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