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Report of the Working Group to Identify Future Challenges Faced by the Implementation of Resource Management in Remote and Distributed Teams

Don Harris[1][0000-0002-2113-8848], Wesley Chan[2], Anna Chatzi[3], Hannes Griebel[4], Wen-Chin Li[2], Ting-Ting Lu[5], Pete McCarthy[6], Miwa Nakanishi[7], Tassos Plioutsias[1], and Dimitrios Ziakkas[8]

[1] Coventry University, UK
[2] Cranfield University, UK
[3] University of Limerick, Ireland
[4] CGI Ltd, UK
[5]Civil Aviation University, P.R. China
[6]Cathay Pacific Airways
[7]Keio University, Japan
[8]Purdue University, USA
don.harris@coventry.ac.uk; wesley.chan@cranfield.ac.uk; anna.chatzi@ul,ie; hannes.griebel@cgi.com; wenchin.li@cranfield.ac.uk; 1172362329@qq.com; pete_mccarthy@cathaypacific.com; miwa_nakanishi@ae.keio.ac.jp; ad3903@coventry.ac.uk; dziakkas@purdue.edu

Abstract. Crew Resource Management (CRM) was introduced on the commercial aircraft flight deck to promote pilots acting in a well-coordinated manner. This was a result of several accidents where aircraft with no, or minor technical faults, crashed from a failure to utilize effectively the human resources available on the flight deck. CRM draws upon the disciplines of management science, organizational and social psychology. It originated in civil aviation, but its practices have now been adopted in other high-risk, high-performance industries where staff work in coordinated teams, e.g. Air Traffic Control, surgery, nuclear power operations and shipping. CRM is now facing new challenges to promote effective, coordinated teamwork. Teams are often now distributed across many locations but are still required to coordinate their activities in real time. CRM now must evolve to support the actions of remote and distributed teams. At the 2023 HCI International Conference in Copenhagen, a working group formed from subject matter experts to identify application areas and describe the key challenges faced in promoting CRM for remoted and distributed teams both during normal and non-normal operations. This paper describes the workings and initial findings of this working group. The results show that process areas, such as such as promoting Team Situation Awareness, workload management, coordination, and monitoring of the cognitive and affective states of others are more important for developing remote and distributed team CRM than are addressing the limitations imposed by the underpinning technology.

Keywords: Crew Resource Management, Remote Teams, Distributed Teams.

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1 Introduction

Crew Resource Management (CRM) is ubiquitous in the aviation industry. Although having its origins on the flight deck, CRM now permeates all aspects of airline operations [1]. The CRM concept evolved following several accidents where the principal cause was attributed as a failure to utilize all the human resources available on the flight deck appropriately, and in particular on accident-involved flights where there was also no major preceding technical failure. CRM-type practices are now commonplace in other high-risk industries which require teamwork, such as medicine [2–4]; nuclear power plant operations [5, 6]; the fire services [7]; Air Traffic Control [8] and shipping [9].

CRM is based upon the disciplines of applied social psychology and management science. Several authors have suggested that in aviation, CRM has progressed through several distinct eras [10]. In its first instantiation, as Cockpit (not Crew) Resource Management, it focused on improving the management style of just Captains. Emphasis was on improving communication, attitudes and leadership. By third generation CRM, the concept extended across the airline as a whole and by fourth generation its principles were being absorbed into all aspects of training and the development of procedures. In the following generation it was suggested that the CRM philosophy had instigated organizational culture changes, emphasizing that error is pervasive because humans are fundamentally fallible, especially when under stress; emphasis was placed on managing error rather than attempting to eliminate it entirely. MacLeod [11] however, argues that these generation apply only to the evolution of CRM in the USA and not elsewhere in the world. CRM practices are instructed in both the classroom and in the simulator and form an essential part of pilot non-technical training.

IATA [12] and ICAO [13] describe CRM in terms of a set of individual and team-related non-technical skills relating to observable descriptions of the knowledge, skills, abilities and personal attributes supporting effective crew performance [14]. These are defined by the job requirements for safe, effective and efficient operations, formulated using evidence collected from accidents, incidents, operations and training (Evidence Based Training - EBT). Mastery of these core CRM competencies are assumed to be effective countermeasures to error and underpin the ability to manage unsafe events.

ICAO [13] defines eight core non-technical skill competencies: Application of Procedures (APK); Communication (COM); Aircraft Flight Path Management using automation (FPA); Manual Aircraft Flight Path Management (FPM); Leadership and Teamwork (LTW); Problem Solving and Decision Making (PSD); Situation Awareness (SAW) and Workload Management (WLM). IATA [14] added a further competence: Knowledge (KNO). Mansikka et al., [15] undertook a principal components analysis of CRM performance scores and extracted four factors, which when incorporated into a path analysis described CRM as an input–process–output (IPO) model of team performance. This was further developed into CRM-DyMo (CRM Dynamic Model) [16, 17] integrating this model of CRM with threats identified during Line Oriented Safety Audits using the Threat and Error Management framework [18]. CRM DyMo demonstrated how performance in one competency was affected by performance in other competencies and illustrated the link between CRM and operational threats.

Distributed teams are not new and are relatively commonplace in many modern operations, for example military C4ISTAR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) involves many networked assets in a distributed team. Airline Operational Control Centers functions include scheduling of aircraft; management of passenger and cargo loads; meteorological support; real-time monitoring of engineering data (often with embedded engineers from the manufacturers); aviation support for in-flight re-routing, and coordination of ground-based resources at the destination airports, etc. It can be argued that distributed teamwork has its roots in Computer Supported Collaborative/Cooperative Work from the 1980s and 90s [19, 20].

Perhaps the most famous example of a remote and distributed team was during the Apollo missions, and in particular the recovery of Apollo 13 after its in-flight emergency during its transit to the moon [21]. In more recent years, operational circumstances have effectively created remote and distributed teams even when all members are contained within a small physical distance. The advent of locked cockpit doors subsequent to the terrorist attacks of 9/11 and the advent of large modern aircraft (e.g. the Airbus A380) where crew members may be separated across two separate floors, create circumstances where flight deck and cabin crews operate as remote and distributed teams even when they are physically on the same aircraft.

However, with increasing interconnectivity and high-speed data links, remote and distributed teams are now becoming more common. Ad hoc teams may also be formed for short periods of time to perform specific tasks (e.g. coordination of multiple agencies during disaster relief). However, such remote and distributed teams pose special problems in terms of the dynamic management of their teamwork.

The working group was tasked to describe the key future scientific and operational challenges for the effective implementation of CRM in remote and distributed teams and identify current and future application areas.

1.1 Overview of Approach

In July 2023 a Working Group was established at the HCI International conference to identify the research and development challenges for remote and distributed CRM. Work progressed in two phases. Phase One identified implementation challenges for CRM in remote and distributed teams and associated target application areas. Phase Two prioritised these challenges.

Working Group members comprised subject matter experts who attended 2023 HCI International in Copenhagen, Denmark and who also participated as Board Members in the Engineering Psychology and Cognitive Ergonomics Conference.

2 Phase One

2.1 Method

In Phase One, Working Group members were asked to make e-mail submissions to address two issues:

- Describe the three main challenges for remote and distributed CRM with a short justification for each issue suggested, and
- To identify the main application areas for remote and distributed CRM both currently and projected areas for its future application.

2.2 Results

Challenges. Working Group members responses describing the main challenges for remote and distributed CRM were collated and grouped into six overarching categories. These were:

- **Link Quality:** Latency and sound/vision quality. For this application area are these important to permit communication, coordination and decision making, etc.?
- **Reduced Interaction Quality**: Modality may be limited to sight/sound/maybe and maybe in advanced cases, haptic interactions.
- **Team Situation Awareness**: Does everyone need to be on the same page all the time or do team members mainly need to be aware of their local responsibilities?
- **Recognition of others cognitive and affective states** (non-verbal/poor interpersonal cues): If human interaction relies on non-verbal cues, how important is it if these are missing or degraded).
- **Coordination**: Leadership and Followership behaviors
- **Teambuilding**: Including team/work culture, speed of team formation and attitudes to remote partners. Teams may have to form quickly for specific purposes and may operate only for relatively short periods.
- **Learning and Training**: Opportunities, effectiveness and appropriateness of the medium.

Application Areas. Seven current and prospective areas for remote and distributed CRM were identified. These were:

- Space operations
- Motor sports
- Aviation (single crew, multi crew and across operational aspects)
- Air Traffic Control
- Telemedicine (including healthcare and surgery)
- Multi-agency search and rescue (including disaster relief)
- Complex military operations

2.3 Discussion

Several of the challenges identified were similar in nature to those for normal CRM, however for remote and distributed CRM they pose particular challenges. These challenges were in part a result of the technological limitations identified, the quality of the data links and reduced quality of interactions (restricted to sound, limited visual field and which may also involve some latency).

Communication and coordination are central to the success of CRM. Communication is closely linked with interpersonal trust, as it is the basis for efficient communication [22, 23]. Building trust is an active process, inspired and promoted within the team. The challenge that remote teams face is to build on their teamwork trust by keeping their team cohesion and members' familiarity at a high level [23, 24]. Remote CRM needs to work when certain non-verbal interpersonal cues are missing. Sharing certain types of data (e.g. a piece of paper) and physical experiences is difficult through remote connections. Communication drives CRM and promotes coordination but this depends very much on the nature and extent of communication [25]. Kanki & Palmer [26] described five ways that communication facilitates CRM. It provides information; establishes interpersonal relations; promotes predictable behavior patterns; maintains crews' attention on the task and is a management tool. These are challenging issues for remote and distributed teams working with limited link quality.

Adopting an Input-Process-Output approach, Team Situation Awareness (TSA) is one of the key processes for promoting CRM. However, the relationship between communication and TSA is complex. Many studies have found that increasing levels of communication promote coordination, Situation Awareness (SA) and decision making [27–30]. However other investigations have observed the opposite. During air combat it was observed that an increased rate of communication was related to decreases in TSA: it was symptomatic of a flight trying to regain SA [31]. TSA was initially predicated upon a common mental model held by all team members developed during air combat training. It was not developed during the engagement itself. In a similar manner, in civil aviation Orasanu & Fisher [32] observed that high performing crews used the low workload flight phases to plan ahead and discuss options but during an emergency they communicated less.

This begins to demonstrate the role of training in general (not just that in non-technical skills) in the development of CRM. It makes a case for the implementation of CRM concepts across all aspects of training (cf. fourth generation CRM [10]. Learning and training was identified as a particular challenge for remote and distributed teams and will be a particular issue for multinational teams and/or those formed on an ad hoc basis to address a particular issue (e.g. military operations or disaster relief). Training, including group training, prior to operations may serve to negate some of the technology limitations identified (link and interaction quality) by providing an underpinning mental model upon which to build [31]. Leadership and followership behaviors are also developed during such training. These are in place before the operational implementation of CRM.

Most of the target application areas identified are of little surprise. Multi-national military and disaster relief operations are relatively commonplace (but still pose challenges). Telemedicine is also a rapidly developing area [33] but in this context it is perhaps the capability to undertake robotic surgery, where several of the surgical team are remote from the nursing staff, anesthetists and perfusionists, where remote and distributed CRM becomes of greater importance.

With the potential for extended duration space missions using multiple components (e.g. Artemis: NASA 2020) and the potential introduction of single crew commercial aircraft in the mid-2030s [34] there will be increasing impetus to develop remote and

distributed CRM concepts in the Aerospace sector. Even with two crew on the flight deck, in emergency and abnormal situations pilots can easily end up task saturated, and remote assistance would offer the potential to reduce workload [35].

Motor racing, and in particular Formula One, provides a new application area and challenge. Teams are distributed along the pit wall, pit garages and back at team operating bases, monitoring the performance of the cars and the race context, and making real time strategic and tactical decisions under time pressure and with data links placing priority on data flows. Although not high jeopardy risk operations, Formula One is a very fast-paced, highly dynamic application of CRM with high data loads, so is particularly challenging.

3 Phase Two

3.1 Method

In a subsequent phase, Working Group members were asked to evaluate the importance of each of the challenges identified for remote and distributed CRM in each of the application areas. Ratings were completed as a matrix using an Excel spreadsheet emailed out to all members (see Tables 1 and 2).

Ratings used a five-point Likert-type scale running from a Very Important (challenge for developing remote and distributed CRM in this application area); through Important; a neutral OK rating; Not Really Important; and finally, Not at all Important (challenge for remote and distributed CRM in this application area).

Ratings were required for each application area in two general scenarios: during normal operations and during non-normal/emergency operations ('emergency' situations were not regarded as applicable for areas such as motor sports).

Subject matter experts were asked to be as discriminatory as possible when making their ratings.

3.2 Results and Discussion

Both Table 1 (normal) and 2 (non-normal/emergency) show that 'teambuilding' was only rated as being an important concept in aviation and complex military/disaster relief operations. In all other application areas it is likely that teams had already formed and may have spent time training and operating together in person before operating in a remote and distributed manner (the exception, to some extent, potentially being telemedicine). It was only in aviation and military operations where ad hoc teams would be rapidly formed. In contrast, learning and training for CRM in remote and distributed teams was seen as being of utmost importance for normal and non-normal/emergency operations. As previously suggested, prior team training could enhance team familiarity and trust, with the potential to circumvent some of the communication shortcomings imposed by the data bandwidth, promoting the basis for TSA and decision making [31]. It is unlikely remote connections will ever be 100% reliable so remote and distributed CRM practices need to be robust enough to survive a certain level of deterioration or break-down in link quality and potentially with communication latencies (e.g. space

operations). However, perhaps surprisingly, overall link and interaction quality were not as highly rated as may initially be expected (particularly during normal operations) suggesting that CRM was not highly dependent on the quality of the link but was more dependent on the nature of the exchanges using the link.

Table 1. Modal values describing the importance of each challenge for remote and distributed CRM for the application areas identified during normal operations.

	Space operations	Motor sports	Aviation (Single crew, multi crew and across operational aspects)	Air Traffic Control	Telemedicine (incl. Healthcare)	Multi-Agency Search and Rescue (incl. Disaster Relief)	Complex Military Operations	
Team Situation Awareness	Very Important	Important	Very Important	Very Important	Important	Very Important	Important	
Link quality	Important	OK	Important	Very Important	Very Important	Important	OK	
Reduced Interaction Quality	Important	Not Really Important	Important	Not Really Important	Very Important	OK	Very Important	
Recognition of others cognitive and affective states	Very Important	Not Really Important	Important	Important	OK	Important	OK	
Coordination	Very Important	OK	Very Important	Very Important	Very Important	Very Important	Very Important	
Teambuilding	Not At All Important	Not Really Important	Important	Not Really Important	OK	Not Really Important	Very Important	
Learning and training	Very Important	Very Important	Very Important	Very Important	Very Important	Very Important	Very Important	

In contrast, coordination was seen as a very important challenge both in normal and in abnormal operating conditions (see Tables 1 and 2). Only in motorsport applications was it not regarded as being very important. Coordination is a product of team management and leadership [12, 13, 36] but is also dependent upon personnel adopting a followership role, as required. Establishing leadership and followership roles will be more difficult in distributed teams, particularly those formed quickly on an ad hoc basis, and may also require cultural sensitivity when operating in multi-national teams [37, 38] or in cross-profession teams with diverging levels of loyalty to the organization or other team members [39, 40].

Table 2. Modal values describing the importance of each challenge for remote and distributed CRM for the application areas identified during non-normal operations.

	Space operations	Motor sports	Aviation (Single crew, multi crew and across operational aspects)	Air Traffic Control	Telemedicine (incl. Healthcare)	Multi-Agency Search and Rescue (incl. Disaster Relief)	Complex Military Operations
Team Situation Awareness	Very Important	Important	Very Important	Very Important	Important	Very Important	Important
Link quality	Very Important	OK	Very Important	Very Important	Very Important	Important	Important
Reduced Interaction Quality	Important	Not Really Important	Important	Important	Very Important	OK	Very Important
Recognition of others cognitive and affective states	Very Important	Not Really Important	Very Important	Important	Very Important	Important	OK
Coordination	Very Important	Not Really Important	Very Important	Very Important	Very Important	Very Important	Very Important
Teambuilding	Not At All Important	Not At All Important	Not Really Important	Not Really Important	Important	Not Really Important	Very Important
Learning and training	Very Important	Very Important	Very Important	Very Important	Very Important	Very Important	Very Important

The inability to 'read' body language as a result of interactions being based solely upon limited visual and auditory channels may provide particular challenges. Follower behavior is also more difficult to establish than leader behaviors.

Recognizing the affective state of personnel was regarded as extremely important in normal space operations, where crews are very isolated and confined [41]. Space station crews may be in orbit for six-eight months. Managing both workload and morale are important for safe and efficient operations. Long duration missions to Mars will also be subject to degraded communication quality, with real-time, two-way communication becoming impossible as a result of transmission delays. Link quality is also likely to be quite poor, with just basic data flows. Support from ground-based elements to manage any non-normal situations will also become increasingly difficult with distance from the Earth. The impact simply of the remoteness of air vehicles, spacecraft or submersibles, and its influence on the relationships between the human operators (together or dispersed) will be an area requiring further attention in the future.

Looking across other application areas, sensitivity to affective and cognitive states of other personnel tends to increase in importance with the longevity of the team. However, being aware of the cognitive status of other team members increases in importance

in non-normal/emergency situations, and in particular being sensitive to the management of workload [42, 43]. While remote team members do not have the immediate sense of shared fate (or incentive) imparted by being in the same submersible, aircraft or spacecraft as the other team members, this may be advantageous as a result of lowered stress and arousal levels.

The motorsports application area was notable in that it received few important ratings. Most CRM areas were regarded as unimportant. This is not to say that they are not challenging or vital for efficient and effective operations. What these ratings probably reflect is the low level of jeopardy risk to participants.

4 Conclusions

Opinion would suggest that the technological underpinnings supporting remote and distributed teams seem to be less important in developing effective CRM than the process areas, such as TSA, workload management, coordination, and monitoring of the cognitive and affective states of others. Teambuilding would not seem to be such a high priority, especially in application areas where teams may have had the opportunity to train face-to-face, gaining familiarity and building trust, before operating in a dispersed manner. Learning and training may be the key area to develop, providing the basis for operating effective distributed teams by promoting strategies and procedures to develop CRM in these types of operation.

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