THE IMPACT OF COMMUNICATIONS MODE ON ASYNCHRONOUS COLLABORATION IN THE NAS

Roger J. Chapman and Philip J. Smith
Cognitive Systems Engineering Lab
The Ohio State University
Columbus, Ohio

The NAS (National Airspace System) is a complex distributed work environment with an architecture that has changed over time. With the development of information systems, for instance, the NAS now generates more data that can be used as feedback to improve performance. Another example of change is the process by which flight plans are developed, with airline dispatchers having greater flexibility in recent years. However, the dispatchers still don't have the same information as FAA (Federal Aviation Administration) traffic managers, suggesting that collaboration might be useful to bridge the gap. In other contexts the communications mode has been shown to have an impact on collaborative performance, with voice and voice-synchronized with pointing shown to have certain advantages over text based communications. This research therefore involved studying the effect of introducing a multimedia asynchronous communications environment to support collaborative analysis of post-operations in the NAS. Of particular interest was if synchronized voice and pointing annotation over asynchronously shared slide shows composed of post operations graphical and tabular data would lead to different cooperative problem-solving performances as compared to text based annotation, as flights for specific city-pairs that ranked low by standard performance metrics were discussed by FAA traffic managers and airline dispatchers. The results showed the combined problem solving and message creation time was shorter when working in the voice and pointing mode than the text based mode, without having an effect on the number and type of solutions generated for improving performance. System constraints and flexibilities were also communicated that are important to improving preflight planning and decision making to react to conditions as they unfold at particular stages enroute, and in some cases the voice and pointing communications mode was found to positively affect the amount of this information. Further, the discourse itself suggests information that needs to be shared to facilitate such improvement.

Background

NAS changing architectures for distributed work

In recent years the airlines have been given greater flexibility in flight planning than in the past, based on the assumption that the airlines have better information about the costs of alternative methods of operation and should therefore be able to make better decisions about the economics of alternative flight plans (Smith, et al., 2000). Today, when AOC (Airline Operations Center) dispatchers construct a flight plan approximately an hour before the departure time they use tools and their own knowledge to model the system and make a plan with priorities on safety, on-time performance, and reducing costs (for instance, by minimizing fuel burn). In doing this they will consider weather conditions to avoid severe weather, monitor FAA (Federal Aviation Administration) advisories for relevant broadcasts, and use flight planning tools to estimate performance parameters such fuel burn for particular routes, involving certain altitudes, and air-speeds with predicted wind conditions. Their understanding of potential enroute congestion is therefore important, but the shift in architecture to give the airline more control of flight plans was not accompanied by a shift in the distribution of information so that the dispatchers could make use of the data and knowledge available to the FAA.

Improving feedback and knowledge exchange

One approach to bridge the data gap for the airlines is to give them access to data formerly only available to the FAA, and to design the information retrieval and visualization of that data combined with their own in such a way as to support identifying where inefficiencies exist so they can investigate them. A tool that has been developed to help provide such feedback is the Post Operations Evaluation Tool (Smith, et al., 2000). This tool supports identifying areas of NAS congestion or inefficiency using a variety of metrics including departure, en route, and arrival delays and filed versus actually flown flight tracks. Users access, filter, and visualize the archived flight information contained in the system's database of both FAA and airline data using interactive charts, tables, and geographic displays. In fact, this tool was initially developed for the FAA, but because it is now used by both the FAA and the airlines they both can identify inefficiencies. However, even when inefficiencies are identified, (1) certain goals and knowledge that drove the recorded decision making may remain hidden and (2) control is distributed, so it may require collaboration between organizations that are part of the NAS to make performance improving changes, as knowledge and control are distributed.

Multimedia for asynchronous problem solving

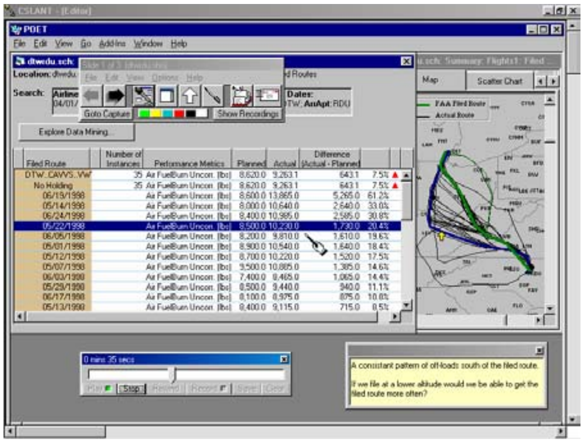

Figure 1. An annotated C-SLANT slide of archived Post Operations Evaluation Tool data

Chapman et al. (2000) describe the design of the Collaborative Slide Annotation Tool (C-SLANT), an asynchronous communications tool developed to support discussion of Post Operations Evaluation Tool results. Using C-SLANT the context of a message is formed by taking computer screen snapshots and annotating them with synchronized voice and pointing; text-based notes, freehand pen marks and static pointers (in the form of movable arrows) to produce a "slide show". An example slide is shown in Figure 1, where a message was created describing a consistent pattern of reroutes to the southwest, from a relatively direct filed route, for a particular flight from Detroit to Raleigh-Durham and the corresponding planned versus actual fuel burns.

Communication Modes

C-SLANT's ability to capture and synchronize both audio and pointer movement means it is able to support *deictic* gesturing, where the subject of a spoken sentence is linked to a visual and dynamic reference. For instance, "holding can occur here, here and here", while pointing to three holding locations on a route.

Voice-based annotations communicated between writers working collaboratively and asynchronously have been found to support more suggestions over the same period of time (Neuwirth et al., 1994) and in another study of collaborating authors, written annotations led to more comments on local problems in the text, while speech led them to comment on higher level concerns (Chalfonte et al., 1991). Voice synchronized with pointing in asynchronous annotation systems have been found to be more efficient in scheduling tasks, than voice-only, or text only communication (Daly-Jones et al., 1997) and synchronized voice and animation has also been shown to focus attention and improve retention of information in multimedia presentation systems better than voice or animation alone (Faraday and Sutcliffe, 1997). Thus, research suggests there could be efficiency and retention benefits when supporting voice and pointing for collaborative solving of NAS performance problems, but the communication mode might also affect the semantic content.

The research described here therefore investigated how synchronized voice and pointing annotation over asynchronously shared slide shows composed of post operations data differs in its effect compared to more traditional text based annotation, as collections of flights ranked low by standard performance metrics are discussed by airline and FAA operations staff.

Method

In a simulation study thirty-six dispatchers from a major airline were paired with thirty-six ARTCC (Air Route Traffic Control Center) traffic managers at eight different Centers and asked to communicate asynchronously about performance issues for flights between nine different city pairs. For each city pair a separate slide show, consisting of screen captures showing post operations data indicating inefficient performance was created. For each slide show, two airline participants were given a version of the program with the voice and pointing option removed and two had the text option removed. After the dispatchers separately created their messages, for each slide show, four traffic managers from a relevant Center for the city pair were asked to respond to the annotated message using the same annotation tools used by the dispatcher he or she was paired with. Two slide shows were used for the Center that surrounds this airline's hub airport.

Data was captured by video taping the participants' computer displays during problem solving and message creation, and from observer notes. After completing their message each participant was asked to complete a questionnaire.

Results

Analysis of the saved messages, the video tapes, and observer notes produced the following results:

1. Efficiency

	Voice & Pointing Mode	Text Mode	Difference
Dispatchers	18:01	28:00	9:59 (55%)
Traffic Managers	17:40	25:22	7:42 (44%)
Dispatchers + Traffic Managers	35:41	53:22	17:41 (50%)

Table 1. Average task times (minutes:seconds) of participants

Time taken. As shown in Table 1, the dispatchers' combined problem solving and message creation time was shorter working in the voice and pointing mode than the text based mode (ANOVA, $\alpha < 0.05$) as was the dispatcher-traffic manager pairs' combined problem solving and message creation time (ANOVA, $\alpha < 0.01$). (A statistical test was not run on the traffic managers' task time as the stimulus was not the same for each instance of the scenarios after the dispatchers created their messages.) The hypothesis that there is no difference between the times across scenario can be rejected (ANOVA, $\alpha < 0.01$). This is not surprising given the number of slides in each show was not the same, and city pairs were selected based on performance parameters, but also for some regional variation.

Number of solutions. It could not be concluded that the communications mode affected the number of solutions generated for improving performance. In both modes 15 dispatchers each generated at least one solution for improving performance, with the total number being 27 for those working in the text mode and 29 for those working in the voice and pointing mode. In the text mode there were 11 solutions that the corresponding traffic manager accepted, 14 that were rejected, 11 new solutions that were proposed by the traffic manager, and none that did not receive a response. In the voice and pointing mode there were 9 dispatcher solutions that the corresponding traffic manager accepted, 18 that were rejected, 10 new solutions from the traffic managers and 2 that were not responded to.

2. Referencing data

18/18 (100%) of the dispatchers in the voice and pointing mode made deictic gestures during the creation of their messages. 17/18 (94%) of the traffic managers responding in this mode also made deictic gestures. There were many incidents where synchronized pointing would tie a lexical reference to locations in the underlying image. The utility of that would depend on the knowledge of the recipient; for instance, whether or not he or she would know where the UKW fix is when it was mentioned. Another benefit was to reducing ambiguity. For instance, pointing clarified the referent for a statement about "the northern route" when more than one was shown, and "these high fuel burns" and "unacceptable delays" when a long list of statistics were shown.

Flight Classifying Data	Dispatchers in the Text Mode	Dispatchers in the Voice and Pointing Mode	Statistical Significance of Difference
City pair	5/18	11/18	Chi squared, $p < 0.05$
Time of day	1/18	4/18	Randomization test, $p = 0.16$
Time of year	0/18	5/18	Randomization test, $p = 0.03$
City pair, time of day, or time of year	6/18	11/18	Chi squared, $p = 0.10$

[The randomization test rather than the Chi squared test is applied to the time of day and year results, because their contingency tables have two cells with expected values less than 5 when applying the Chi squared test.]

Table 2. Number of dispatchers mentioning certain basic flight classifying data to introduce the problem

As Table 2 shows, when dispatchers started making comments about the scenario on the first slide, many did not mention certain basic flight classifying data to help define the problem. Although this information was available by searching through the data on the first slide in each scenario, these dispatchers either did not notice it or didn't take *distant responsibility* (Clark and Wilkes-Gibbs, 1986) for ensuring common ground on these parameters important for establishing the context as they projected the traffic manager following their messages. In addition only one dispatcher used pen marks or static pointers to annotate this information, and none of the dispatchers working in the voice and pointing mode pointed to this data while recording their comments. The benefit of making this information more salient was demonstrated in the ZDC scenario, for instance, where one of the traffic managers looking at the information for a flight instance on slide four made the comment that the holding he saw might be connected to the time of day, but he did not see that information on the slide. (The time of day and year can indicate traffic flows and densities that would likely be in effect as well as the likelihood of certain weather conditions.) In fact the time of day information for all the flight instances in that scenario were shown on slide one, but the dispatcher didn't mention it and the traffic manager either didn't notice it or remember it by the time he reached slide four.

3. Types of solution

Table 3 shows a classification of the dispatcher solutions, showing for instance that 11 dispatchers made at least one comment about a new preflight route in the text mode and 9 in the voice and pointing mode. The table also shows the number of traffic managers who accepted the category of their dispatcher's solution as a possible performance improving approach or added that category as an approach through their comments. For dispatchers and traffic managers in both modes the most popular solution was to change the route flown, which may be at least partly explained by the fact that every scenario included flight route maps. The dispatchers offered a greater variety of solutions than the traffic managers, which the traffic managers tended to rule out, unless the solution was a new route or a change in the flight schedule (which was the second most popular solution for traffic managers).

Category	Dispatchers		Traffic Managers	
	T	VP	T	VP
A. New preflight route	11	9	9	10
B. Enroute reroute	2	3	2	0
C. Change schedule	1	1	7	3
D. Ground delay/stop	3	4	1	1
E. Same route but miles in trail	0	1	0	0
F. Change Center staffs' workload/traffic volume	2	0	0	0
G. Share more information for planning	3	3	0	1
H. Hold at a different location	1	1	0	1
I. Change altitude	2	2	0	0
J. Fix balancing	0	1	0	0
K. Other	0	1	0	0
Totals:	25	26	19	16

Table 3. Classification of dispatcher and traffic manager solutions for performance improvement

4. Constraints and flexibilities

As was mentioned earlier, in developing flight plans the dispatchers want to be aware of potential delays and how likely they are, so they can either be avoided or planned for with contingency fuel and appropriate planned departure and arrival times. Thus it is perhaps not surprising that the dispatchers not only made suggestions for improving performance, but they also asked questions in order to understand better what the policies and tendencies are for certain situations and they sometimes stated their preferences when they saw multiple approaches to handling congestion. In addition, the traffic managers' responses were not just to agree or disagree with the dispatchers' solutions and possibly add their own. When asked a question about procedures they gave an answer, but even unprompted they explained policies and constraints they considered to be relevant in flight planning. Thus, it isn't only important what specific solutions were generated, but also the knowledge that was exchanged to facilitate more informed plan development in the future. Some examples of this are as follows:

Other interacting flight paths. As shown in Table 3 the number of dispatchers and traffic managers proposing or supporting a new route as a solution was very similar in both modes, but the number mentioning other interacting routes (such as arrival routes crossing departure routes, traffic merging onto a route segment from a different direction, and international arrivals from the North Atlantic into the same airport), was different in the two modes. As shown in Table 4, 4/18 pairs in the text mode and 11/18 pairs in the voice and pointing mode mentioned such routes, which is a statistically difference at $p < 0.05$ (Chi squared, $p = 0.018$). Further, the collective total number of such paths mentioned in the text mode was 4 versus 19 in the voice and pointing mode, because in the text mode more than one interacting path was never mentioned, whereas in the voice and pointing mode more than one interacting path was mentioned by 5 of the 11 pairs mentioning interacting paths.

Text Mode Pairs	Voice and Pointing Mode Pairs	Statistical Significance of Difference
4/18	11/18	Chi squared, $p < 0.05$

Table 4. Dispatcher – traffic manager pairs mentioning flight paths for other interacting traffic

Fan-out route patterns. When developing a flight plan a particular segment of a flight path being considered may have multiple alternative branches from it. In that situation it is useful to know (1) when are these alternative paths realistically available? (2) what are the advantages and disadvantages of each? (3) if one is filed, how likely is it that it will actually be flown? and (4) is it plausible to request a reroute enroute when approaching this point? The Post Operation Evaluation Tool can usefully reveal routes successfully filed and where rerouting occurred, but it doesn't reveal the FAA's reasoning that affects those outcomes. It is beyond the scope of this paper to discuss all the interactions in detail, but there were examples of traffic managers providing answers to all of these types of questions. In one scenario involving flights from Minneapolis/St. Paul (MSP) to Dallas/Fort Worth (DFW) the screen captures showed three alternate routes out of MSP: (1) a route over Wichita, Kansas, where often the flight would be rerouted over Tulsa before reaching Wichita; (2) a route over Tulsa which could be filed to then approach DFW from the northeast or the northwest, but which was most often flown to approach from the northeast even when filed to approach from the northwest; and (3) a more easterly route infrequently flown which would approach over Fort Smith, Arkansas. The dispatchers asked why the rerouting was occurring and suggested a route over Tulsa or Fort Smith should normally be filed based on the data given. In response the traffic managers noted that traffic would be moved from the Wichita route when there was heavy traffic approaching from the west; that traffic from Tulsa to the airport works on a "switch" with all being routed over the northeast or northwest until it changed and the Kansas Center could be contacted to see which way the switch is operating; and that traffic through Forth Smith would cross into Memphis Center airspace where they sequence over Fort Smith and have miles-in-trail for traffic that must be merged with arrivals from two other routes headed towards the northeast arrival into DFW. This demonstrated feedback on alternative routes and also how uncertainty could be reduced. In another scenario involving a flight from Detroit (DTW) to Newark (EWR) the traffic manager suggested one solution for the congestion that can quickly develop on the most direct route would be to wait until approaching the point where traffic could either head north through Canada or stay on a more direct route and use current predictions of congestion to make the decision. This is another example of reducing uncertainty, but by supporting airline input even later in the decision making process.

Fan-in route patterns. When multiple routes converge at or near one location to continue on a common path congestion can be an issue that requires careful spacing and sequencing. A route map can reveal those locations, but it does not indicate any preferences that may be given to flights on one converging path over another, or where traffic may be slowed down, or how likely holding is to accommodate the merging. Discussion of traffic being merged at Fort Smith occurred in the MSP to DFW scenario. Another example occurred in a scenario involving traffic that was merged from multiple routes south of Washington in preparation to move north through the "northern corridor". In this case the traffic managers pointed out that the route most often filed to join this "funnel" was bad because the traffic was largely sequenced already at that point and traffic from the current route would be a low priority in the merging process. It was therefore suggested to approach the funnel further south where the flight would be a higher priority.

Holding. Having flights fly in a holding pattern at designated locations is one approach to managing congestion. Seven of the nine scenarios included instances of holding and the comments made by the participants indicate many of the parameters related to holding. For instance, for a particular route there are multiple holding locations on a route, each with a capacity for a certain number of aircraft at one time holding at different altitudes. The dispatchers asked if the holding could be avoided by different routes, if holding could be closer to the destination rather than further back enroute, and in some more severe cases asked if the flight could have been held on the ground. In their responses the traffic managers described the holding locations, why holding normally occurred at each location, such as holding for fix balancing into an airport or for enroute spacing as aircraft are merged, and discussed alternate routes. Some dispatchers requested that more information about the forecast holding situation for their flights be made available, such as when and where it is predicted and how long it is forecast to last. Knowing when holding is likely to occur based on traffic forecasts could be useful to the airline decision makers, but knowing why is also important. For instance, if the holding is due to congestion at the arrival airport considering other routes may be pointless, but if it is not, the congestion could be potentially avoided that way.

Discussion and Conclusions

Decision makers benefit from accurate, relevant, and timely data presented in a form that can be efficiently interpreted and applied in the time available for a decision. When decisions have to be repeatedly made in the same or similar context, feedback on performance from previous decisions can provide learning and lead to beneficial adaptation. Collaborative decision makers further benefit from accurate models of each other's goals and decision making processes, and efficient communications with each other. In the context of the NAS, this research investigated a situation where collaborating decision makers were given accurate information about their collective past performance and asked to decide what changes could be made to improve that performance. The information was represented in a particular way and the communications environment was also specific. The results show the voice and pointing mode was more efficient for generating solutions without affecting the types of solutions discussed. Voice and pointing mode dispatchers were also more likely to mention certain basic flight classifying information when introducing the problem and traffic managers were more likely to describe other interacting routes. Thus, while it is a rare form of communication, there is evidence that designers of environments for asynchronous collaboration in the NAS should consider supporting deictic gesturing and not just the traditional text based form of communication. This conclusion should be qualified by noting that, while it is not a statistically significant difference, 2 out of 15 dispatchers who raised issues regarding performance improvement did not receive a response to all of them in the voice and pointing mode, compared to 0 out of 15 in the text mode. Designers of this type of interface may therefore want to consider designing to encourage visual reminders of key semantics such as questions.

The type of information provided to the dispatchers by the traffic managers could be potentially useful for (1) preflight planning or (2) in-flight replanning. Relatively static knowledge, such as which traffic is given preference where routes merge, is the type of information that might be covered in dispatcher training (possibly created using tools similar to C-SLANT). More dynamic information, such as which way traffic will be directed where a jetway splits might be better communicated in the form of advisories, but technology could assist the process of filtering this type of information to ensure it is delivered to only those for whom it is relevant. Airline initiated changes to flight plans for airborne traffic require coordination between the dispatcher, flight crew, and ATC (Air Traffic Control) personnel and may require carefully compiling pre-approved conditions, procedures, and options to make the workload manageable for all those involved. Knowing airline preferences can be useful to the FAA as they seek to serve their "customers", and for both parties dealing with factual knowledge about past events can ground their discussion.

Other aviation applications for C-SLANT and/or the Post Operations Evaluation Tool suggested by participants were:

- Analyze the effectiveness of new routes;
- Exchange information and ideas between air traffic facilities;
- Explain why decisions were made during the severe weather season;
- Leave notes for fellow employees or to document situations that may be reviewed later;
- Dispatcher to chief dispatcher/ATC coordinator communications;
- Report generation;
- Create scenarios to train other dispatchers;
- Communicate with flight crews during pre-flight briefings.

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