Problem Solving in a Distributed Collaborative Environment: The Necessity of Shared Knowledge within the Air Traffic Management System

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Abstract

The investigation described in this paper is situated within the context of the United States Air Traffic Management (ATM) System. The study included eight dyads engaged in a specific collaborative problem-solving task focusing on inefficiencies in the ATM system. The investigation focuses on how problem solving proceeds when the team members are from two distinct yet interdependent organizations with unique knowledge and expertise, are spatially distributed, have a shared display available to them, and must communicate by telephone rather than face to face. The findings reported here include results of an analysis of the verbal interaction behavior of each dyad with particular focus on the proposal of solutions to the problem task and the sharing of uniquely held knowledge that was necessary to create an environment of shared understanding between the dyad partners.

Introduction

This study is situated within the context of the Air Traffic Management (ATM) System in the United States. ATM is a very broadly distributed system with command, control, and communication responsibilities spread across a large number of FAA and air carrier organizations. This distributed problem-solving system is comprised of a large number of decision makers, distributed across organizations that often have conflicting and competing goals. In spite of these conflicting goals, these problem solvers must come to agreements concerning the management of the ATM system, a dynamic environment where changes occur in rapid and unpredictable ways. The complexity of this environment is characterized by a high level of uncertainty with only partial overlap of data and knowledge among the decision makers. However, it is this data and knowledge that ties the very complex, highly distributed system together (Billings, Smith, et al, 1997).

The Traffic Flow Management (TFM) component of the ATM system provides strategic planning and control when necessary in order to avoid situations where potentially safe or inefficient operations are likely to arise (Kerns, Smith, et al., 1999). The TFM system is a distributed cognitive system where a major task is flight planning in an uncertain and dynamically changing environment. Access to needed information is distributed among the various FAA facilities, as well as the commercial airlines. Also distributed among these members are different types and levels of knowledge and expertise. Even within the same organizations, tasks, responsibilities, information, knowledge, and expertise is differentially distributed.

Traffic flow management has traditionally been a function under the control of the FAA, with traffic managers at various facilities making decisions about what routes could be flown by flights scheduled by the airlines. Recent changes in the National Airspace System (NAS) have given air carriers greater flexibility with the assumption that the airlines have better information about the costs of alternative methods of operation, and should, therefore, be in a position to make better decisions about the economics of alternative flight plans (Smith, McCoy, et al.,1995). In essence, this shifts the locus of flight planning control without necessarily shifting the distribution of information that airline dispatchers must consider if, in fact, they are to improve the efficiency of the NAS (Smith, Billings, et al., 1999).

Across these different organizations, the goals and priorities are different, yet linked in ways that cannot be separated. The decision-making function is distributed over many practitioners and teams of practitioners, who, while geographically dispersed, must coordinate their information resources and activities in order to achieve their goals.

The goals of this study included the following:

1. To develop an understanding of factors influencing collaboration between spatially distributed inter-organizational members of a dyad who have different priorities, perspectives, and knowledge as they engage each other in a problem-solving task.
2. To determine what knowledge the participants find relevant to share with each other as they identify problems found within the scenarios and generate solutions to those problems.

3. To study the use of the cognitive artifacts made available in this study for facilitating the collaborative process between these dyad partners.
4. To explore what tools and processes are needed to more effectively support synchronous communication, collaboration and problem solving between distributed intra- and inter-organizational problem-solving teams.

Method

For this descriptive study the following data were collected.

1. Verbal protocols collected as the dyad members engaged in their problem-solving task.
2. Behavioral protocols based on the use of the shared display.

The study took place with the Airline Operation Center (AOC) dispatchers and Air Route Traffic Control Center (ARTCC) traffic managers located at their respective work sites. The participants were eight dispatchers (from one commercial airline) and eight traffic managers (from four different en route centers). Each scenario used in this study indicated an example of inefficiency occurring for a particular set of flights between two cities. Five different scenarios consisting of five different city-pairs were developed for use in this study. Each dyad pair was given only one of the scenarios for their problem-solving task, and each dyad's interaction lasted for approximately one hour.

Results and Discussion

In recent years, the changing architecture of the Air Traffic Management (ATM) System has resulted in giving the air carriers greater flexibility in making alternative flight plans. If the organizations do not share knowledge and data with one another, they both may suffer losses. An example of this is when a dispatcher files a route, taking into consideration what will bring the greatest benefit to the airline without taking into account other conditions occurring in the airspace (e.g., congestion over certain arrival fixes). At the same time the FAA traffic manager amends the route in order to maximize benefits to his/her organization. By doing this without considering the impacts such a change will have on the bottom line of the affected air carrier (e.g., putting a flight in airborne holding rather than moving it to another less congested arrival fix) unnecessary costs may be realized. Because these organizations have unique knowledge and different perspectives as well as different goals and constraints, it is understandable how they could make decisions that appear to be in competition with one another.

Currently the organizations represented by the participants in the present study are engaging one another in collaborative efforts to manage the NAS. For benefits of these efforts to be realized, the organizations need to provide access to the requisite knowledge and processes to enable the sharing of that knowledge so that it is also located with the individuals who have control of decision making.

In the present study, many types of domain knowledge need to be shared in order to do the experimental task. One type of knowledge is facts that were made directly accessible from interactions with objects and data found within slides that were presented (e.g., flight data found within a table and displays found on the map). A second type of domain knowledge is the inferences from the presented data drawn by the dyad partners (e.g., the extra fuel burn in the flights that held must be due to airborne holding).

Other types of domain knowledge that need to be shared are the different strategies and procedures in which the participants engage when they encounter situations similar to the events observed in the scenarios. Explanations and reasons why traffic management and dispatch engage in these strategies and procedures also need to be shared. This knowledge has to be grounded (Clark, 1996) as the dyad proceeds through their task goals of identifying problems, generating and evaluating alternative solutions, and arriving at the best solution for the identified inefficiencies. This grounding process is accomplished by verbal and artifact-derived representations as the interaction unfolds.

Proposed Solutions

The results of the interactions between dyad partners document a wide range of potential solutions to deal with air traffic congestion and weather constraints. These solutions include the following:

- Changing arrival fixes in order to balance the traffic flows between fixes
- Delaying aircraft on the ground at the originating airport as a way of minimizing en route delays
- Improving communication and collaboration between the different organizations in the Air Traffic Management System (e.g., AOC dispatchers, ARTCC traffic managers, and ATCSCC personnel) to arrive at more effective decisions
- Routing aircraft on alternate routes to avoid weather events or traffic congestion
- Vertical or horizontal separation of arrivals and departures to reduce controller workload in affected sectors and in effect reducing delays
- Adjusting arrival schedules to avoid peak arrival and departure pushes at the destination airport
- Utilizing airports close to the currently scheduled destination airport to reduce traffic congestion and resulting delays
- Increasing the flexibility of the airspace by dynamically redesigning it (e.g., moving arrival fixes when

weather is impacting the airspace, or sector redesign to reduce delays due to controller workload).

These findings provide insights into when each solution is applicable from both FAA Traffic Management and AOC perspectives. For example, the solution to impose a ground delay at the originating airport may be seen by traffic managers as a way to space traffic more effectively, reduce controller workload, and reduce the likelihood of airborne holding at the arrival fixes. However, AOCs may feel that having ground delays imposed on their flights would impose a greater negative impact on performance than if they encounter airborne holding. Table 1 categorizes by dyad the solutions that were proposed as the dyads worked on their task.

	Dyad	Arrival Fix Changes	Ground Delays	Improve Real-Time Communication	Alternate Routing	Altitude Separation/LAA DR	Arrival Schedules Adjustment	Proposed Solutions Offered by Only One Dyad
Scenario 1 Chicago to Atlanta	D-1	*X*	X	X				
	D-2		X	X	X	X		Plan Closer to Time of Departure
Scenario 2 Dallas-Ft Worth to Atlanta	D-3						*X*	
	D-4			X				
Scenario 3 Dallas-Ft Worth to Minneapolis-St. Paul	D-5		X	X		X	X	Dynamic Redesign of Airspace
	D-6	X						Better Training
Scenario 4 Chicago to Boston	D-7	*X*		X				Additional Runways; Utilize Close-in Airports
Scenario 5 Dallas-Ft Worth to Newark	D-8				X			Change Fuel Metric Computation Process

Table 1. Alternative solutions proposed by dyad within each scenario

Knowledge Shared

In the course of generating these solutions, the dyad partners shared rich domain knowledge as they worked to build a common ground. This shared knowledge includes the following categories.

Strategies traffic managers use for handling airspace congestion. These strategies include:

- Balancing arrival fixes
- Placing miles-in-trail restrictions on aircraft
- Re-routing aircraft to avoid congested airspace, to reduce congestion, or to avoid a weather event
- Vectoring aircraft as a means of delaying them from entering congested airspace
- Separating aircraft by altitude to reduce sector controller workload

Constraints with which traffic managers must cope with include:

- Configuration of the arrival airport, which determines aircraft arrival routes
- Airport arrival rate
- En route traffic crossing over arrival and departure traffic

Priorities and constraints the airline dispatchers must consider include the following:

- Strategies pilots use in order to avoid getting into a minimum fuel situation (e.g., diverting to an alternate airport);
- Federal Aviation Regulations (FARs);

- Determining which strategies are most efficient for reducing delay due to congested airspace (e.g., ground delay versus airborne holding);
- Satisfying intra-organizational differences as they pertain to on-time performance and fuel usage goals.

Table 2 illustrates by dyad the classes of knowledge the dyad partners shared. These classes of knowledge contain various categories within them, and it is at the level of these categories that the knowledge is shared.

Classes of Knowledge	Scenario 1		Scenario 2		Scenario 3		Scenario 4	Scenario 5
	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8
Airline/Center Collaboration	√	√		√	√	√	√	
Air Traffic Management Considerations							√	
Arrival Flow Management strategies	√	√			√	√	√	√
Arrival Flow Management Constraints			√			√		
Airline Considerations	√	√	√	√		√	√	
Unique Proposals					√		√	
Tools		√		√	√		√	

Table 2. Knowledge shared between dyad

Examples

Following are two examples that illustrate the knowledge and solutions shared and the importance of collaborations between those with the locus of control and those with the knowledge.

Example 1: Knowledge of Traffic Flows. A concrete example of a situation where the locus of control and the necessary knowledge do not reside with the same person is provided in the interaction of one of the dyads working the Chicago to Atlanta scenario. (See Figure 1 for a picture of one of the slides available to the dyad.)

The dispatcher in this dyad thought that one solution to the problem of airborne holding would be to file some of the flights from Chicago to Atlanta to another arrival fix. It was only when the traffic manager shared his knowledge about other Atlanta arrival and departure traffic and the en route traffic crossing the Atlanta airspace for the timeframe in question that the dispatcher realized that this solution was not a viable one. This knowledge included:

- Traffic flows crossing the Atlanta airspace
- Traffic arriving into Atlanta from the Northeast, the South, and the West
- Arriving international traffic
- Departing traffic
- The distance the flights from Chicago would have to fly if rerouted to another fix
- The involvement of other en route centers

Not only would filing some of those flights over another fix result in no net gain (and possibly more delay) to the dispatcher's flights, but the probability of negatively affecting other arrival traffic into Atlanta, as well as departure and crossing traffic would be almost assured (according to the traffic manager).

Distributed work brings with it the possibility that those who have a decision-making role may not have sufficient knowledge to support his or her decisions.

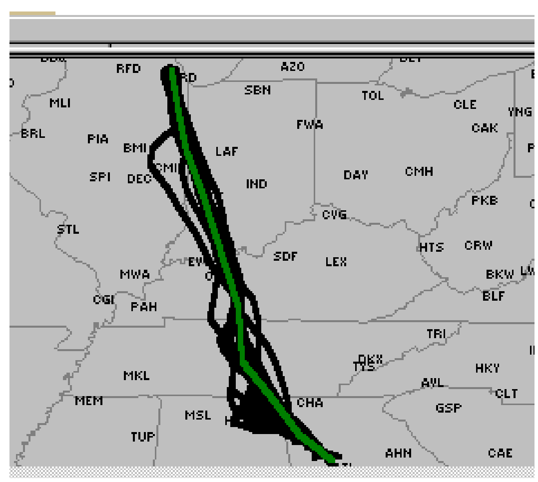

Figure 1. Chicago to Atlanta scenario

Through collaboration and knowledge sharing with those who have that requisite knowledge, the probability increases that more well-grounded solutions can be realized.

Example 2: Different Preferences. Another finding of the present study is that there are large individual differences in preferences expressed by individual dispatchers. These varying preferences make it difficult for the traffic managers to decide how to best incorporate an airline's priorities and constraints when making decisions. These are rich examples of the different preferences that specific dispatchers have on whether to delay on the ground at the originating airport or encounter airborne holding at the arrival airport.

It was only by comparing the conversations of the different dyads during the analysis of this research that an underlying consistency between the dispatchers' preferences was discovered. It appears that the common denominator was weather. One dispatcher situated his preferences of ground delay over airborne holding within the assumption of clear weather conditions. Another dispatcher, when discussing his preference for airborne holding, assumed thunderstorm activity. He suggested that because of the uncertainty of such weather events (i.e., it is unknown how quickly the storms are moving and where they will be located at any given time) he preferred to take a chance of an aircraft encountering airborne holding over the certainty of its delay if held on the ground at the originating airport.

What is suggested by these examples is that the knowledge necessary to make a decision does not likely reside with individual agents (e.g., individual airline dispatchers) within this complex, inter-dependent system. Rather, the complexity of locating relevant knowledge with the locus of control may require a process that provides the agents within the Air Traffic Management System an understanding of the roles, responsibilities, goals, constraints and procedures of the other parties with whom they interact.

Issues for the Design of Distributed Collaborative Work Environments

The findings in this study have implications for the design of distributed collaborative work environments (Obradovich, 2001) and include the following.

- Access to relevant data and knowledge needs to be available to those who have decision-making control.
- Identifying the source of relevant knowledge and having a process that enables real-time collaborative interaction and dissemination of this knowledge is necessary for effective decision making.
- Dealing with incomplete understanding of the organizational characteristics and the different perspectives and preferences that exist within the collaborative team can lead to incorrect assumptions and inefficient and/or undesired decisions.
- Introducing tools to mediate and enable interaction serving as aids to the collaborators in establishing common ground and building shared perspectives.
- To ensure accurate situation assessment and problem identification several factors need to be taken into consideration by designers of interaction technologies and practitioners who engage in problem-solving tasks.

Future Tool Development

Computer support can be very effective in improving the way in which information is shared among teams. Three classes of tools needed to support teams include communication tools, coordination and management tools, and task-oriented tools designed to facilitate the completion and integration of specific work products.

Findings of the present study suggest features that could aid distributed collaborative work. These include features that would enable the following:

- Interactive search for data to support the dynamic problem solving process
- A history of the interaction so the problem solvers are able to see where they have been to better decide where they need to go
- The ability for different representations of the data which may provide different insights
- An external memory that can mediate interaction through which the team members construct and maintain shared interpretations

This study also provided insights into process improvements that might enhance mutual understanding and provide feedback to the distributed partners. These include the following:

- Process facilitator
- Communication and interaction protocols.

Acknowledgments

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