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Aiding Planning in Air Traffic Control: An Experimental Investigation of the Effects of Perceptual Information Integration

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16. Abstract

Prior research examined how controllers plan in their traditional environment and identified various information uncertainty by perceptually representing important constraints. This included integrating spatial information on the radar screen with discrete information (planned sequences of air traffic). Canning et al. (1999) and Moertl et al. (2000) reported improved planning performance and decreased workload in the planning aid condition. The purpose of this paper was to determine the source of these performance improvements. Analysis of computer interactions using loglinear modeling showed that the planning interface led to less repetitive, but more integrated, information retrieval gave rise to the performance improvements. Potential applications of this research include the design and evaluation of interface automation that keeps users in active control by modification of perceptual task characteristics.

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Aiding Planning in Air Traffic Control: An Experimental Investigation of the Effects of Perceptual Information Integration

Air traffic control equipment has changed in recent years as the Federal Aviation Administration (FAA) adapts its procedures to the growing volume of air traffic across the country. However, two major components of control equipment have stayed constant over the years. Specifically, generations of air traffic controllers have utilized a radar screen and flight progress strips as separate representations of aircraft entering their controlled sector and cognitively integrated those representations. This equipment has proven to be highly beneficial and, therefore, forms the foundation from which any innovation to the air traffic control system should begin.

If controllers are to manage the increasing volumes of air traffic, planning will be of increasing importance. This is evidenced by recent efforts to provide controllers with plan-aiding technology (e.g., URET, User Request Evaluation Tool, Arthur & McLaughlin, 1998; CTAS, Center-Tracon Automation System, Denery, & Erzberger, 1995; ERATO, En Route Air Traffic Organizer, Bressolle, Benhacene, Boudes, & Parise, 2000). Such interfaces offer additional functions to the controller like conflict detection algorithms (URET), automated traffic advisory functions for descending, sequencing, and spacing aircraft (CTAS), and decision aid tools like filtering options and problem reminders (ERATO). The approach we took in this study can enhance plan-aiding technology by identifying essential informational elements that support air traffic planning and determining the extent to which air traffic planning could be improved by optimizing the representation of that information.

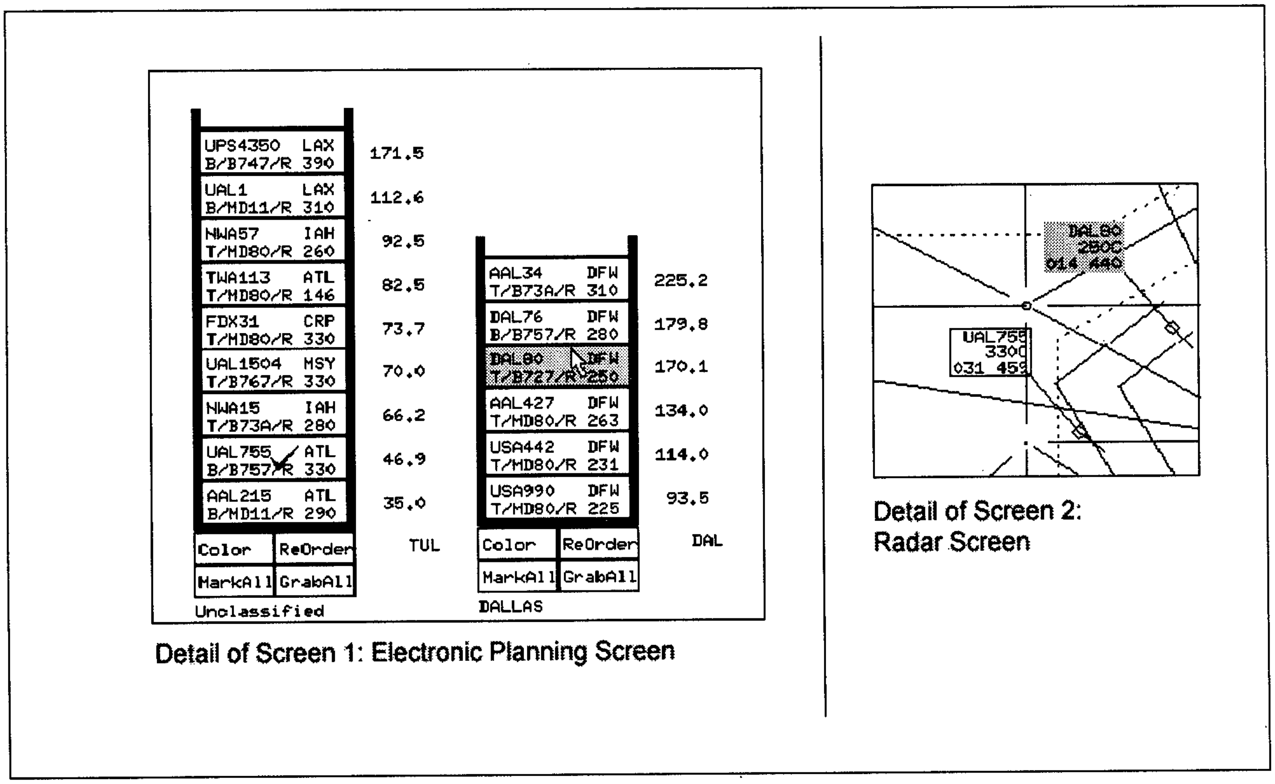
Air traffic controllers manage a complex flow of aircraft through their airspace. They maintain strict rules of separation between the aircraft while allowing all aircraft to reach their destinations as safely and expeditiously as possible. In planning the routes for the aircraft, two forms of planning can be distinguished. Controllers make tactical plans when they make decisions that relate to the current moment and involve the separation of (usually) pairs of aircraft that could soon violate the separation rules and hence, need immediate action. They make strategic plans when their plans span longer periods of time (about 10 minutes or longer) and typically involve multiple aircraft. An examination of strategic planning in air traffic control is timely, given future concepts being proposed. For instance, there have been discussions regarding the creation of a strategic controller position (N. Lawson & K. Thompson, personal communication, Dec. 15, 1997; see also Vivona, Ballin, Green, Bach, & McNally, 1996). The proposal provides for one person who would be responsible for a multiple-sector airspace, making decisions about traffic in that airspace, and delegating responsibility for tactical decisions to sector-level controllers. A goal of our project was to develop interface tools for a strategic controller position.

Dougherty, Gronlund, Durso, Canning, and Mills (1999) studied how air traffic controllers make strategic plans for en route traffic (high altitude, high speed traffic between destinations) using the radar screen and paper flight progress strips. They identified aircraft sequencing for approach to a common destination as a strategic planning task by analyzing controller verbalizations and use of flight progress strips. The specific sequence of a group of aircraft is determined by many factors– aircraft speed, altitude, destination, and airspace restrictions. Therefore, sequencing aircraft was a complex cognitive task that involved the consideration of many aircraft over an extended period of time. Dougherty et al. (1999) argued that controllers could benefit from an interface that supported planning the sequences of aircraft.

We begin by outlining the relevant aspects of the traditional air traffic control environment that guided our interface design. Following that, we describe the electronic planning aid and outline its design principles. Finally, we report the evaluation of the planning aid by comparing participants' planning performance using the interface to their performance in the traditional air traffic control environment.

Traditional En Route Air Traffic Control Environment

Air traffic controllers primarily use information from two different sources, the radar screen and the flight progress strips. The radar screen shows the spatial position and progress of aircraft, together with some characteristics of the controlled sector (e.g., boundaries and airways). The radar screen displays the spatial location of aircraft as well as the most vital flight information (identifiers, altitude, speed, and sometimes, flight destination). Discrete information



Detail of Screen 1: Electronic Planning Screen

Detail of Screen 2: Radar Screen

Figure 1. The dynamic linkage between the planner screen and the radar screen. On the radar, every diamond-shaped aircraft representation is linked to a datablock of flight information (in order from top, left to right: aircraft identification, altitude in 100 feet, computer identification number, and speed). The two aircraft on the radar screen (UAL755 and DAL80) are grouped into different categories of traffic (i.e., final destination Dallas and Unclassified). Different categories of traffic are represented in different colors. Aircraft are selected by clicking on them (UAL755). Moving the cursor over any token on the planning screen or a target on the radar screen puts a rectangle around the two representations (DAL80).

The planning aid allowed participants to categorize aircraft and updated that representation on the radar screen in the color corresponding to their category. Figure 1 shows two aircraft (UAL 755 and DAL80) that a controller placed into different categories. Because each column of aircraft was in different colors, participants do not have to encode and remember the categories of each aircraft after they were categorized because they were represented perceptually on the radar screen.

The planning aid also allowed the controller to automatically sort categorized air traffic according to time or distance to specific points (fixes) along the route. This information was displayed adjacent to each aircraft token. Note that this automatic sorting did not include higher-level conflict information; it simply was based on distance/time measures and therefore provided only an initial approximation of aircraft order. These initial sequences needed manual updating and checking. Participants also could get distance information between points on the radar screen by using a distance-measuring tool. This tool was similar to how controllers measure distance on traditional radar screens.

One essential consequence of this design was that a planned sequence could be perceptually compared with the current sequence by sliding the cursor across the sequence on the planning screen. This allowed the controller to observe how the sequenced position of each aircraft corresponded to its current position on the radar screen. Any discrepancy between the planned sequence and the current sequence was therefore made perceptually salient to the controller. If the planned sequence differed from the current sequence, this discrepancy signaled the need for modifications to either the planned sequence or to an aircraft's path. The discrepancy represented an important constraint as it guided the controller toward the aspects of the situation where control interventions were needed.

$\chi^2(1) = 17.07$, $p < 0.01$), of primary interest was determining the source of these differences. We compared the observed frequencies with the expected frequencies and determined how participants interacted with the radar screen differently in the two conditions.

Participants performed nine different types of actions on the radar screen (listed in Table 1). We compared observed frequencies for each action with expected frequencies assuming no differences between conditions (i.e., standardized residuals for each action and condition). The standardized residuals were calculated as the difference between the predicted and observed frequency divided by the square root of the predicted frequency. Table 1 displays the results of this analysis; the last column shows the standardized residuals. The model predicted the observed frequencies satisfactorily (within a 95% confidence interval) for all but three of the actions. This meant that these three actions occurred with differing frequencies in the two conditions. We discuss these three user actions in turn.

Select token. Participants selected significantly more aircraft on the radar screen in the strip condition than in the planning aid condition. Selecting an aircraft creates a border around its datablock that enhances its visibility. Participants in the planning aid condition did not need this perceptual aid as frequently, presumably because they could rely on the dynamic linkage between the two screens to perceptually locate aircraft on the radar screen.

Distance measurement. Participants measured the spatial distance between points on the radar screen more frequently in the strip condition. Distance information was crucial for planning, as it allowed estimation of when aircraft would reach specific points in the sector. Participants in the planning aid condition did not measure the distances on the radar screen as frequently, presumably because they could rely on the time/distance information that was presented to them next to each aircraft on the planning aid.

Datablock adjustment. Datablock adjustments included changing and adjusting datablock position. Participants adjusted datablocks more frequently in the strip condition than in the planning aid condition. As mentioned above, controllers declutter their radar screen to make datablock information visible. These adjustments are an important index of the usage of the radar screen. In the strip condition, participants had to get their flight information from the radar screen and had to declutter the radar screen to get to this information. However, when using the planning aid, participants adjusted datablock position less frequently and instead relied on the planning aid to review flight information. This was consistent with the greater ease of information access in the planning aid condition and more time spent in the strips condition on "housekeeping" functions.

Participants interacted with the radar screen less when they worked with the planning aid. They manipulated aircraft less (visually highlighted or marked aircraft less) and adjusted datablocks less often. They

Table 1.

Observed and Expected Frequencies for a Loglinear Model Assuming no Difference Between Experimental Conditions

User action	Frequency in strip condition	Frequency in planner condition	Predicted Frequency	Standardized residual for strip condition
Adjust Vector Length	3	6	4.5	-0.71
Invalid command (error)	72	83	77.5	-0.62
Zoom in/out	10	11	10.5	-0.15
Move information table	2	2	2	0
Altitude filter	12	10	11	0.30
Invalid track (error)	3	2	2.5	0.32
Select Token	482	408	445	1.75*
Distance measurement	108	56	82	2.87*
Datablock adjustment	661	520	590.5	2.90*

Note. * Observed frequency is outside a 95% confidence interval around the expected frequency.

aid condition. The planning aid especially was beneficial in this situation because adapting plans to the current traffic situations depended strongly on the integration of planned sequence information with the current air traffic situation. The planning aid was designed to do exactly that. Participants could see on the radar the sequence of aircraft that they had proposed on the planning aid. By sliding the cursor over the corresponding aircraft on the planner, they could see how the plan was progressing. This visual display of a planned sequence on the radar gave the controller an important indication of where changes were required. Aircraft that were out of sequence and did not "light-up" where they should have would focus the participant on relevant decision points.

The current interface has many characteristics of an ecological interface (e.g., Effken, Kim, & Shaw, 1997; Lintern, 2000; Pawlak & Vicente, 1996; Rasmussen & Vicente, 1990; Vicente & Rasmussen, 1990). Ecological interface design argues for a perceptual formulation of user goals within the interface. The interface then facilitates actions as the user perceives his or her goals mirrored in the affordances of the interface. In this way, the interface guides users' interactions without major intrusions or the need for automation. It replaces effortful cognitive processes with parallel, perceptual processes.

Perceptual information integration proved a successful design principle when we examined the cognitive task of planning air traffic in isolation. Future experiments should be directed at integrating strategic planning with other controlling tasks (e.g., tactical planning). Only then can it be determined if the planning aid can replace strips, or if other controller tasks still require the availability of paper flight progress strips. Also, it is important to keep in mind our focus on strategic planning and the accompanying decision to isolate the strategic planning tasks from the tactical planning tasks by assigning these responsibilities to two different individuals. It is possible that a single controller responsible for both tactical and strategic planning would not find the planning aid useful. However, that was not the goal of our project; the goal was to develop an interface for a possible future strategic controller position. A different interface may have resulted if our goal had been to develop an interface to enhance the strategic planning capabilities of a controller working a sector alone. An important next step will be to compare the planning aid with conflict probe software to determine what aspects of the air traffic control task can best be accomplished through information re-organization and what can be best handled by automation.

Recent research suggests the advantage of active control over passive monitoring in air traffic management (e.g., Metzger & Parasuraman, 2002). Our findings can be applied to the design and evaluation of interfaces that keep the controller in-the-loop. Specifically, reliance on perceptual processes could serve as an alternative to outsourcing plan development to a piece of software. This allows the controller to do what humans are good at (parallel perceptual processing) while allowing the computer to do what it is good at (organization and linking information). Simple modifications to the perceptual properties of an interface will decrease task difficulty and increase human performance without impinging on higher-level cognition. Furthermore, the perceptual optimization of interfaces should be accompanied by an empirical analysis of behavioral differences between the new and old interface. As a result, tasks that are best accomplished by a human operator could be delineated from those more appropriately left to a computer. The design and evaluation of interfaces would benefit from this process.

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