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A Survey of Time-Sensitive, Cross-Organizational Team Collaboration Research for Application to Aviation Crisis Management

Abstract

Because of pressing needs in the US aviation security community to collaborate effectively and quickly across organizations and time-zones, we surveyed the literature pertaining to synchronous, non-collocated, cross-organizational, time-sensitive collaboration for crisis management (especially if the crises occur in the context of the aviation domain). We examined the theoretical constructs that researchers have proposed for collaborative systems and determined that several of these, such as common ground and awareness theory, have particular applicability to our research context. We surveyed collaboration models that were developed to provide frameworks for understanding the multiple facets of technological support to group work. Because teams normally need to come to a common understanding of the situation and the relevant decisions, we examined research in team awareness, sensemaking and decision-making. Types of group tasks affect technology use and adoption, so we considered the literature surrounding these topics, as well, before turning to case studies of new collaboration technologies and current aviation collaboration state-of-the-practice. We end with the findings most relevant to developing new aviation security collaboration approaches, including procedures, needed functionality, and candidate capabilities.

1. Introduction

Today's air transportation system is not expected to be able to handle the anticipated growth in air traffic demand and complexity. Numbers of aircraft are increasing along with their diversity, bringing Unmanned Aircraft Systems, Very Light Jets and similar "unscheduled" operations into an already complex system. The increasing number and types of aircraft and their unpredictable schedules also bring new challenges to aviation security.

The aviation security mission has two primary objectives: prevent and (if not prevented) counter attacks on air vehicles as well to prevent attempts to use aircraft as weapons. Assessing risk, detecting and communicating threats, identifying and implementing mitigation strategies, executing joint responses, and recovering from security incidents are the key actions of airspace security.

Today's aviation security procedures bypass most of collaboration technologies to emphasize use of the telephone for cross-organizational collaboration. Further, current security procedures give all potential threats equal priority, rather than differentiating them based on risk. Presently the airspace security function primarily involves visually identifying potential threats, with the need to respond in a only handful of minutes. As air traffic grows, airspace security operations will no longer be able to rely solely on manual coordination. In contrast, airspace security will require more automation support and flexible collaboration to allow humans to pool resources and focus on the greatest threats.

Our research customers are US Government agencies but we are engaged in questions that have global themes. This aviation security mission is shared by Government and the private sector. The three most prominent US Government stakeholders are the Federal Aviation Administration, the Department of Homeland Security (Transportation Security Administration, US Secret Service, Coast Guard, Customs and Border Protection), and the Department of Defense. Airspace users (flight operators and crew) are the main private sector stakeholders. Although we use the aviation security domain as a way to ground our literature review, the review is pertinent to other domains such as military command and control and nuclear power plant control that require team decision-making in time-sensitive, safety critical situations.

1.1 The Next Generation Air Transportation System

The vision for meeting future air transportation and security challenges in the United States is the Next Generation Air Transportation system (NextGen) Secure Airspace concept, which is part of a multi-layered, adaptive security service. By "multi-layered," we mean that NextGen is being developed based on a seven-layered framework, depicted in figure 1 (from Bolczak and Fong, 2008), that includes integrated risk management, secure airports, secure people, secure checked baggage, secure cargo/mail, secure airspace, and secure aircraft. NextGen will operate in a network-enabled, information-rich environment to provide information from numerous sources to authorized users.

Figure 1. NextGen Layered, Adaptive Security (from Bolczak and Fong, 2008)

Although its purpose and high-level concepts do not differ from the current airspace security operation, NextGen will include an increased emphasis on automation and information to help identify risks. Further, NextGen will implement security measures that are scalable and targeted towards the greatest risks. This includes more flexible airspace restrictions such as risk-based airspace volume extensions as well as flight-specific risk assessment. This flight-specific risk assessment is based on information regarding a particular flight's associated people, cargo/baggage, flight operation, aircraft, and route/trajectory (for more detail see Bolczak and Fong, 2007).

1.2 Collaborating in NextGen

Excuting the aviation security mission requires tightly orchestrated activities from a number of organizations: the FAA, airlines, one or more branches of the military; and/or local, state, and federal emergency responders. Today this coordination occurs via voice over the FAA's audio conference call known as the Domestic Events Network (DEN). Our research focuses on developing a common coordination approach that will include tools and interfaces for each participating organization; and in particular, the training in inter-agency techniques, procedures, and practices for inter-agency decision-making, collaboration, and response coordination. In other words, we aim to develop a blueprint for cross-organizational, non-collocated collaboration to handle aviation security issues in NextGen.

There has been considerable research in areas related to collaboration, and we wished to build upon these previous results. The purpose of this document is to share our review of the literature pertaining to collaboration upon which we are building, particularly collaboration that is, at the same time: synchronous, non-collocated, cross-organizational, time-sensitive, and dealing with crisis management in the aviation domain.

Note that we have not been able to find research that is specific to *all* of these characteristics. Instead, we report on work that addresses various subsets of these characteristics, beginning with a brief summary of the theoretical basis for collaboration and then moving from the abstract to the concrete. After the theory in section 2, we will discuss collaboration models in section 3, and sensemaking, awareness, and team decision-making in section 4. Section 5 discusses use of technology by groups, then research applications to collaboration follows in section 6, before presenting current collaboration state-of-the-practice in the aviation industry in section 7. This paper ends with a summary and implications for research.

2. Summary of collaboration theories

There is no agreement regarding which single theory constitutes the foundation for understanding how participants interact with collaborative computing applications. Consequently, several theories need to be considered, because each theory sheds some light on how groups collectively accomplish tasks with computer mediation. Since there is debate about what constitutes a "theory" when applied to collaborative computing, the term is used here to mean any body of research that resulted in a predictive description of how people will collaborate to accomplish tasks synchronously.

2.1 The theories

Eight theories appear in alphabetical order in the following paragraphs. Their characteristics can be compared in Table 1.

- **Activity theory** (Leont'ev, 1974) grew out of Soviet philosophy of individual action in the 1920s and has been more recently adapted and extended to group activities (Engestrom, 1987; Kuutti, 1996). Activity theory postulates that actions are conscious, goal-directed, dynamic processes mediated by objects and undertaken by individuals or communities in accordance with their rules and division of labor.

- **Workspace awareness** consists of an understanding of other people and their activities in a shared workspace (Gutwin et al., 1995). Benchmarks for workspace awareness (Villegas and Williams, 1997) were developed as an inspection method for evaluating workspace awareness tools, and operate on a set of elements that address users' understanding of others' presence, actions, and intentions within a shared workspace.

- **Common ground** (Clark and Brennan, 1991) in communications is obtained through "grounding," the process by which all participants come to the point where they mutually believe they understand each other well enough to accomplish their current purposes.
- **Coordination theory** (Malone and Crowston, 1990) consists of a body of principles that address how people can work together harmoniously.
- **Distributed cognition** (Flor and Hutchins, 1991) grew out of the cognitive science tradition. It is defined as the representation of knowledge inside the heads of people and the world, the propagation of knowledge between individuals and artifacts, and the transformations of external structures by individuals.
- **The information ecologies metaphor** as applied by (Nardi and O'Day, 1999) asserts that biological ecologies can provide a metaphor for small, information-oriented systems.
- **Situated action models** emphasize "the emergent, contingent nature of human activity, the way activity grows directly out of the particularities of a given situation" (Lave, 1988).
- **Situation awareness** (SA) is an understanding of the state of the environment, and **team SA** is the degree to which each team member possesses the SA required for his or her responsibilities (Endsley, 1995).

2.2 Discussion of theories

Table 1 shows each theory's emphasis as well as the basic unit for analysis and their components; meaning, the smallest-scale portions of a collaborative system whose analysis will yield an assessment of the collaboration. The theories have different emphases; for example, one emphasis is assurance in communication and another is real-time decision making in crisis management systems. The theories also have different levels of granularity; the unit of evaluation may be an activity, an individual's presence, a conversation, or a system of people, practices, values and technologies (to name four examples). Despite these differences, the theories have some commonalities. Components of units of evaluation usually include people (actors, subjects), their activities (practices), and interdependencies (division of labor, mutualities, community). Artifacts (objects) are often included, as are values (also expressed as rules or goals). Aggregations of the analysis units figure prominently in the models described in the next section.

Besides applicability at the level of analysis units, the theories as a whole can inform much of the aviation security work. For example, there is an obvious connection between SA theory and the aviation security domain, since aviation team members will need to understand the state of the environment in order to be able to project what may happen, and plan for that eventuality. Closely related to situation awareness, workspace awareness comes into play because team members need knowledge of their collaborators' activities to avoid duplicating work or dropping important tasks inadvertently because "I thought someone else was doing it." Collaborators also need insight into colleagues' identities and their presence or absence during the collaboration period.

Table 1

Theories Relating to Computer-Mediated Collaboration (adapted from Drury, 2001)

Theory	Basic unit for analysis	Components of basic analysis unit	Emphasis
Activity theory as applied to groups (Kuutti, 1996)	An activity, which is "a form of doing directed to an object that transforms an object into an outcome"	• subject • tool • object(ive) • rules • community • division of labor	Mediation through tools; consciousness (unifies attention, reasoning, speech, etc.)
Benchmarks for workspace awareness (Villegas and Williams, 1997)	An individual's presence, actions, and/or rationale for actions in the shared workspace	• who is in the workspace • what others are doing • where others are working • when changes take place • why others are taking their actions	Understanding the extent to which a collaborative application supports knowledge of others in the shared workspace
Common ground (Clark and Brennan, 1991)	A communication unit, such as a conversation or letter	• clues that participants understand each other • mutual belief that addressees have correctly identified a referent • specialized techniques to ensure understanding of verbatim content	Assurance that a communicative message has been understood as it was intended
Coordination theory (Malone and Crowston, 1990)	A coordination process: a set of actions leading to a coordinated outcome	• actors • goals • activities • interdependencies	Types of interdepen-dence (prerequisite, shared resource, and simultaneous)
Distributed cognition (Flor and Hutchins, 1991)	A cognitive system composed of individuals and the artifacts they use	• people • shared goals • activities • artifacts • representations	Behavior results from the interaction between internal and external representational structures
Information ecologies (Nardi and O'Day, 1999)	An information ecology: "a system of people, practices, values, and technologies in a particular local environment"	• people • practices • values • technologies	"...human activities that are served by technology."
Situated action model (Lave, 1988)	The activity of persons-acting in setting	• people • relation between acting people and arenas (stable institutional frameworks)	Responsiveness to the environment and the improvisational nature of human activity
Team situation awareness (Endsley, 1995)	An individual's SA (team SA is the overlap of SA among team members)	• Perception of elements in current situation • Comprehension of current situation • Projection of future status	Support for making decisions in real-time, safety-critical situations

Common ground theory is especially pertinent to the verbal exchanges of information that will occur in aviation security collaboration. Conversational grounding, which is at the core of common ground theory, works to ensure that all team members correctly understand what each person intended. Such grounding is made harder with non-collocated team members. For example, not using jargon specific to a single collaborator or single organization (van de Ven et al., 2008), and providing video so non-collocated collaborators can see non-verbal cues, improves understanding (Dourish and Bly, 1992; Nardi et al., 1996; Nunes et al., 2006). Repetition of what is heard is no guarantee of understanding intent.

Activity theory, situated action models, and information ecologies all emphasize the importance of understanding what people are doing in the context of their environment. Without doing so, it is easy to miss important subtleties of how people work together and use artifacts and information. When asked to describe their work in interviews, people often do not report on many of their routine activities because they do not consider them noteworthy. "Because the things people do every day become habitual and unconscious, people are usually unable to articulate their work practice. People are conscious of general directions, such as identifying critical problems, and they can say what makes them angry at the system. However, they cannot provide the day-to-day detail about what they are doing to ground designers in what the [work] practice entails and how it might be augmented with technology….Field data overcomes the difficulties in discovering tacit information." (Holtzblatt, 2003, pp. 944 - 945). Thus aviation security collaboration reserach is collecting and analyzing observation data as well as interview data.

Coordination theory emphasizes interdependencies, which will be a big part of aviation security collaboration. By knowing which partners are interdependent, and how they are interdependent, we can recommend and describe ways to facilitate their collaboration. Interdependencies also play a part in distributed cognition (DC), but DC also asks the analyst to examine the interplay between knowledge spelled out in the world for all to see versus knowledge that is in team members' heads. Since aviation security collaboration will involve team members who do not necessarily work together on a regular basis, it may be harder for them to know what everyone else knows; thus, we plan to investigate a mechanism to provide summaries of group knowledge in an explicit, externally-viewable format.

3. Collaboration Models

Consonant with the lack of agreement on the theoretical basis for collaboration, there is no consensus on the best way to develop abstract representations of collaboration processes (that is, models of collaboration). Consequently, there are a number of models, ranging from very general or high level models to models that were developed with one or more types of collaboration in mind. Note that these models aren't necessarily based on any of the theories discussed above (except where noted); they appear to have been developed through their authors' experiences.

3.1 General or high-level collaboration models

Robertson (2008) is evolving a high-level collaboration model that he calls "Three Tiers of Collaboration." Depicted in figure 2, Robertson states that, "each tier builds on the one below, starting with capacity (pre-requisites for collaboration), through capability (strength of collaborative activities and approaches) to strategy (overall focus on collaboration)."

Robertson further notes that "This is a *descriptive model*, that outlines all the elements of collaboration, and it can be used in a variety of ways," such as "the basis for a self-assessment of where collaboration activities are currently focused in the organisation" and "to identify areas of strength and weakness in collaboration strategies." The Capacity level encompasses the aspects of organizational context that are needed for collaboration, the Capability level includes the means of collaborating, and the Strategy level sets the policy for how and why collaboration is intended to occur. Because it is a simple model that purports to encompass all the elements of collaboration, we use it as a point of comparison to the other models presented below.

Corresponding to Robinson's Capacity level, Maybury (2006) models organizational culture in terms of the levels of collaboration that an organization's members practice. Developed as a portion of Maybury's Knowledge Management Capability Maturity Model (Maybury, 2006), the levels of collaboration build upon each other and are, from lowest to highest: awareness, shared information, coordination, joint work, and shared intent. For example, team members operating at the highest level of collaboration maturity may be aware of each others' activities and availabilities, share information via email, coordinate on work plans, jointly execute those plans, and, along the way, grow to have the same goals.

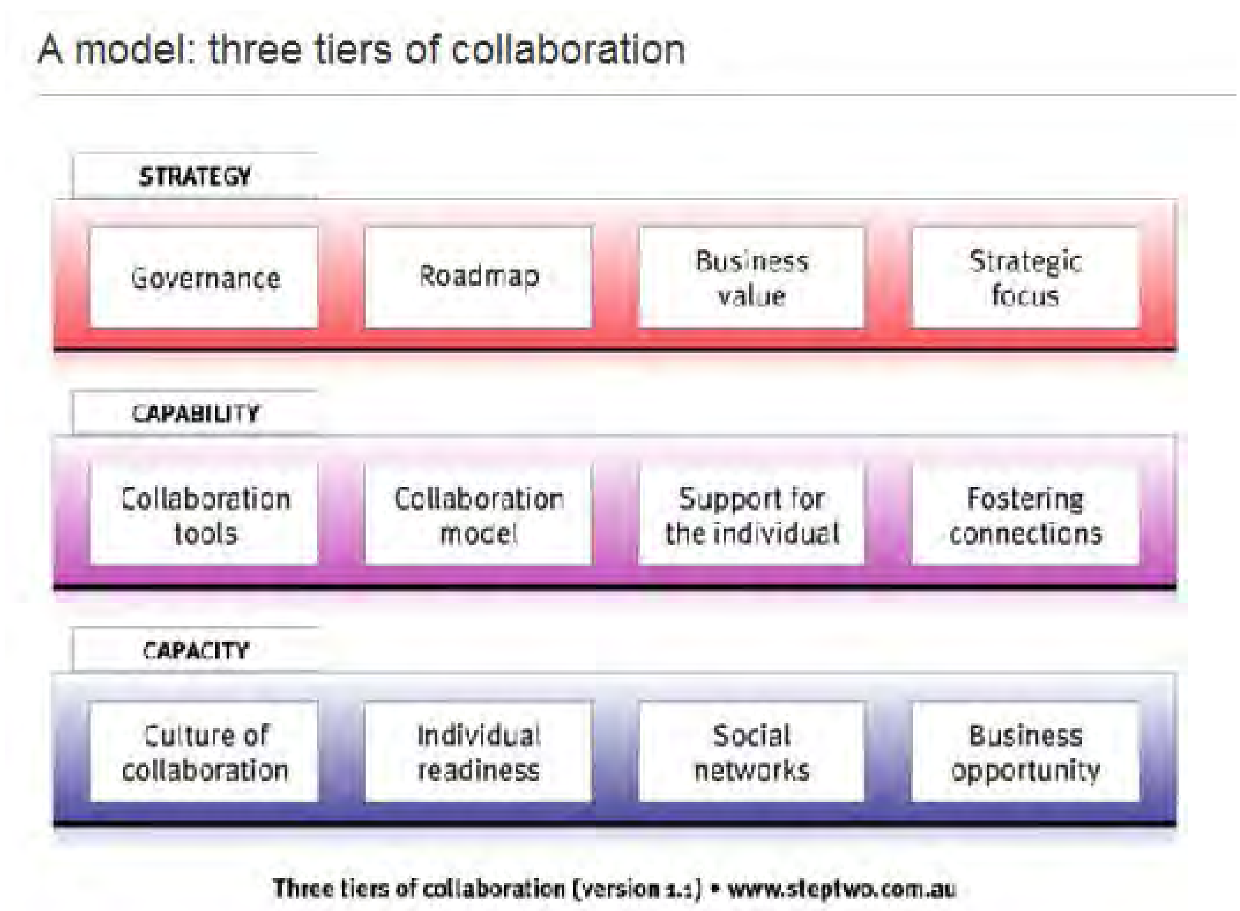

Figure 2. Robertson's Three Tiers of Collaboration

In their Normative Model of Team Performance (see figure 3), Salas et al. (1992) also start with the organizational context (which corresponds to Robertson's Capacity level). Of equal importance to team performance are five further elements: a group design that "facilitates competent group work on the task," "assistance to the group in interacting" (termed "group synergy"), appropriate criteria to evaluate group processes, "group effectiveness", and adequate "material resources" (Salas et al., 1992). These five elements would be categorized by Robertson as belonging in the Capability level. Salas et al.'s model does not include elements from the Strategy level.

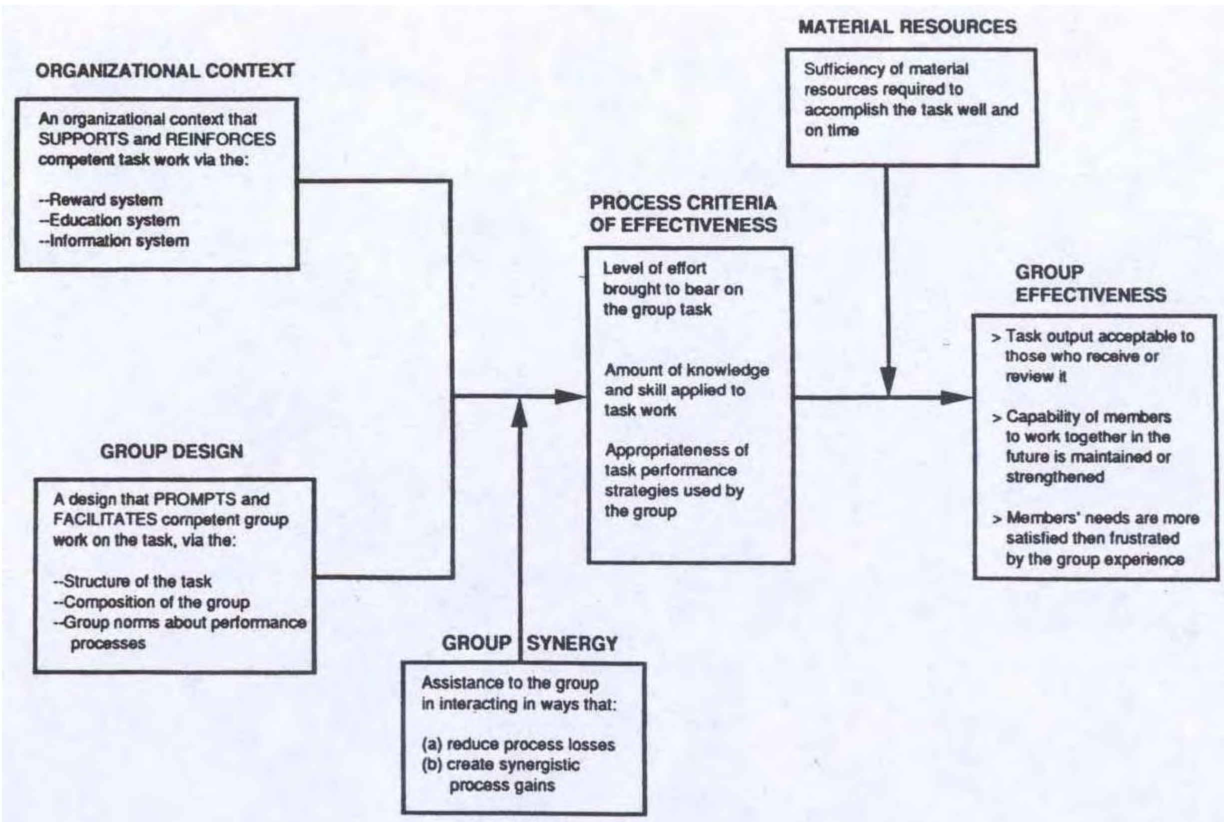

Figure 3. Salas et al.'s Normative Model of Team Performance (adapted from Hackman, 1983)

Warner and his colleagues from the US Navy have developed models of team collaboration that focus on cognitive processes. Figure 4 shows their Structural Model of Team Collaboration (Warner et al., 2005). The authors describe it as follows:

> "The model is a *synthesis* of the literature in team collaboration, human information processing, and team communication together with the results obtained during the 2003 Annual Workshop on Collaboration and Knowledge Management (Letsky, 2004). During the Collaboration and Knowledge Management (CKM) workshop 12 initial conceptual models of team collaboration were produced each providing some unique

information along with overlapping information. The models varied in their approach from information-processing, team recognition primed decision making, transactive memory, discovery and innovation, and hybrids including multi-stage and process models." (Warner et al., 2005).

As described under "problem area characteristics" in figure 4, the model was designed with time-sensitive, safety-critical, military tasks in mind, although the model teams were characterized as acting asynchronously, as opposed to the aviation security partners which need to coordinate their actions synchronously. The model also makes reference to "culturally diverse," distributed teams with heterogeneous knowledge: all characteristics shared with the aviation security domain. Although these problem area characteristics are quite specific, the description of the collaboration stages is very general, as one might expect from a model that strives to find a common denominator among many studies with diverse theoretical underpinnings. The team builds knowledge via individual cognition and information processing, then collaborates on the problem, comes to consensus, evaluates the outcome, and iterates as necessary. This model is similar to the late US Air Force Col. John Boyd's "Observe-Orient-Decide-Act" (OODA) loop (Boyd, 1995). Very little can be seen in the model that is specific to the kinds of military tasks the model was intended to address.

Using the terminology defined by Robertson, the Structural Model of Team Collaboration is almost exclusively situated in the second level ("Capability").

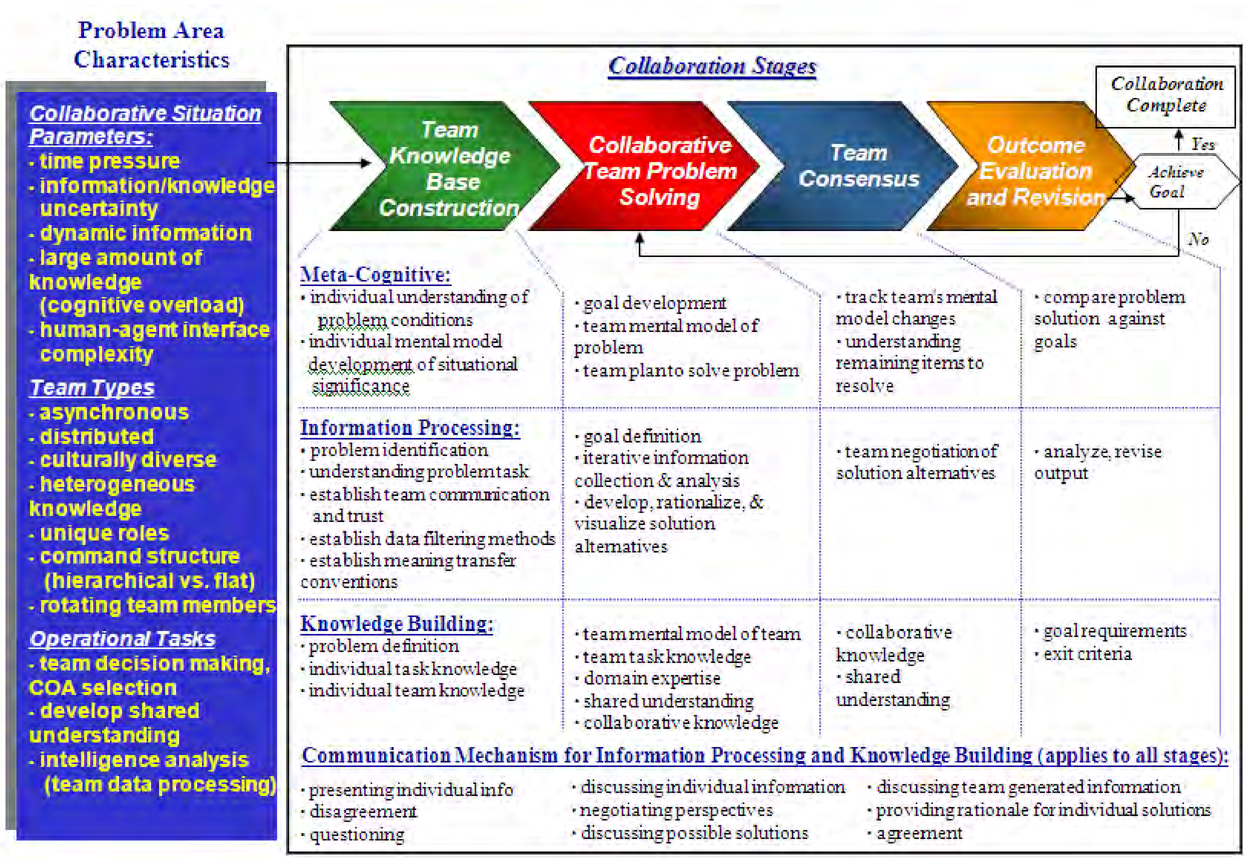

Figure 4. Warner et al.'s Structural Model of Team Collaboration

3.2 Collaboration models developed for more specific situations

Several collaboration-related models are more specialized, although they are still quite general. These models address intra- or cross-organizational collaboration, time-sensitive collaboration, interdependencies, coordination, team situation awareness, and collaboration needs for national emergency response.

Interorganizational information systems (IOIS) models (Hong, 2002 and Chi and Holsapple, 2005) are relevant to the aviation security domain because they were developed with cross-organizational collaboration in mind. For example, IOIS models, primarily developed for the business domain, may be used to illustrate collaboration among retailers and suppliers.

Hong's framework for IOISs, depicted in figure 5, is interesting because it introduces the idea of vertical versus horizontal links across organizations. Vertical systems connect suppliers and sellers with the goal of more efficient marketing. This type of system gives sellers, for example, the capability to place orders quickly but also gives suppliers sales data to help them plan production. Horizontal systems link homogeneous groups of businesses. Partnerships within an industry, often consisting of smaller businesses, benefit from improved access to information. The aviation security domain will likely involve both types of collaboration: collaboration among the airlines or among the same type of state agencies located in different states is horizontal, while collaboration between the airlines, FAA, and military is vertical. Since Hong argues that the two types of linkages require different collaboration mechanisms, approaches, and/or procedures, it may be helpful to keep in mind the distinction between the two linkages when developing collaboration approaches for aviation security.

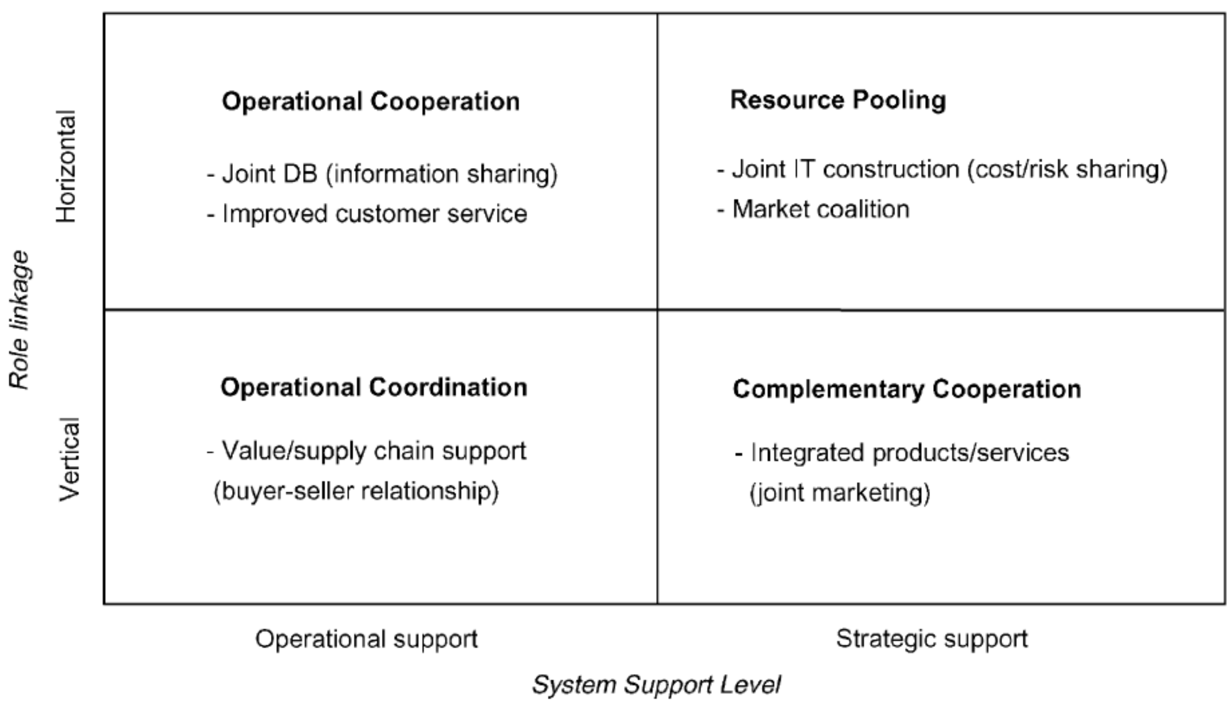

Figure 5. Hong's Framework for Interorganizational Information Systems

While Hong’s framework is very different from Robertson’s model, it can be viewed as being situated in the “Capability” and “Strategy” levels.

Using a slightly different approach for cross-organizational collaboration modeling, Fawcett et al. (2000) documented a “Model Memorandum” for use by “state and community partnerships, support organizations, and grantmakers in working together to build healthier communities.” Fawcett et al. are using the term “model” in the sense of an example, and not in the sense of an abstract description of an entity or process. Specifically, they provide an example memorandum of agreement among collaborating parties. The model was developed to facilitate the process of “community change and improvement” and was developed after performing case studies with more than 20 different community partnerships.

This model takes the form of seven prescriptive steps. It recommends that collaborators identify specific, interrelated roles and responsibilities that they carry out while performing the following actions (Fawcett et al., 2000):

- Set a clear vision and mission
- Develop an action plan for specific changes that are being sought
- Develop and support leadership within communities
- Document the process of change and improvement and use feedback for improvement and celebration
- Secure and provide technical assistance
- Secure and provide financial resources
- Make outcomes matter

Fawcett et al.’s cross-organizational model agreement can inform the aviation security domain via its recommendations for identifying clear roles and making certain critical information explicit, such as a vision and a detailed action plan. It is related to all three of Robertson’s collaboration tiers.

In contrast to Fawcett et al.’s prescriptive approach to modeling, D’Amour et al. (2008) developed a more traditional model of collaboration based on analyzing operations in four perinatal healthcare facilities (figure 6). The purpose of the model is to act as a benchmark against which collaboration practices can be evaluated (perform “a diagnostic of collaboration and implement interventions to intensify it,” according to the authors). Each of the four rounded boxes contains a list of 2 – 4 “indicators” such as “goals”, “centrality”, “leadership”, etc. D’Amour et al. (2008) explains in detail what each of the indicators means. It is sufficiently general to cover most parts of Robertson’s three collaboration tiers.

What is of interest to the aviation security domain is D’Amour et al.’s description of how these indicators can be used to determine the degree of collaboration attained. Collaboration is defined as occurring at three levels, with level 1 being “potential or latent collaboration,” level 2 being “developing collaboration” and level 3 being “active collaboration.” These levels are described in table 1. This table illustrates the difficulties that ad-hoc, cross-organizational, distributed teams will have in climbing to the highest level of collaboration. A virtual operations center for aviation crisis response will likely not have a central governing body nor will it engender frequent opportunities to meet (characteristics of the highest level of collaboration). Instead, these operations centers will likely have strong organizational interests driving their orientations and will work in ad-hoc discussion venues that are related to specific issues (characteristics of the middle level of collaboration). A lot is known about how high-performance collaborative teams work. But how can we optimize performance for an ad-hoc, virtual team when we know that it is likely that they can only attain the characteristics of a mid-level collaborative team? We could not find definitive research in the literature that answers this question.

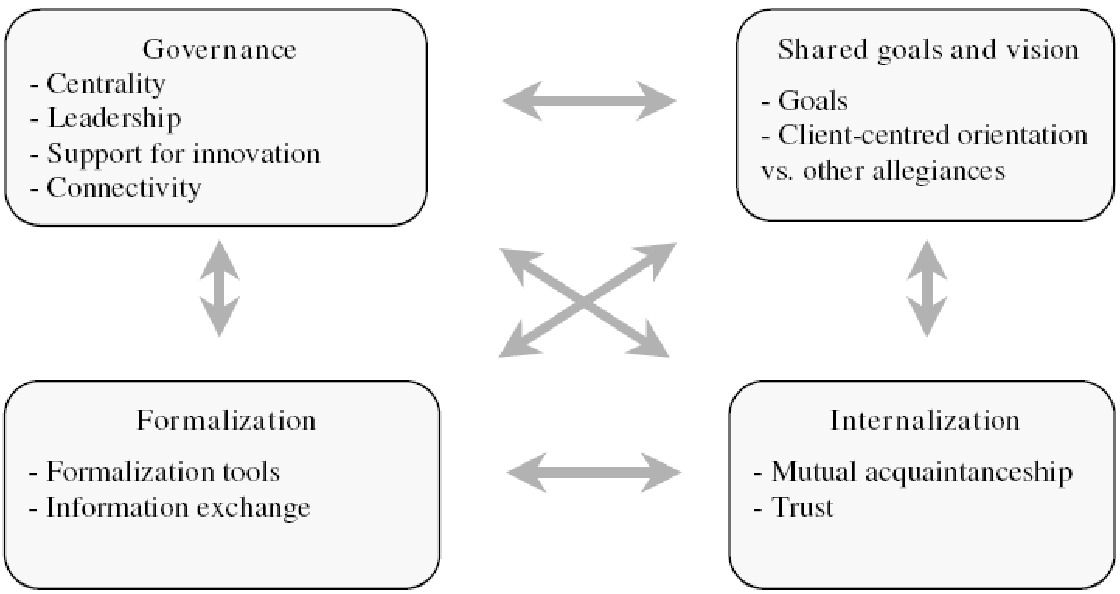

Figure 6. D'Amour et al. (2008)'s Four-Dimensional Model of Collaboration. The bulleted items are the ten indicators associated with each of these dimensions. The arrows indicate the interrelationships between the four dimensions and how they influence each other.

Most projects assume that collaboration should be of the highest level possible and that constructs such as D'Amour's "indicators of collaboration" should be used as a way to diagnose and correct collaboration shortfalls on the way to achieving Active Collaboration (Level 3). Instead, aviation security collaboration research needs to assume that there may always be some structural impediments to achieving full readiness for Active Collaboration. We hypothesize that knowing how the aviation community exhibits D'Amour's indicators of collaboration will help us to devise strategies for mitigating the effects of specific indicators such as "few opportunities to meet." We provide a preliminary assessment of the indicators of collaboration for the aviation community in table 2.

Table 1. D'Amour et al. (2008)'s Indicators of Collaboration

Indicators	Active Collaboration LEVEL 3	Developing Collaboration LEVEL 2	Potential or Latent Collaboration LEVEL 1
Goals	Consensual, comprehensive goals	Some shared ad hoc goals	Conflicting goals or absence of shared goals
Client-centred orientation vs. other allegiances	Client-centred orientation	Professional or organizational interests drive orientations	Tendency to let private interests drive orientations
Mutual acquaintanceship	Frequent opportunities to meet, regular joint activities	Few opportunities to meet, few joint activities	No opportunities to meet, no joint activities
Trust	Grounded trust	Trust is conditional, is taking shape.	Lack of trust
Centrality	Strong and active central body that fosters consensus	Central body with an ill-defined role, ambiguous political and strategic role.	Absence of a central body, quasi-absence of a political role.
Leadership	Shared, consensual leadership	Unfocused, fragmented leadership that has little impact	Non-consensual, monopolistic leadership
Support for innovation	Expertise that fosters introduction of collaboration and innovation	Sporadic, fragmented expertise	Little or no expertise available to support collaboration and innovation
Connectivity	Many venues for discussion and participation	Ad hoc discussion venues related to specific issues	Quasi-absence of discussion venues
Formalization tools	Consensual agreements, jointly defined rules	Non-consensual agreements, do not reflect practices or are in the process of being negotiated or constructed	No agreement or agreement not respected, a source of conflict
Information exchange	Common infrastructure for collecting and exchanging information	Incomplete information-exchange infrastructure, does not meet needs or is used inappropriately	Relative absence of any common infrastructure or mechanism for collecting or exchanging information

Table 2. Indicators of Collaboration for the Aviation Community

Indicator type	Aviation Community Assessment	Level of Collaboration
Goals	Overarching shared goal is clear (maintain safety), but other goals may conflict (e.g., airlines want to stay in business, potentially at fellow airlines' expense)	2.5
Allegiance	Professional or organizational interests drive orientations	2
Mutual acquaintanceship	Few opportunities to meet at most, few joint activities	1.5
Trust	Trust is conditional	2
Centrality	Absence of a central body, ambiguous strategic role beyond that implied by goal of maintaining safety	1.5
Leadership	Diffuse leadership	2
Support for innovation	Expertise in collaboration and innovation is not consistently available	2
Connectivity	Discussion venues related to specific issues	2
Formalization	Consensual agreements with jointly-defined rules	3
Info exchange	Common infrastructure for exchanging limited info types	2.5

While D'Amour's domain of perinatal care can involve time-sensitive decision-making, Boiney (2005) squarely addresses time-sensitivity and crisis management. Boiney's Integrated Team, Systems, and Environment (ITSE) model, shown in figure 7, was originally developed to provide a framework for collecting and analyzing data from fast-paced military decision-making tasks.

The ITSE model may be useful to the aviation security collaboration work because it encourages teasing out the effects of team-related concepts (e.g., group cohesion and culture) from the work environment and systems that are being used by the team. It is situated primarily in the lower two levels of Robertson's three tiers (the Capability and Capacity levels).

The ITSE model includes coordination as one of its "team" components. Malone and Crowston (1994) have made a study of coordination, which they define as "managing dependencies between activities." They provide a framework for studying coordination that consists of four parts (Malone and Crowston, 1994):

- "Managing shared resources (including task assignments)
- Managing producer/consumer relationships (including pre-requisites and usability constraints)
- Managing simultaneity constraints
- Managing task/subtask relationships"

The second bullet point is strongly related to Hong's concept of vertical linkage, and the framework as a whole addresses the middle level of Robertson's three tiers of collaboration ("Capability").

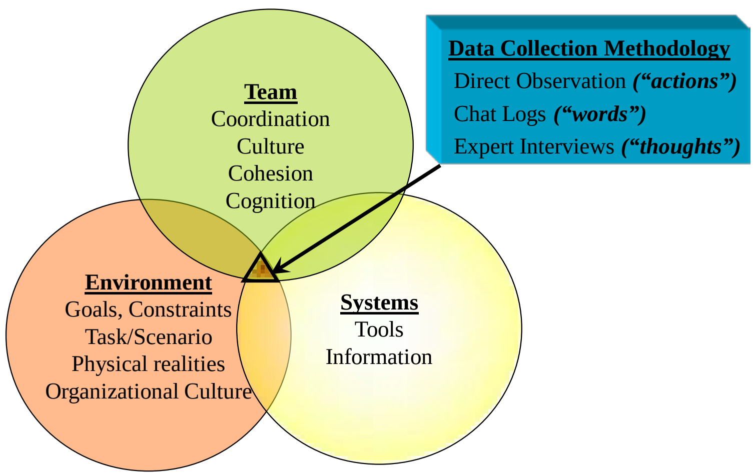

Figure 7. Boiney's Integrated Team, Systems, and Environment Model

Interdependency is also the focus of Thompson's (1967) work. He defines three types of interdependencies. Pooled interdependence occurs when team members independently create work products and then combine them for use by others, such as when individuals contribute information to a central database. Sequential interdependence occurs when one person's work product must be completed before another person can perform a task. Reciprocal interdependence occurs when two or more people must work closely together, such as when they must iterate on each others' work products. Klein et al. (2008) used Thompson's work as a basis for their Collaboration Evaluation Framework.

The relevance to aviation security of both the coordination framework and Thompson's work lies in the fact that there will be significant interdependencies among stakeholders' activities. It may be helpful to explicitly analyze collaboration needs in terms of coordination interdependencies.

Interdependent tasks imply that team members need to be aware of other team members' activities as well as the state of the external situation. Endsley (1995) developed a Team Situation Awareness (SA) model, illustrated in figure 8, to address this need.

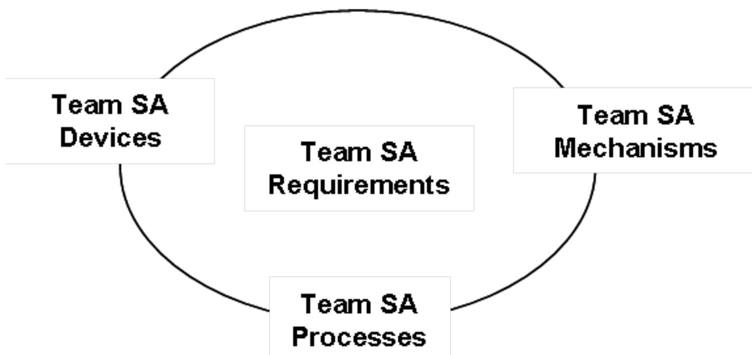

Figure 8. Team Situation Awareness Model (figure is copyright Mica Endsley), adapted from Endsley and Jones, 1997 and Endsley and Jones, 2001

Situation awareness (based on SA theory described above) is defined by Endsley (1988) as having three levels: perception (a user perceives elements of an environment in time and space), comprehension (the user understands what he or she perceives), and projection (the user can predict what will happen in the near future). While SA was originally defined as being pertinent to an individual, the Team SA model extends the SA concept for a group of collaborating individuals. A description of the Team SA model can be found on Wikipedia (which was edited by Endsley):

> "1. Team SA Requirements - the degree to which the team members know which information needs to be shared, including their higher level assessments and projections (which are usually not otherwise available to fellow team members), and information on team members' task status and current capabilities.
>
> "2. Team SA Devices - the devices available for sharing this information, which can include direct communication (both verbal and non-verbal), shared displays (e.g., visual or audio displays, or tactile devices), or a shared environment....
>
> "3. Team SA Mechanisms - the degree to which team members possess mechanisms, such as shared mental models, which support their ability to interpret information in the same way and make accurate projections regarding each other's actions….

> "4. Team SA Processes - the degree to which team members engage in effective processes for sharing SA information which may include a group norm of questioning assumptions, checking each other for conflicting information or perceptions, setting up coordination and prioritization of tasks, and establishing contingency planning among others." (from Wikipedia.org)

The Team SA model is pertinent to the two lower tiers of Robertson's model: the Capacity and (to a lesser extent) the Capability tiers. It is relevant to aviation security because managing aviation security issues requires a significant degree of situation awareness, both of the team's activities and intentions as well as of the external situation. People handling time-sensitive, crisis management issues often speak of needing "more SA" or "better SA"; it is worthwhile understanding at more than a superficial level what constitutes SA for teams of aviation security collaborators.

Finally, Ozceylan and Coskun (2008) developed a "National Emergency Management Model" that encapsulates the various "success factors" that they mined from the literature (figure 9). This model has relevance to aviation security because the technical, cultural, socio-economic, political, organizational, and risk factors identified for managing national emergencies are applicable to crisis management in the aviation domain.

3.3 Discussion of models

The Team Situation Awareness model is based on SA theory, and Thompson's work gave rise to "contingency theory" in the field of organizational studies. But the remaining models are either syntheses of multiple theoretical backgrounds (e.g., the Structural Model of Team Collaboration or the National Emergency Management Model) or do not have an explicit theoretical basis (e.g., the ITSE model). Regardless, many of the models can be understood in terms of many of the theories listed in section 2. All of the models can be thought of as "a cognitive system composed of individuals and the artifacts they use" (Flor and Hutchins' (1991) basic analysis unit for distributed cognition). Several of the models emphasize types of interdependencies (an emphasis of coordination theory). To the extent that all models involve communication among collaborators, they can benefit from applying common ground theory, which emphasizes that communicative messages are understood as they were intended.

4. Making sense of the situation, the team's activities, and the group's decisions

This section covers three inter-related topic areas, the first of which is sensemaking. As part of jointly making sense of the situation, team members usually need an awareness of what each other is doing and how their individual activities fit into the group's work as a whole. Accordingly, team awareness (usually just called "awareness") is the second topic of this section. Joint activities usually result in a decision on a course of action, which constitutes the third topic area. The final subsection discusses the relevance of these topics to aviation security.

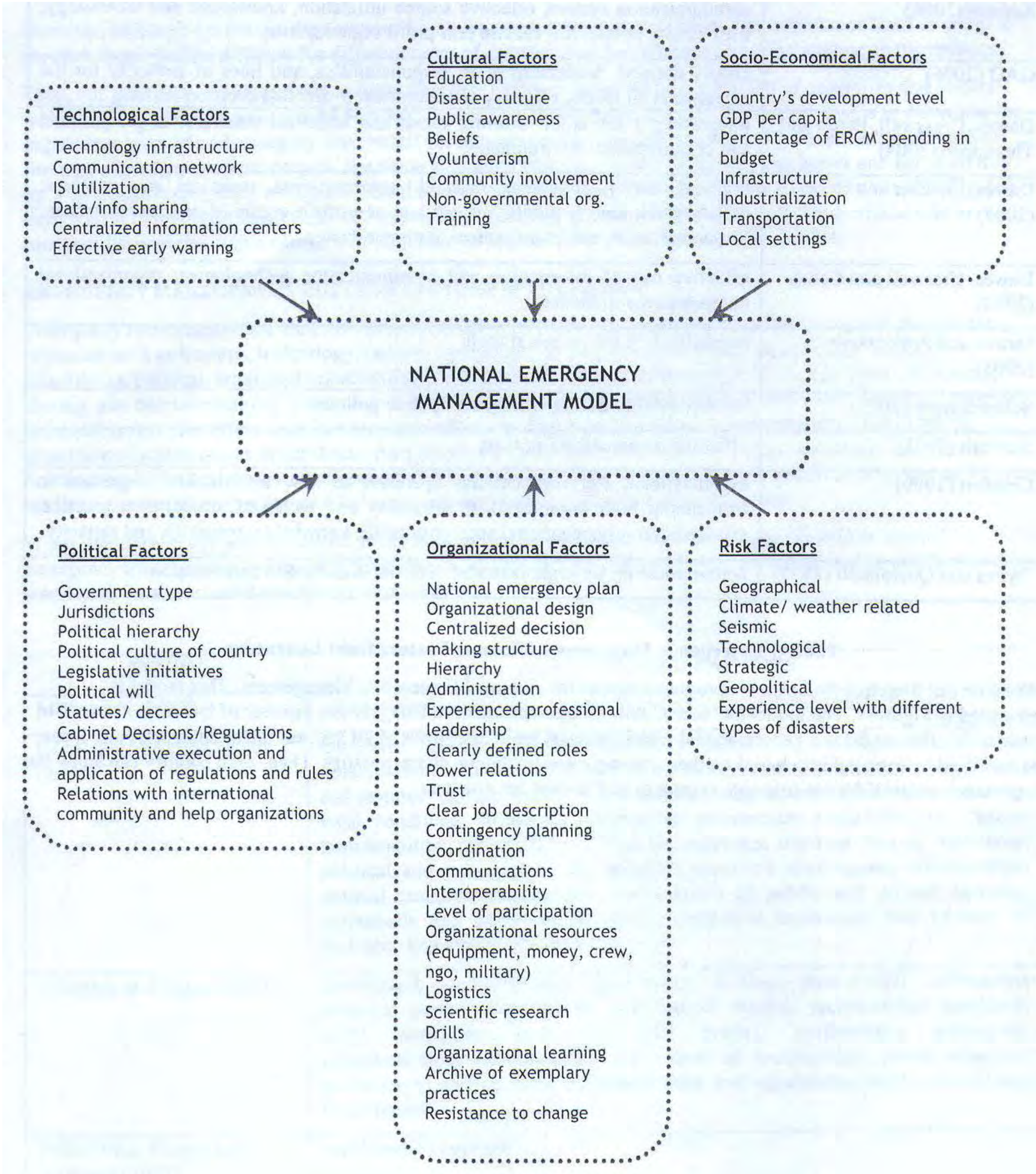

Figure 9. Ozceylan and Coskun (2008)'s National Emergency Management Model

4.1 Sensemaking

At the highest level, sensemaking is the process by which people understand what is happening. Hinrichs et al. (2008) state that "Sensemaking is a continuous cycle of learning and action, and decision-making is a critical phase of it" (p. 132). It is possible to think of sensemaking as occurring after the first level of situation awareness, which is perception, and in conjunction with the second level, which is comprehension. In other words, comprehension occurs when teams make sense of the situation.

Beyond this very high-level definition of sensemaking, there does not seem to be a simple definition of the term. Researchers at the University of Twente (The Netherlands) define sensemaking as "an approach to thinking about and implementing communication research and practice and the design of communication-based systems and activities. It consists of a set of philosophical assumptions, substantive propositions, methodological framings and methods" (U.Twente, 2004). Endsley sees sensemaking as "forming level 2 SA from level 1 data through effortful processes of gathering and synthesizing information, using story building and mental models to find some formulation, some representation that accounts for and explains the disparate data" (Endsley, 2004, p. 324).

Rather than provide a definition, Weick (2001) identifies several themes associated with sensemaking:

1. Reality is an ongoing accomplishment
2. People attempt to create order
3. Sensemaking is a retrospective process
4. People attempt to make situations rationally accountable
5. Symbolic processes are central in sensemaking
6. People create and sustain images of wider reality
7. Images rationalize what people are doing (Weick, 2001, page 11)

Qu and Furnas (2005) note that "Sensemaking arises when people face new problems or unfamiliar situations, anywhere their current knowledge is insufficient (Dervin, 1992). It involves finding the important structure in a seemingly unstructured situation" (p. 1989). They found a tight coupling between information seeking behavior and building structured representations of concepts derived from the resulting information. "We found that the various flows of information in the sensemaking entail not just pieces of content, but structural information important to creating the representations that are a core goal of the sensemaking activity" (Qu and Furnas, 2005, p. 1992).

A practical interpretation of sensemaking is offered by Leedom (2004) to describe military activities.

> Sensemaking within a military context can be defined as the multidimensional process of developing operational understanding within a complex and evolving battlespace. *Cognitively*, it can be seen as the process of collecting, filtering, interpreting, framing, and organizing available information into actionable knowledge for command decisionmaking. *Operationally*, it can be seen as an active and dynamic process in which the commander is attempting to construct and impose a specific intent or reality against a reactive adversary. *Socially*, it can be seen as the process of reconciling and integrating multiple stakeholder perspectives into a common operational vision that is driven by command intent. *Organizationally*, it can be seen as the process of building up appropriate bodies of staff expertise, equipping those bodies with effective information systems and collaboration technology, and efficiently structuring the knowledge management and decisionmaking battle rhythms of those bodies. *Doctrinally*, it can be seen as the process of utilizing these bodies of staff expertise, information and

> collaboration technology, and battle rhythms to effectively plan and execute actions in accordance with the military's future concepts of operation. (Leedom, 2004, page 2).

A major contribution of Leedom (2004) is that it "reviews the development of two methodological threads—cognitive task analysis and social network analysis[1]—and demonstrates how these methods can be combined to build richer and higher fidelity models of sensemaking within a military C2 organization" (page 3). While aimed at the military domain, Leedom's methods have broader applicability to hierarchical organizations' time-sensitive, safety-critical tasks.

More recently, Gary Klein and his colleagues at Klein Associates have formulated a model of sensemaking based on the concept of frames. They explain it in Sieck et al. (2007) as follows:

> "…we have defined sensemaking as the process of fitting data into a frame, and fitting a frame around the data. People will try to make sense of data inputs they receive by finding or constructing a story to account for the data. At the same time, their repertoire of stories will affect which data elements they consider and how they will interpret these data. Thus, the frame and the data work in concert to generate an explanation. Based on the results, we have differentiated and described six activities, or building blocks, of sensemaking: elaborating the frame, questioning the frame, preserving the frame, comparing frames, seeking a frame, and reframing. Our research also suggests that developing a comprehensive mental model for a complex, open system is unrealistic. Instead most people, and even most experts, rely on fragments of local cause-effect connections, rules of thumb, patterns of cues, and other linkages and relationships between cues and information to guide the sensemaking process (and indeed other high-level cognitive processes). We believe that a set of fragmentary mental models contribute to the frame that is constructed by the sensemaker, therefore guiding the selection and interpretation of data." (Sieck et al., 2007, page v – vi)

Sensemaking is becoming increasingly popular as a way of analyzing crisis management response activities. In addition to Klein's work in this area, Muhren et al. (2008) have applied sensemaking theory to analyzing responses to the ongoing humanitarian crises handled by humanitarian workers in the Democratic Republic of Congo.

4.2 Team Awareness

As teams begin the process of making sense of emergency situations, they usually need an awareness of each others' activities so that they do not duplicate work or omit a critical task by mistake. Awareness is especially important in distributed, synchronous group activities because it aids coordination of tasks and resources, and it assists in transitions between individual and shared activities (Dourish and Bellotti, 1992) in real-time despite the group's geographic dispersion. By facilitating shared activities, awareness promotes interdependence as described

[1] There are many definitions of cognitive task analysis (CTA) and social network analysis (SNA), A classic textbook (Preece et al., 1994) states that "Cognitive task analysis seeks to model the internal representation and processing that occurs for the purpose of designing tasks that can be undertaken more effectively by humans" (p. 417). Wikipedia defines a social network as "a social structure made of nodes (which are generally individuals or organizations) that are tied by one or more specific types of interdependency, such as values, visions, ideas, financial exchange, friendship, kinship, dislike, conflict or trade" (Wikipedia, 2009). SNA involves constructing and understanding such networks.

by coordination theory (see section 2). The need for awareness of team members' activities is the prime distinguishing feature between single-user and synchronous collaborative computing applications.

While some researchers consider team awareness to be a subset of situation awareness, many people think of SA as knowledge of the environment *external* to the team members who are trying to formulate a response to this larger situation. In contrast, team awareness is inward-facing: knowing, on a moment-by-moment basis, which collaborators are working and what they are doing. Note that the term "awareness" is often used without the "team" modifier in the literature described below.

4.2.1 Early team awareness work

Before the term "awareness" began to be widely used, Stefik et al. (1987) used the term WYSIWIS: what you see is what I see. A collaborative tool is strictly WYSIWIS if all participants see exactly the same thing at the same time. Stefik et al. (1987) discussed the need to provide "relaxed" WYSIWIS in collaborative tools to avoid distracting participants (e.g., imagine six participants' pointers moving around the shared workspace simultaneously) and to provide, in addition to the shared workspace, private workspaces with limited access.

Dourish and Bellotti (1992) defined awareness as "an understanding of the activities of others, which provides a context for your own activities." Dourish and Bellotti introduced the idea of providing information about individuals' activities via feedback on operations participants are taking within a shared environment. Synchronous collaborative applications developed since Dourish and Bellotti's paper have tended to provide the types of "passive" awareness features based on shared feedback that were prefigured by their paper.

Building upon their concepts of shared feedback, Dourish and Bly (1992) developed an application called "Portholes" to provide awareness of the presence and activities of geographically distributed colleagues. Portholes presented live video imagery transmitted over an internet. Even though the initial version of Portholes had a low frame update rate and did not use color, Dourish and Bly determined that Portholes provided a lightweight means of determining the availability of a colleague and enhanced the feeling of community between distributed work groups in their case study. The Collaborative Virtual Workspace project (Jones, 2000) also aimed to provide awareness of colleagues' availability, within the metaphor of a virtual office building.

Roseman and Greenberg's (1992) GroupKit, "a groupware toolkit for building real-time conferencing applications" provided the infrastructure for testbeds that facilitated a tremendous amount of investigation into awareness. For example, Gutwin et al. (1995) used GroupKit to prototype "awareness widgets" suitable for educational applications. One such widget was a multi-user scrollbar that uses color-keyed rectangles to indicate where other participants are focused and how much of the workspace they can see. Another widget developed using GroupKit was the "radar view"[2]: a miniature overview of the entire workspace with rectangles indicating what other participants can see and color-coded dots indicating where others' cursors are located (Gutwin et al. 1996b). Greenberg (1996a) used GroupKit to merge the concepts of a

[2] Note that the term "radar view" has nothing to do with radars. The term was chosen by researchers who do not have experience with physical radars.

full-sized window and the radar overview window into a single “fisheye view” window. The fisheye view shows full-sized, color-coded objects where participants are focused and collapses material that no one is viewing into a small visual area.

Gutwin et al. (1995) included several definitions for awareness. “Social awareness” is the understanding that participants’ have about the social connections within their group. “Task awareness” is the participants’ understanding of how their tasks will be completed. “Concept awareness” is the participants’ understanding of how a particular activity or piece of knowledge fits into the participants’ existing knowledge. “Workspace awareness” is the up-to-the-minute knowledge of other participants’ interactions with the shared workspace, such as where other participants are working, what they are doing, and what they have already done in the workspace. Gutwin et al. (1996a) developed yet more definitions of awareness: “informal awareness” is “the general sense of who is around and what others are up to” and “group-structural awareness” is “knowledge about such things as people’s roles and responsibilities, their positions on an issue, their status, and group processes.”

Vertegaal et al. (1997) defined workspace awareness as “who is working on what” and “conversational awareness” as “who is communicating with whom.” Vertegaal’s conversational awareness appears to be a part of workspace awareness as described by Gutwin et al., since knowledge of communications occurring within the context of the workspace would be a part of a participant’s up-to-the-moment understanding of others’ interaction with the workspace. How well a system supports workspace awareness of the types defined by Vertegaal and Gutwin et al. can be gauged by applying the Benchmarks for Workspace Awareness (Villegas and Williams, 1997) described in Section 2.

4.2.2 Recent team awareness research

More recently, van Aart and Oomes (2008) define “collaboration awareness” as “knowing how organizations do work and achieve their goals.” They developed a dynamically changing set of graphics called an “organigraph” (Mintzberg and van der Heyden, 1999)—which represents roles, groupings of team members, and flow of formal authority—for helping to answer questions about collaboration awareness among collaborators in a disaster response control center. While collaboration awareness appears to be somewhat broader than the team awareness concepts previously presented, some of the organigraph questions pertain directly to team awareness, such as “Are people aware of each others’ activities?” and “Who is solving what problem?”

Although there is no consensus on exactly how to provide awareness information, researchers now agree that systems should be designed so that team members do not have to take explicit actions to generate team awareness information about themselves, nor should they have to explicitly request awareness information about others. The idea is that the awareness information will be generated and consumed as byproducts of the normal course of performing tasks. Recent work has largely focused on innovative ways to provide and measure awareness.

Drury and Scholtz (2004) defined team-based awareness as “Given two participants p_1 and p_2 who are collaborating via a synchronous collaborative application, awareness is the understanding that p_1 has of the identity and activities of p_2.” In recognition of the dynamic nature of many workplaces, they later amended this definition to include knowledge of the presence (or absence) of participants at any given moment as well as their identities and activities. This work included developing and utilizing an evaluation method to determine whether distributed, synchronous collaborative computing applications supply the "right" amounts of awareness and privacy regarding collaborators' identities and activities. This paper and Drury (2001) discuss various team awareness requirements and provides guidance on developing them for specific applications.

Stach et al. (2007) posit that team awareness can be improved if collaborative applications can incorporate rich virtual personifications of remote collaborators. Up to now, real-time presence indicators for remote collaborators has consisted of approaches such as participants' names, a tiny photograph, perhaps a thumbnail live video feed, and/or representations of the remote users' cursors. Stach et al. are plowing new ground by using parametric texture synthesis (abstract patterns that map to real-world parameters) to encode information about virtual embodiments that represent the presence and/or activities of a remotely collaborating colleague. Also related to awareness via video feeds is the work by Nunes et al. (2006), who are developing a novel use of video data by taking one-pixel-wide video slices and concatenating them into a timeline-like video trace that is available to collaborators. As a result of the concatenation process, collaborators see a somewhat abstract pattern that they learn to read over time, for example to pick out the times of day their colleague's face was usually in view of the camera versus when it was not.

Almost all work so far on team awareness has been in the visual (such as the radar view and fisheye view mentioned above) and tangible modalities. An example of a tangible means of providing awareness is Kuzuoka and Greenberg's (1999) concept of a "physical surrogate," such as a figurine representing a remote collaborator on a small turntable that turns towards the wall when the remote collaborator is not available for joint work. While the audio modality has not been exploited much so far in awareness research, Schneider and Gutwin (2008) have started to work on using audio cues to enhance team awareness. They have developed a shared blackboard application and have incorporated directional audio to indicate physical locations of remote collaborators. Further, their application also provides sonic cues regarding the speed and pressure of other users' chalk while they are drawing on the shared board.

Pertinent to the increasing popularity of e-learning and webcasting, Birnholtz et al (2008) have tackled the issue of providing awareness of the audience to a speaker who is webcasting to a distributed group. They determined that a webcast system should provide speakers with both overview (aggregate data about the class) and detailed information about the audience (data about specific students), with the detailed information being kept private to the speaker.[3]

In the ComPlan (Combined Collaborative Command and Control Planning) tool (Leifler, 2008), if two non-collocated emergency response managers attempt to make plans using the same resources, they each receive automated instant message-like responses from the system warning them of the conflicting uses for the resource(s), including which resource(s) are in contention and which collaborator has already allocated it to what activity. Called "synchronization support" by Leifler, these automated responses are intended to provide awareness of remote collaborators' planning activities. Note that the system does not provide an automated means to

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[3] "This [detailed] information could consist of video images, or other cues that could reliably indicate engagement for particular students (e.g., data from sensors). This information could be provided either upon deliberate selection of students by the instructor, or by using an automated selection algorithm based on a combination of cues (e.g., sensor data, *a priori* interest in a student, random selection). Specific implementations and cues are topics for future work." (Birnholtz et al., 2008)

resolve the conflict; users of the tool needed to use a phone or another medium such as a chat window to resolve the issue.

4.3 Team decision making

Decisions are made using the facts of the situation (the "situation space") but can also be aided by fused or pre-processed data that provides information on the consequences of the different courses of actions available for a particular decision. This latter construct is called the "decision space" by Hall et al. (2007). While a decision space may be useful to individual decision-makers, they can also be used for team decision-making.

The literature usually treats a single group decision differently from a group of individual decision-makers. A single group decision consists of an agreement on a set of courses of action with all participants having cognizance over all the components of that decision. In this case, a group of individual decision-makers may each decide their own subcomponent without taking cognizance of what others are deciding on their own subcomponents.

There is some controversy in the literature regarding whether "decision-making" refers to the moment at which a decision is made, or the entire process leading up to this choice-point. The consensus in the more recent literature seems to be that decision-making is the process that includes all activities related to making the decision, such as gathering data, clarifying uncertainties, and forming/weighing alternatives, as well as the moment of choice. Some researchers use the term "option selection" to mean decisions involving specific strategies that consider the pros and cons of options either to screen out undesirable options or to make a choice of the best (or at least an acceptable) option (Zsambok et al, 1992).

Decision-making theories have been grouped in many ways, with no real consensus on which ones are "the" most important theories to highlight.[4] Because of its emphasis on team coordination, time pressure, high stakes, ill-structured problems, high uncertainty, and dynamic environments, Naturalistic Decision-Making (NDM; especially Klein's (1998) version called Recognition-Primed Decision Making) seems well-suited to analyzing the types of decision-making that occurs in aviation security crisis management. The key features of NDM are summarized by Wong and Blandford (2002) as:

1) "situation assessment is an important part of decision making,
2) "feature matching and story building are key to situation assessment because of missing information and uncertainty about available information,
3) "situational information are not presented in an optimal manner and often arrive over a period of time, making it hard to piece together a picture of the situation, and
4) "decision makers in dynamic environments do not appear to analytically generate and simultaneously evaluate all possible options, but instead seek to identify the actions that best match the pattern of activities recognized in the situation assessment, one option at a time." (Wong and Blandford, 2002)

[4] Zimm (2003) suggests that five theories (or theory groupings) are noteworthy: Rational Choice/Scientific Management (Taylor 1947); Bounded Rationality such as Simon's "Satisficing" (Simon 1955), Muddling Through (Lindblom 1959), Garbage Can (Cohen, March, and Olsen 1972), and the Naturalistic Decision Making (NDM) model such as Recognition Primed Decision Making (Klein 1998).

One focus of recent team decision-making literature is on studying teams in their normal work locations. For example, Selvaraj et al. (2007) studied decision-making among air traffic controllers and, in the course of doing so, determined that "decisions play a significant role in organizing various aspects of collaborative work and are not just mental acts" (Selvaraj et al., 2007, p. 243).

Based on their previous work in emergency response management (Linstone and Turoff, 1975; Turoff, 2002; White, Turoff, and Van de Walle, 2007), Turoff et al. (2008) cite eight characteristics of a group decision support system that will result in better decisions:

- "Asynchronous interaction by an individual
- "Anytime, anywhere participation in decision processes
- "Informative visual feedback of present group state on issue
- "Ability to vote on an issue, not vote, wait for more information to vote, or change a vote based on the changes in merit from evolving information input
- "Visual feedback system on real time vote outcome
- "Anonymous voting
- "Total vote changes on any item and histograph of recent vote changes over time
- "Contribution to any part of the decision process by any team member" (Turoff et al., 2008)

Although voting is not the only means of building consensus, it can be used in consensus-building. Consensus-building implies that everyone eventually comes to the same conclusions (or can live with the same outcomes). Voting can also be used when consensus building is NOT the goal. Voting can be used by a decision-maker to determine which idea has the MOST support regardless of whether a minority will never agree with the opinion of the majority.

More examples of recent research involving decision-making can be found below in the section that describes case studies.

4.4 Discussion of sensemaking, team awareness, and team decision-making

There is no consensus on how to best attain sensemaking in a crisis management situation. We feel Leedom's recommendation to use task analysis and social network analysis is a practical and reasonable approach for developing collaboration processes that will facilitate sensemaking.

Given the interdependencies among colleagues across locations and organizations, we believe that a set of "team awareness requirements" is needed to determine the kinds of information that team members in each role will need to know about other team members (Drury and Scholtz, 2004). These requirements will likely point to particular collaboration modalities used to provide the awareness of team members (e.g., via computer-driven audio, video, text, graphics, haptic/tactile feedback, or physical surrogates; or face-to-face meetings, paper, conference calls, or radio channels).

Recognition-primed decision-making characteristics map well to crisis response situations. As such, it will be helpful to provide information that enables crisis responders to see patterns in data and that will trigger associations with patterns formed via previous experience (since this is how recognition primed decision-making works). Beyond facts about the situation, which might be accessed via a shared database into which the collaborators all enter pertinent information, we feel it is helpful to provide the "decision space" to show information that was developed through automated analysis techniques (Hall et al., 2007).

5. Adopting collaboration technologies for specific tasks

There is a great deal of diversity in the tasks that groups need to accomplish together. It is important to match collaboration technologies to the tasks that need to be supported. McGrath's Task Circumplex (1984) is a useful means of thinking about the research into how groups perform different types of tasks, and the types of collaboration support that may be most appropriate. Matching collaboration support to tasks is challenging but critical to technology adoption, which we discuss at the end of this section.

5.1 Task types

McGrath's Task Circumplex (1984) consists of a set of eight categories of tasks that lie along a circular continuum (hence the name). As part of a DARPA working group that developed methodologies for evaluating collaborative systems, Drury et al. (1999) adapted McGrath's Circumplex slightly to be more appropriate for group tasks. Table 3 is taken from their final report (Drury et al., 1999), and includes both definitions of the tasks and a summary (provided by McGrath, 1984) of the research findings that applies to each task. To illustrate the point that different collaboration methods are needed for each type of task, Drury et al. (1999) added sets of recommended collaboration capabilities that are differentiated by task.

It is likely that tasks in a virtual aviation security command center would fall mostly under the categories of planning, decision-making, cognitive conflict, mixed motive, and dissemination of information. Thus considering the "capabilities" listed for these categories in table 3 may help in the situations most likely to be encountered by aviation security collaborators.

Table 3. McGrath's (1984) Task Types as Tailored by Drury et al. (1999)

Type	Definition	Known Research Findings (From McGrath, 1984)	Suggested Capabilities (From Drury et al., 1999)
1	Planning. Group members are given a goal and asked to develop a written plan for carrying out the steps needed to reach that goal. The written plan should include alternative paths or actions.	– Social relations hinder task efforts – There can be a strong effect on the group due to social influence and conformity – Groups often have trouble seeing alternatives; tend to focus on only a few alternatives – Participation can be very unequal; this increases as group size grows – Groups tend to avoid conflict and spend more time on non-controversial issues. Controversial issues tend to become personalized	– Calendar support – Text object creation, editing, displaying, arranging, storing

Type	Definition	Known Research Findings (From McGrath, 1984)	Suggested Capabilities (From Drury et al., 1999)
2	Brainstorming and group creativity. Members of a group are given a particular topic area and asked to brainstorm ideas.	– Creativity of individuals is stifled by social influence of group – Individuals are able to take advantage of creativity-enhancing forces in group - social support, cross stimulation	– Anonymous communication – Synchronous communication – N way communication – Shared workspace
3	Intellective. The group is asked to solve a problem for which there is a recognized solution. The group is asked to determine a concept, given instances of the concept.	– Written media is slower to arrive at a solution than voice media is. But voice media uses more messages than written. – Audio only does not differ significantly from face to face (and hence, probably video) – Interacting groups are almost always more accurate than their average member – Groups seldom do as well as their best members	– Shared workspace – Gesturing, pointing, agreeing, disagreeing – N way communication – Private group communications
4	Decision-making. Group members are asked to develop consensus on issues that do not have a single correct answer.	– Groups may not use their collective knowledge fully or efficiently – Some members may have more influence than others; the influence may not be based on competency – May be pressure towards quick, rather than good, decisions – Diversity of views and values may make reconciliation difficult	– Shared workspace – N way communication – Side chats
5	Cognitive conflict tasks. Members of the group hold different viewpoints. The group is asked to make a series of decisions from available information that is imperfectly correlated with criterion.	– Verbal interactions can lead to clarification of why group members are consistently using different policies. But if policies are used inconsistently, this leads to a distrust of and a reduction in understanding of the other. – Group members may change policy to increase accuracy.	– Shared workspace – N way communication
6	Mixed motive tasks. A range of tasks, differentiated by the degree to which a group member's outcome is affected by a combination of his own actions and the group's outcome.*	See below under tasks 6A, 6B, and 6C. *Note that McGrath also includes dilemma tasks in this category. However, since the dilemma decisions are made independently, no collaboration occurs. Therefore, we have not included dilemma tasks.	See below under tasks 6A, 6B, and 6C.

Type	Definition	Known Research Findings (From McGrath, 1984)	Suggested Capabilities (From Drury et al., 1999)
6A	Negotiation task. The group is divided into x subgroups with a negotiator elected for subgroup. The different subgroups disagree; tradeoffs have to be made in multiple dimensions. It is not necessarily a zero-sum problem.	– Negotiators are more competitive when any of these conditions hold: – They think constituents distrust them – They were elected – They are being observed – They have a prior commitment – Their constituents belong to a highly cohesive group –Negotiators who do not belong to the group feel freer in the negotiation process but are less supported by the group.	– N way communication – Group private communication – Shared workspace – Private workspace
6B	Bargaining task. A conflict of interest must be resolved between two individuals (or groups), but whatever one individual gains results in a loss for the other individual. The trade-off is made on a single dimension: what one party gains, the other party loses.	See under task 6A.	– N way communication – Group private communication – Shared workspace – Private workspace – Text object manipulation
6C	Winning coalition tasks. Subsets of members make agreements. The subset that wins then allocates the resources among the group members. Two research questions are the formation of the coalition, and the allocation of the resources.	– Strong tendency towards the formation of coalitions of minimum winning resources – For groups larger than 3, there is a tendency towards coalitions with minimum numbers of players – Females play the coalition game accommodatingly; males play exploitatively	– N way communication – Side chats – Shared workspace – Private workspace – Gesturing, pointing, agreeing, disagreeing – Support for computational object – 2D object manipulation
7	Competitive performances. Groups compete against each other with no resolution of conflict expected. The goal of each group is to win over the other group. In the original McGrath work, these performances are physical. Here, these types of tasks may be physical or nonphysical.	– Inter-group competition increases within-group cohesion. – Success in a competitive task also increases within-group cohesion. – Groups do not always distinguish between good group performance and winning.	– N way communication – Side chats – Private communication – Secure communication – Private (to group) workspace
8	Non-competitive contests. Groups perform some sort of complex group task. The plan for the task has already been decided upon. In this type of task, the group is merely executing the plan.	– Increased interpersonal interaction does not always lead to higher productivity – Groups influence their members toward conformity with the group's standards - this may increase or decrease productivity	– Shared workspace – N way communication

Type	Definition	Known Research Findings (From McGrath, 1984)	Suggested Capabilities (From Drury et al., 1999)
9	Non-McGrath. Dissemination of information. Group members may share information with each other, or a superior may disseminate the information to the group.		– 1 way communication – Feedback channel – Object displaying – Summarization capabilities

Obradovich (2001) performed a more recent search of the literature surrounding how groups use technology to collaborate on decision-making. Interestingly, despite the passage of seventeen years between McGrath and Obradovich, the summary of Obradovich's search indicates that there is no consensus yet on the impact of groups' use of technology for decision-making:

> "The contributions of researchers investigating the effect that interaction technologies have on group decisions show no consistent pattern of effects on time to decision, equality of participation, decision quality, confidence in the decision, agreement with the solution, or satisfaction with the process (Dennis & Gallupe, 1993; Koop, 1994; McGrath & Hollingshead, 1995). On the issue of decision quality, the findings of some studies show that interaction technologies have a positive influence on the quality of a group decision (e.g., Gallupe et al., 1988), other studies show that these technologies had a negative influence (e.g., Watson et al., 1988), and still others show that technologies used to mediate or facilitate social interaction have no effect or a mixed effect on decision quality (George et al., 1990)." (Obradovich, 2001, p. 57)

In light of these equivocal results from the literature, Obradovich suggests that designers of interaction technologies tailor technology (which Obradovich refers to as "artifacts") to individuals' and groups' specific work practices based on an understanding gained through qualitative empirical work such as ethnography.

> "…designers need to consider what is required in order to design artifacts that become part of the distributed cognitive system that will improve a group's ability to represent their interpretations, to reflect upon them, to engage in dialogue about them, and to inform action with them. What factors will provide the conditions for surfacing and challenging important assumptions (Argyris, 1982; Schon, 1983), for 'complicating the users' thinking' (Weick. 1990), and for enabling significant change when it is required (Bartunek & Moch, 1987; Orlikowski & Gash, 1994)" (Boland, Tenkasi, & Te'eni, 1996, p. 251)?
>
> "There is a growing body of research on distributed cognition that is examining the ways in which artifacts function to support collaborative cognitive work (e.g., Brown, Collins, & Duguid, 1989; Galegher, Kraut, & Egido, 1990; Goodwin & Goodwin, 1996; Hutchins, 1990, 1995; Lave, 1988; Norman, 1988; Smith, Billings, McCoy, & Orasanu, 1999; Suchman, 1987, 1996). These researchers represent a growing concern within anthropology, psychology, communications, sociology, cognitive science, and cognitive engineering that the impact of interaction technologies is not reduced to simply a study of the specific technology and how group interaction is impacted by that technology. The research traditions found in socially distributed cognition (Flor & Hutchins, 1991; Hutchins, 1988, 1990, 1995), activity theory (Engstrom, 1987, 1990; Kuutti, 1991; Nardi,

Kuchinsky, Whittaker, Leichner, & Schwartz, 1996), and situated action (Lave, 1988; Suchman, 1987), among others, rely on empirical work and ethnography, allowing researchers to arrive at a collection of findings about how people work and think together as they interact through and with artifacts as situated in a "community of practice" (Lave & Wenger, 1992)." (Obradovich, 2001, p. 59.)

In other words, it is likely that the conflicting results obtained by the literature are due to the fact that the technology being studied in each case varied in how well it suited the groups' work practices. Processes and modalities must be matched with the workflow observed or anticipated in a virtual command center, to ensure it will be used.

5.2 Collaborative technology adoption challenges

Besides the challenge of matching technology to work practices, there are further challenges to successful collaborative technology adoption. For example, picture a calendar management application that takes so much work to enter activities that many people within a workgroup don't make an effort to keep their calendars up-to-date. This case illustrates the fact that a collaborative application is likely to fail if the work people need to put into the application exceeds the perceived value of their benefits from using the application (Grudin, 1988).

Besides an imbalance in work versus benefits, we found through the experience of developing and using collaboration systems at our organization that collaboration technology adoption failed when:

- Users did not perceive a need to collaborate.   Such a finding is consistent with Rogers' (1995) work on diffusion of innovations, which notes that the rate of adoption of innovations is related to the extent to which the innovation (e.g., a new collaborative application) satisfies users' needs.
- The application did not provide functionality (and/or interaction modality) that users felt was relevant. Relevant functionality depends on the tasks the users need to perform and the conditions under which they normally perform those tasks.
- Users were not available to log in frequently. Users who often engaged in activities that precluded access to the system did not embrace its use.
- Users did not develop a well-articulated communications strategy. Some would-be technology adopters were hindered by not determining in advance which situations would call for use of the new collaborative application versus other tools such as email. This strategy could be articulated in conjunction with a "concept of operations" document that outlines how the system will be used.
- The application was not easy to learn or use.   Rogers (1995) also notes that adoption of innovations is related to the complexity or ease with which an innovation can be understood.

Regarding ease of use, Obradovich and Smith (2008) provide design recommendations for distributed teams that include advice for which technology modalities to employ for which purposes. Their recommendations are as follows (from Obradovich and Smith, 2008):

- "Decompose the overall task into independent subtasks
- "Design the system to foster detection of situations where interaction is necessary.

- “Use technology to create systems that will ensure needed interaction.
- “Design into the system subtasks that have prerequisite dependencies.
- “Match the locus of control and the distribution of resources.
- “Provide support for coordination of distributed, highly interdependent tasks with the ability for nonverbal communication.
- “Support coordination and synchronization among team members.
- “Use technology to ensure critical assumptions are assessed and evaluated.
- “Support coordination of work across several media.
- “Ensure procedures and processes allow virtual teams to quickly resynchronize.
- “Use video when an accurate and informative picture is needed.
- “Use one-way communication and ‘listening-in’ technology to enable situation awareness.
- “Design the system to allow teams that must interact asynchronously to view the sequence of events and reasoning behind decisions.
- “Use shared visual displays combined with synchronized voice and pointing technology to support grounding and focusing of attention.
- “Assign tasks to ensure critical information and knowledge is shared.
- “Design tasks to enable team members to engage in behaviors that will aid effective decision-making.”

5.3 Discussion of technology use by groups

Prudent designers of aviation security applications should take into account the facts that (primarily) non-collocated participants will perform a number of McGrath tasks synchronously using multiple sets of preferred work practices that will differ based on users’ varying organizational procedures. Further, designers should pay attention to what each group will perceive as a benefit of using the system to ensure that they will enjoy a positive return on their investment of effort. The applications should also be designed in conjunction with a concept of operations, so that the intended communications strategies and functionality will be supported. Finally, the completed system should attain a balance of ease-of-learning and ease-of-use. Ease of learning is important for systems that are used infrequently, because users must remind themselves how to operate an application each time they return to it after a hiatus; and ease of use will be important when users have little time and thus require an efficient design.

6. Case studies and new ideas for technology-enabled collaboration

There are thousands of recent research projects in collaborative technologies, as can be seen by browsing through the proceedings of conferences such Computer Supported Cooperative Work (CSCW), Association for Computing Machinery (ACM) Special Interest Group Conference on Groupware (Group), International IEEE Workshops for Enabling Technologies/Infrastructure for Collaborative Enterprises (WETICE), International Conference on Collaborative Computing (CollaborateCom), Collaborative Technologies and Systems (CTS), and International Conference on Communities and Technology. In addition, most conferences on human-computer interaction or human factors include collaboration tracks or sessions (especially the Human Factors in Computing Systems (CHI) conferences). Further, research on collaborative systems that are being developed for particular domains is often presented at conferences specific to those domains, such as the Information Systems for Crisis Response and Management (ISCRAM) conference.

It should be obvious from this partial list of conferences that it is not possible to survey the entire collaboration literature in a report of this scope. Thus we narrowed down the case studies and new collaborative technologies included in this review to examples of those systems that relate most closely to collaboration for aviation security: crisis management and/or safety critical collaborative systems, especially those designed for distributed, inter-organizational collaborators. Both the crisis management and military domains contend with collaboration challenges that are comparable to the challenges facing aviation security. Aviation security collaboration can benefit greatly from the lessons learned from these two domains.

To organize the case studies and collaborative technologies described in this section we used a very helpful taxonomy that divides all technologies used for collaborative purposes into four categories based on whether they are used by collocated or non-collocated collaborators at the same time or at different times (synchronously or asynchronously). For example, email is used by non-collocated collaborators asynchronously, rapid transit system control rooms contain collocated synchronous collaborators, war rooms host collocated asynchronous collaborators across shift changes, and virtual command centers support non-collocated synchronous collaborators. Situating the collaboration among the quadrants of the “time-space taxonomy” (Ellis, Gibbs, and Rein, 1991) is important because different technological approaches are normally needed to support collaboration in the different quadrants. Cross-organizational emergency response in the aviation security domain will tend to fall mostly into the synchronous/non-collocated quadrant of the taxonomy.

This section is thus organized based on the collaboration space-time taxonomy, minus the asynchronous collocated quadrant. We did not investigate examples falling into this taxonomy quadrant because of its limited applicability (e.g., a security partner’s shift changes) to aviation security collaboration. Although there is some literature on shift changes, it is older and not specific to collaboration tools.

6.1 Synchronous, non-collocated collaboration examples

We start with systems and studies in which distributed groups are expected to work together in real-time since we believe that this will be the primary mode of operations for a virtual aviation security response organization.

Hanumantharao and Grabowski (2006) examined the use of two versions of the collaborative Vessel Traffic System (VTS) application on the shore and aboard vessels in the St. Lawrence Seaway. This study is particularly relevant to ATM emergency response because it includes cross-organizational, distributed, synchronous, safety-critical collaboration using a heterogeneous suite of equipment. The shore-based collaborators were using a "second generation" VTS that included visualizations of the Seaway and decision-aiding tools, whereas shipborne team members were using a "first generation" system that included neither visualization nor decision support. They identified seven propositions, such as "Participants in a richer technology environment will show more communication than participants in a leaner technology environment." While some of their results were in line with previous literature, other results were somewhat surprising, such as the fact that there was no statistically significant increase in the amount of social communication as a percent of total communication for team members collaborating in the richer environment. The researchers concluded that:

> "New technology introduction in safety-critical and maritime systems is generally thought to produce enhanced performance and productivity—increasing the safety of operations, the effectiveness of task completion, improving communication and collaboration.…The results of this study show, however, that organizational culture and structure, roles and responsibilities are powerful forces in safety-critical systems that can mitigate against and alter the expected results of new technology introduction, a message that managers in safety-critical systems ignore at their peril. Without an understanding of the role of technology in a strong organizational culture and structure, or without significant training and/or changes in procedures and processes with new technology introduction, the intended benefits of new technology may not materialize, or may manifest themselves in unexpected ways (Weick and Roberts, 1993; Tenner, 1996)" (Hanumantharao and Grabowski, 2006, p. 717-718).

We need to keep in mind Hanumantharao and Grabowski's finding regarding the importance of organizational culture, structure, roles, and responsibilities when pursuing aviation security collaboration work.

Researchers from the Dutch government lab Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Dutch Organization for Applied Scientific Research, abbreviated TNO) are investigating how to best take advantage of networked information in crisis management. Similar to Hanumantharao and Grabowski, this work also assumes cross-organizational teams. TNO recently developed three case studies based on observing crisis management field exercises which resulted in several lessons learned (van de Ven et al., 2008). We have paraphrased these results slightly for brevity and clarity, as follows:

- Create easy access to information at all levels of the organization: not just for people at a stationery command center, but also for mobile responders in the field.
- Provide different information formats for different needs.
- Ensure that responders understand that an information-rich environment will result in people looking at information that used to "belong" to other parts of the organization. van de Ven et al.'s recommendation is that organizations should thus "encourage professionalism."

- Encourage responders to be aware of, and deal with, greater possibilities for conflicting information. A network-centered approach means that there will be more instances of conflicting information because more information will be exchanged. As a corollary, van de Ven et al. notes that sometimes people knew of information that conflicted what was being shown by the system but distrusted their own information rather than brought up the conflict to others and work on the conflict's resolution. Thus they also recommend encouraging others to add to the database *especially* when their knowledge conflicts with what is already in the database.
- Train responders to enter information that might be of use to others using jargon-free language that the broader team is likely to understand.
- Train responders to differentiate between facts and assumptions.
- Facilitate use of networked information as a pre-warning by subteams high in the hierarchy. (Source for these bullets is van de Ven et al., 2008)

While the first two bullets are recommendations primarily concerning developers of a crisis management system, the remaining five bullets pertain to how users of such a system should be trained to think differently about how they make use of this highly collaborative environment. Some of the recommendations, such as to use jargon-free language, are candidates for inclusion in a set of collaboration processes developed for crisis responders.

Another group of researchers, from the University of Lancaster and University of Aarhus, also developed guidance for designing distributed collaborative emergency response systems. They performed a case study of the use of an experimental collaboration system during the 2007 Tall Ships races in Aarhus, Denmark (Buscher et al., 2008). As a result, they recommend that systems be designed to support:

- Flexible redundancy to help build trust, because responders are more likely to trust information if they can come to the same conclusions based on two different information sources or modes
- Flexible interaction modes to suit multiple motivations and different information discovery needs
- Quick and implicit experimentation that allows responders to quickly probe cause-effect relationships in complex systems
- Easy inspection of states, processes, and connections so responders can examine the situation in detail if necessary, down to the "primitives" of computational processes such as GPS strings or data being sent and received

(Buscher et al., 2008)

Note that Buscher et al. (2008) focused on ways that the emergency response system can help responders build trust in the system. Altschuller et al. (2008) also investigated trust, but trust of one's colleagues in an ad-hoc, virtual crisis response team. They examined the situation in which non-collocated people must handle an emergency despite little (or no) previous experience working together. Their results implied that emergency response systems should be designed to include features to allow team members to identify themselves, for example with pictures or avatars, to quickly introduce themselves and remove any layer of anonymity. Further, the system should include features showing members how to formulate their messages, to reduce the level of focus on editing one's own messages and shifting focus to the salience of others in the communication (Altschuller et al., 2008). Altschuller et al. (2008) also suggest incorporating a short introduction exercise in the initial meeting of a post-emergency response team to give each team member the opportunity for self-disclosure. These practices are good guidance for aviation security collaboration efforts.

A repeated theme, especially in Hanamantharau and Grabowski (2006) and van de Ven et al. (2008), is that training is needed to teach team members to think differently from how they think in their regular jobs. There are commercially-developed virtual emergency operations center training products such as Alion Science's Emergency Command System Training and Exercising Tool™, BreakAway's Incident Commander™, and ETC Simulations' Advanced Disaster Management Simulator Command™. These commercial products are most appropriate for collocated team members, however. Wright and Madey (2008) are developing a prototype virtual emergency operations center training system that is specifically designed to be used with non-collocated team members.

6.2 Asynchronous, non-collocated collaboration examples

While the time-sensitive nature of aviation security issue response will likely dictate that team members work together at the same time, some of the work may be carried out by distributed teams at different times. Thus we examined the research falling into this quadrant of the time-space taxonomy.

Zhang et al. (2008) asked the question of whether web-based group decision support systems could be productively used to facilitate a team of collaborators involved in crisis management. They used GroupSystems' ThinkTank™, a general purpose decision-support application for brainstorming, organizing ideas, voting, prioritizing, and building consensus among collaborators using the system in an asynchronous and distributed fashion. Zhang et al. (2008) found that ThinkTank did not help users describe their ideas in a way that would be understood by collaborators, nor did it help them focus on the key tasks.

The last five years have seen a grass-roots movement among state and local agencies towards developing interactive web sites to help quickly disseminate information or coordinate activities across organizations and geographical and temporal separation. This movement has given rise to at least one commercial product, www.mystateusa.com, which was extensively used in an emergency response exercise in Coos County, Oregon in 2003 (Morrissey, personal communication) but does not seem to be in wide use today. Lickfett et al. (2008) implemented the RESCUE Disaster Portal, which was used during the 2007 Ontario, California wildfires to alert residents to evacuation areas and shelters. RESCUE also provides a means for anyone to add to, or search, a database of missing people. On a national scale, Shneiderman and Preece (2007) advocate developing and maintaining a "911.gov" collaborative web site/wiki that would enable anyone to contribute content (much as they do to Wikipedia), for example by sharing digital photos of destruction after a Katrina-like event. They envision that such a site could also serve as a way of rapidly coordinating a diverse set of responders, including volunteers. White et al. (2008) also propose a wiki for crisis response, but recommend including a "Dynamic Delphi" system that will manage asynchronous voting and consensus-building among those who are planning the response.

6.3 Synchronous, collocated collaboration examples

Although we have placed most emphasis on understanding how distributed teams collaborate, some teams or subteams in the aviation security response community will surely be working together in the same location.

A significant portion of the research completed under the Navy under the Tactical Decision Making Under Stress (TADMUS) program pertains to the individual decision-maker and synchronous, collocated teams. The goal of TADMUS was to "apply recent developments in decision theory and human-system interaction technology to the design of a decision support system for enhancing tactical decision making under the highly complex conditions involved in antiair warfare scenarios in littoral environments" (SPAWAR, 2001). As an example of their work, TADMUS researchers developed a decision support system (DSS) with the aim of "minimizing the mismatches between cognitive processes and the information available … to facilitate the decision making" (Kelly et al., 1996). They then tested the DSS via team-based decision-making exercises, with some teams performing tasks without the DSS as a control group. They found that "with the DSS, teams were observed to focus on critical contacts earlier and to be more likely to take appropriate action" (Kelly et al., 1996). Tools that are matched to work processes appropriately, then, are useful to collaborative teams.

We have been involved in a series of major military exercises that included hundreds of participants working in a large operations center—so large that a lot of chat and instant messaging went on among the collaborators collocated in the same room. We examined team collaboration in these noisy, complex, fast-paced, information-rich environments and made recommendations that designers of systems and collaboration procedures provide the following:

- Explicit "Collaboration CONOPs"
- Tactics, techniques, and procedures (TTPs) on chat technique and chat discipline
- TTPs for effective cueing of others to important information
- TTPs for backup collaboration procedures if key technologies fail
- Training on team workflow, the "big picture" of how they work together
- Training *as a team* using systems to step through a scenario
- Ready access to resources such as organization charts that clarify others' roles, positions, ranks, shifts, who to call, etc.
- A team VTC to increase familiarity and trust with dispersed members
- Mechanisms to help understand status and workload of others
- Means to "bookmark" where collaborators last read entries in chat rooms
- Means of searching chat rooms for key information
- Ability to set filters and/or alerts on chat and email
- Ability to *selectively* share information within a public display

A number of these recommendations pertain to chat. Its popularity has caused chat to become less helpful as users struggle to divide their attention between 6 – 9 chat rooms simultaneously.

Because the military command and control environment has a number of similarities with the aviation security, we are considering these lessons learned from the military when designing collaboration approaches for the aviation security domain.

While usually not involving cross-organizational collaboration, medical teams also need to collaborate in time-critical and safety-critical situations. Sarcevik (2007) investigated collaborative processes in collocated trauma teams working together synchronously. Sarcevik found that team members failed to anticipate others' information needs consistently and did not communicate information without being asked. Also, the rapid pace often limited full explanation of decisions, which contributed to incomplete shared mental models, and the hierarchical team structure may have inhibited bidirectional information exchange (Sarcevik, 2007).

7. Air Traffic Management (ATM) collaboration state-of-the-practice

Any recommendations for future collaboration approaches for the ATM domain need to be informed by current ATM collaboration practices. Further, it is important to take into consideration future collaboration directions that stakeholders are contemplating.

In fact, there is much discussion in the ATM community about adopting collaborative decision-making approaches, as can be seen in the following examples.

- To date, a number of tools have been developed or are in development for the Collaborative Decision-Making program (FAA, 2008). Even organizations who are not on contract to work on this FAA program are attempting to enter the arena. For example, Lockheed is working on a prototype collaborative traffic flow planning system that is based on providing a common database that all parties can add to or access (Jha et al. 2008).
- The National Center for Excellence in Aviations Operations Research (NEXTOR), one of five Centers of Excellence established by the FAA, released a paper in 2000 outlining current and future collaborative decision-making research in ATM (Ball et al., 2000). Their paper discusses collaborative ground delay program enhancements, collaborative routing; performance monitoring and analysis, collaborative resource allocation mechanisms, game theory models for analyzing collaborative decision-making procedures and information exchange, and collaborative information collection and distribution.
- The FAA sponsored a project at Virginia Tech to develop a detailed, large-scale, airspace planning and collaborative decision-making model (Staats, 2003). Given a set of flights that must be scheduled during some planning horizon, this approach used a mixed-integer programming formulation to select a set of flight plans from among alternatives subject to flight safety, air traffic control workload, and airline equity constraints.
- The US Air Force's Battle Control System-Fixed (BCS-F) is a North American Air Defense (NORAD) system that maintains air sovereignty over US airspace. BCS-F has a flight plan feed from the FAA so that its operators can have an understanding in common with the FAA regarding what aircraft have filed flight plans (Raytheon, 2005).
- The Department of Homeland Security implemented a joint program between the FAA, Customs and Border Protection (CBP) and TSA known as Automatic Detection and

Processing Terminal (ADAPT). "ADAPT serves as an advance warning system for air traffic controllers and security personnel by allowing them to validate the identity, threat and movement of aircraft operating worldwide" (NBAA, 2008).

- Europe and the UK's Airport Collaborative Decision-Making system is described as bringing "new technology and procedures which, for example, will provide accurate estimates of arrival and departure times so improving aircraft handling, stand and gate management, air traffic control and air traffic flow management" (quote from NATS, 2008; also see EUROCONTROL, 2008).

To the degree that we could obtain insight into the nature of each of these current or planned collaborative systems, we determined that the automated assistance to collaboration consists of access to sets of shared databases. (Non-automated assistance consists of teleconferences such as the FAA's 24 x 7 Domestic Events Network.) Besides face-to-face interaction and telephone interaction, collaboration occurs (or will occur, in the case of planned systems) via one person entering data into the database and others viewing or changing it, with all cooperating but non-collocated parties having access to the same database. Thompson (1967) calls this collaboration approach pooled interdependence and Malone and Crowston (1994) classify it as managing shared resources.

Note that this approach of pooled interdependence is an indirect and anonymous form of collaboration. It involves operators interacting with the computer system and its databases without knowing which colleagues might benefit from those interactions. Team members who do find the information useful (or not useful) normally don't know who took the trouble to enter it and so cannot provide feedback on its utility nor use the information exchange to help build trust among colleagues (as opposed to trust in the database, which may be increased by usage). Other collaboration mechanisms could be considered to augment shared database usage to facilitate understanding of what collaborators are doing (e.g., via Gutwin et al., 1996b's radar views), or can facilitate more direct interaction (e.g., via chat, instant messaging, video, or shared 3D virtual environments).

A decade ago, there was some concern that commercial collaboration technologies were not mature enough to be used in an ATM environment (Kerns et al., 1997). The technologies have matured considerably since then and we feel that there is room to push the state-of-the-practice in ATM collaboration more towards the state-of-the-art. Specific technical recommendations for aviation security collaboration must be based on a more detailed understanding of the stakeholders' work practices, but will likely involve additional use of presence and team awareness mechanisms such as video, telepointers, "radar views," and/or common views of shared workspaces.

8. Summary and applicability to aviation security collaboration

This paper began with the theoretical constructs that researchers have proposed for collaborative systems. Several of these seem particularly useful for collaboration in the aviation security domain. Common ground theory (Clark and Brennan, 1991) can inform support for verbal or textual conversations, such as processes and training that emphasize jargon-free communications, as well as guide implementation of video that helps provide nonverbal cues for conversational partners. Team situation awareness (Endsley, 1995) and team awareness (Drury, 2001) illustrate the need for providing insight into collaborators' identities, presence or absence, and activities. The situated action model (Lave, 1988) and information ecologies metaphor (Nardi and O'Day, 1999) emphasize the need for designing collaboration processes and technologies that take into account all elements of team members' environments, including their socio-cultural and organizational cultures.

Next, this paper presented a number of models of collaboration, some of which were based on one or more theories but many of which were ad-hoc. We compared the models with Robertson's three tiers of collaboration (Robertson, 2008), which we paraphrase as the strategic, tactical, and readiness levels. Some models concentrated on the middle level or lower two levels, but we believe that collaboration for aviation security will need to be supported at all three levels in order to be successful. New aviation security collaboration processes and technologies need not be based on a single model (or theory, for that matter), but instead can be informed by the relevant parts of a number of models. Hong's framework for interorganizational information systems introduced the idea of vertical (complementary or heterogeneous organizations, such as Air Traffic Control centers, military operations centers, and airlines) versus horizontal (competing or homogeneous organizations, such as different airlines) collaboration and the fact that they should be treated differently (Hong, 2002). Fawcett et al. (2000) pointed out the need for making critical information explicit and identifying clear roles: advice that can benefit most (if not all) collaboration situations. D'Amour et al. (2008) introduced the idea of maturity levels of collaboration, and the mid-level "Developing Collaboration—Level 2" has many characteristics in common with the aviation security environment, leading us to consider collaboration support that is well-suited for organizations that have only a moderate amount of collaboration readiness. Coordination theory (Malone and Crowston, 1990) and Thompson's work (Thompson, 1967) both concentrate on interdependencies of the types that may be exhibited by aviation security teams[5].

The team situation awareness model (Endsley, 1995) functioned as a segue to the sensemaking section, because sensemaking occurs after the first level of situation awareness but before the second level. We felt that Leedom's (2004) view of sensemaking was perhaps most practical for the aviation security domain; he advocates a combination of cognitive task analysis and social network analysis to achieve sensemaking.

While some researchers consider awareness of team members to be a part of situation awareness, we believe that these two concepts are achieved via different mechanisms and therefore should

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[5] Examples of interdependencies in aviation security are (to use Thompson's language): pooled interdependence through multiple parties accessing a shared database of flight plan parameters, sequential interdependence when a Joint Air Defense Operations Center waits for others to declare a track as a hostile before taking action against it, and reciprocal interdependence during the given-and-take of negotiations regarding large-scale commercial flight re-routing.

be studied separately. Consonant with Boiney's (2005) finding that mechanisms are needed to understand the status and workload of collaborators, we believe that new aviation security collaboration technologies should include means for team members to know about collaborators' identities, presence, and activities. Further, this awareness should be provided without collaborators having to ask for it or explicitly provide it to others: it should occur as a byproduct of performing mission-related tasks. Examples of mechanisms that provide this type of awareness are radar views (Gutwin et al., 1996b), miniature video windows (Dourish and Bly, 1992), physical surrogates (Kuzuoka and Greenberg, 1999), and aural cues (Schneider and Gutwin, 2008). We can take advantage of research in developing team awareness requirements (Drury, 2001), coupled with observations and interviews in the field, to describe what aviation security collaborators need to know about each other's work.

As teams make joint decisions, we believe they will be doing so in accordance with recognition-primed decision-making (Klein, 1998). Thus tools should be provided to collaborating team members that enable them to map the current situation to patterns that have developed over time as "typical" of certain types of incidents.

We identified a number of lessons learned from case studies of collaborative systems. Of prime importance is the finding that organizational culture and structure, roles, and responsibilities are "powerful forces in safety-critical systems that can mitigate against and alter the expected results of new technology introduction" (Hanumantharao and Grabowski, 2006, p. 717). Findings by Obradovich (2001) and experience at our own organization support this view. Obradovich found that research did not show a consistent pattern of positive impacts of interaction technologies on group decisions, and attributed this inconsistency to the fact that the technologies being studied were inconsistently matched to groups' organizational culture and work practices (in some cases, there was a conscious and careful match and in other cases there was not a good match). We found that a collaboration system must provide functionality relevant to team members, be easy for the intended users to work with, and include a well-articulated communications strategy that is compatible with team members' work practices (which we term Collaboration CONOPs).

Several researchers emphasize the role of trust in collaboration: trust in both the information being provided and the people providing the information. Buscher et al. (2008) advocate "flexible redundancy" so that collaborators can see how multiple sources of information cause them to draw the same conclusion, thus building their trust in the information being provided. Altschuller et al. (2008) recommend that emergency response systems be designed so that team members can identify themselves in ways that remove tendencies towards anonymity. Providing opportunities for team video teleconferences and training as a team can also facilitate trust-building.

Training has a bigger role than trust-building, however. van de Ven (2008) recommends that team members should be trained to differentiate between facts and assumptions, to enter information that others may find helpful, and to consciously use jargon-free language. Hanumantharao and Grabowski (2006) emphasize the need for training in new procedures, processes, and technologies. Boiney (2005) notes that training should emphasize team workflow and the "big picture" of how collaborators need to work together.

Given the breadth and depth of collaboration research, it is difficult to identify the most relevant findings that we should take into account when pursuing research in aviation security collaboration. We attempted to distill the most important lessons that we learned from this literature search into three broad categories of findings related to organizational, cognitive, and systems issues.

> *Organizational category*: How groups of people are organized, socialized, and work together.
>
> *Organizational finding*: Issues of organizational culture, work practices, interdependence, coordination, trust, and processes are "entangled" with each other and with how people work with the technology. We need to determine how to dis-entangle them enough to understand how they affect each other, then re-entangle them in a way that provides for the smoothest joint work.
>
> *Cognitive category*: How people think about their work, the information they use, and the technology that they work with.
>
> *Cognitive finding*: Level 2 situation awareness and sensemaking are closely related, and both are needed for recognition-primed decision-making: the type of decision-making that is most likely to be practiced in aviation emergencies. Team awareness is distinct from situation awareness, because it is focused inward at the team as opposed to outward at the extermal environment; but team awareness is critical for coordinating joint work.
>
> *System category*: How people, technology, information, and processes all come together.
>
> *Systems finding*: Cross-organizational technology, cross-organizational training, and widespread knowledge of the big picture are needed to flexibly and efficiently execute the mission as a whole (also known as "agile" mission execution).

When weighing the value of virtual aviation security collaboration, consider the following quote from Beyerlein et al. (2008), who are referring to virtual team collaboration in particular: "Collaboration can feel slow and cumbersome at first, but effective organizations have learned that superior results justify the time investment in a deliberate and disciplined collaborative process." (p. 689).

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