User Study: Air Traffic Control Interface

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Abstract
A lot of HCI work has been done focusing on Air Traffic Controllers (ATC). Specifically, artifacts such as the flight progress strip have been studied in depth with varying results. In this project, I have done a user study to investigate further the bridge between digital data accessed by controllers and the static data that is printed and annotated on flight strips. My primary point of focus has been the behavior of controllers in high traffic periods as opposed to average to low traffic loads. With the continued call to eliminate paper strips from control towers, this study seeks to verify the usefulness of paper strips. The study shows that a combination of paper strips and digital strips is what controllers prefer. While the controllers want to use digital strips because of the significant functionality obtained from them, paper strips are still maintained as a backup interface because of their inherent reliability.

Keywords
Air Traffic Control interface, paper strips, digital strips

Introduction

The interface for air traffic controllers has been a point of focus for a lot of HCI work. With the digital wave sweeping through many facets of society, there has been increased pressure by information technology advocates to completely digitalize control towers. Citing obvious advantages of digital systems, tremendous effort has been done to get rid of paper strips. Some of these advantages are well outlined in numerous papers published and include the ability to interact with data in real time e.g. to radar, better prediction of flight events resulting to more effective planning, automatic information update, etc. Despite the named advantages, various projects that have focused on replacing paper strips have failed. It has been noted that the failure of these projects is largely attributed to ignoring the affordances of paper such as reliability, efficiency in use, flexibility in annotating, etc. Therefore, the human factors perspective has not been given as much weight as it deserved resulting expensive mistakes. Although most of the research has focused on eliminating flight strips, some research has focused on making the existing paper strips better instead of eliminating them thereby achieving the best of both worlds. Suggested solutions include use of augmented paper strips with interaction capability to the rest of the digital system such as barcodes and electronic pens.

This study seeks to understand the way controllers interact with the interface. Specifically, a keen look is taken at the

role of paper strips, and how these can be improved to obtain a better work experience for the users. Three interaction methods are provided – use of paper strips, use of digital strips, and use of augmented paper – and the controllers decide what is optimal for them. The findings of the study indicate that controllers prefer a combination of digital strips and paper strips.

To proceed on, we shall first look at the previous work that has been done in this area, and then proceed to identify the problems that have been tackled and those not yet solved. We will then look at the methodology used in this study, the results obtained, discussion of the finding and finally the conclusion.

Previous work

As mentioned earlier, significant work has been done in this area. Benefits of paper flight strips have been outlined in several publications (Mackay, 2000). Some work has been done focusing on preserving the coordinative functions of the current system in any newly developed electronic systems [1]. Work has also been done on having systems that completely replace paper strips by transferring all the paper functionality to a digital platform. Some of this work involves use of electronic strips with various color codes and animations to depict certain events. Others [Mackay] have developed various approaches of using augmented paper such as use of resistors on the strip rack to monitor the positions of the strips therefore gain better visualization of aircraft. Prototypes have also been developed whereby the paper flight strips are encoded with information that can be scanned by an electronic pen that communicates with the rest of the digital system. The use of PDAs as a replacement of flight strips has also been suggested citing its mobility and wireless connectivity potential. Research continues in many of these areas.

Throughout this project, it has been interesting to note the clear distinction between two camps; one that favors paper strips (including augmented strips) and one that proposes the complete elimination of the same. The camp that favors paper strips stresses on the affordance that paper provides. This camp also advocates for the use of augmented paper strips whereby paper is given some electronic characteristics while still maintaining its physical form. The other (electronic strips) camp claims that all paper functionality can be transferred to an electronic medium, and additional functionalities added. However, none of the work has been done in combining both approaches as an acceptable solution. This is probably because of the general agreement that having one interface is better than having multiple interfaces. The results obtained in the user study done in this project favor having two separate interfaces. The implications of this will be probed further in the discussion section.

Typical Scenario

A control tower controls airspace in a center. A center's airspace is divided into different regions, and each region has several sectors. The sectors can be adjusted by the center administrators as appropriate to conform to traffic loads. Adjustment includes combining sectors into one sectors, or diving a sector into two or more sectors.

Each sector is manned by at least three controllers, the R, the D and A. The R (radar) controller is the main paint of contact between the tower and the pilot. He/she is responsible for communicating with the pilot information about attitude, speed, emergency messaging, etc. He is the one in constant touch with the flight strips and annotates on them as appropriate. The D (data) controller sits next to the R controller and is responsible for providing all the required data to the R controller. This is the person who would consult with Air Traffic Publications on various protocols and flying equipment. He would also avail various sectionals (large maps) and approach plates to the R controller. When the R controller takes a break, the D controller could fill up his space temporarily. Lastly, there is the A (assistant) controller. He sits next to the printer that prints out the paper flight strips and is responsible for making sure that they are properly printed and displayed on the paper strip bay. He would also be the one moving around the tower to collect any other information needed by the R or D controllers.

Flight strips feature prominently in the work of controllers as far as monitoring air traffic is concerned. A typical strip would contain the relevant information needed by a controller about a flight such as callsign (e.g. DAL for Delta Airlines), aircraft type, navigation equipment, altitude, flight plan, etc. In addition to the information printed, controllers annotate the strips with both short and long-time flight amendments and other symbols which aid situational awareness.

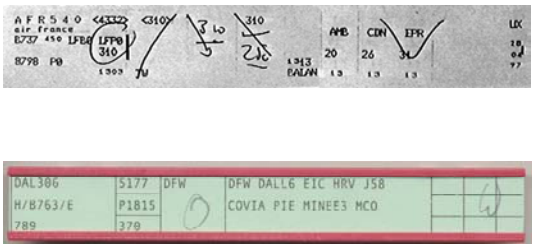

Figure 1: Annotated paper strips

The flight strips are placed on strip bays that hold the strips in columns as shown on the figure below. As aircrafts approach a sector, the controllers make sure that they have the corresponding flight strip for that aircraft. Generally, the first aircraft to enter the sector would be the last one first one to leave. Strips on the strip bay are arranged in such a way that the strips near the top of the bay represent aircrafts about the leave the sector's airspace.

Figure 2: Strips on a strip bay

When a controller is working, several actions are done simultaneously. For instance, each sector could have several aircrafts of different specifications and with different flight plans. The controller is responsible for feeding both the pilots and the ground crew (if applicable) with information that enforces the laid down protocols. To do this, he/she must access several sources of information such as the radar, flight strips, maps, etc.

Figure 3: Controllers working

He must also communicate using his voice (on radio) and with a pen when writing on the flight strips. While this is going on, care is taken to make sure that the traffic load does not overwhelm the controllers. The supervisors closely monitor the work of the controllers and assign them duties depending on the traffic loads. While working, the controllers need to have a visual of the aircrafts just about to enter their sectors and must first check to make sure they are able to man them before they get in, therefore and acknowledgement is needed. The controllers are responsible for spacing the aircrafts on both the horizontal and vertical (altitude) plane for safety concerns.

Given the general user scenario above, I designed a user study to investigate the controller interface from the user's perspective. Specifically, I wanted to know whether controllers prefer the functionality afforded by augmented paper strips as compared to either plain paper strips or digital strips. My claim was that the use of augmented paper would provide an ideal bridge between the paper (static) media and the electronic media in control towers. This benefit would translate to better visualization of aircraft by the controllers, better time efficiency in performing controller tasks, and a general improvement in planning and control of tower events such as flight scheduling.

Methodology

For this user study, the target subjects were present or former controllers, and people with an intimate familiarity with the work of air traffic controllers and their artifacts especially the paper flight strips. These include human factors engineers in various ATC-related projects, requirements specialists and developers. The subjects included eight controllers, two engineers and two developers.

Three of the controllers I spoke with had worked with both paper strips and their digital equivalent, hence were in a favorable position to offer a comparative analysis of both systems. Two of these were undergoing training on a digital system (URET). Both of the engineers I spoke with had experience in designing electronic systems to replace the paper flight strips. They were knowledgeable on the functionalities of the paper strips and requirements of an equivalent digital system.

Depending on the subjects' availability, I interviewed them or had them fill a questionnaire or do both. The key questions to be answered included an overall rating of the paper-based strips, an evaluation to get feedback on use of augmented paper, and an overall review of the all-digital system. For the controllers not familiar with augmented paper, I took time to explain to them what these were and their capabilities based on previous research and implementations.

Results

The results obtained from this user study were in contradiction with a lot of the previous findings in the field. Whereas previous research has shown that controllers generally prefer air paper flight strips as compared to digital strips, this study's results indicated a digital strips preference. Possible reasons for this discrepancy will be explored in the discussion section of this paper.

Five of the eight controllers interviewed were not familiar with augmented paper. Even after explaining to them how this paper would work for their situation, they had difficulty visualizing its benefits, and clearly opted for an all-digital or purely paper-based strips.

Nine of the twelve people interviewed liked the idea of having digital strips citing their added functionality. This included two thirds of the controllers. The remaining three subjects were hesitant to accepting the digital system. The results are summarized on table 1 below. Those who were opposed to digital strips attributed their dislike to safety concerns and familiarity with the paper-based system. They also pointed out that paper strips were easier to write on compared to the equivalent in an electronic environment.

Subject	**Like digital strips**	**Don't Like digital strips**	**Total**
Controllers	6	2	8
Non Controllers	3	1	4

Table1: Opinion on use of digital strips

On the question of augmented paper, it was interesting to note that most of the subjects preferred the electronic system. These results are summarized on table 2 below. However, all subjects interviewed insisted on having the paper strips in the control tower incase of system failure or any other unseen eventuality. They cited the fact that paper is reliable and can always be counted upon even when the electronic system goes down.

Subject	**Like augmented strips**	**Don't Like augmented strips**	**Total**
Controllers	1	7	8
Non Controllers	1	3	4

Table 2: Opinion on augmented strips

Based on the user feedback, the following points can be made as a comparative analysis of the various systems.

1. Reliability

Paper strips were seen as clearly more reliable than digital strips. This is because paper is always available. The greatest problem pointed out by the subjects interviewed was recovering from automation outages. This is fear will not be realized with the use of paper strips.

A persistent concern that would envelop any digital system is the possibility of a power outage. The study found out that precautions have been instituted to take care of this event. These include the use of redundant processors and power supplies, use of backup paper strips, and a requirement that controllers memorize the maps for the areas they control.

2. Accuracy

With a digital system, accuracy of data can almost be guaranteed. This is because human error is as far as entering information is reduced. In addition, the system is designed to reject invalid values and notice outlier entries. One concern noted in the study is that confusion is sometimes caused by failure to understand the controllers' handwriting in the annotations on the flight strips. This situation is completely avoided in an electronic system.

3. Time Efficiency

One observed drawback of the electronic system was the need to perform multiple steps to accomplish tasks previously easily accomplished by much shorter and quicker steps. Those familiar with both systems said that this concern was more evident in the initial training periods and its significance dwindled with experience of the new system. On the other hand, an electronic system dynamically does a lot of the updating of the data itself. With the constantly increasing volume of equipment in the air, it is crucial that the work the controllers do per aircraft be reduced so that they are able to cater for larger volumes

4. Space Efficiency

The use of the Better utilization of real estate at the controller terminals was welcome by many controllers. Without the bay for paper strips, more room is left for making the other displays larger or displaying additional needed information such as references to callsigns, aircraft information and airport facilities directory

5. Cost

A concern voiced by the engineers and developers is the cost of developing an electronic system. This is compounded by the effort involved in synchronizing the digital media with the database that prints out the flight strips.

6. Acceptability

For some of the controllers, there was a reluctance to learn the new system so they preferred using what they already know well and works. Specifically, one electronic system [URET] needed the controllers to memorize a set of color codes to represent certain events and actions.

7. Monitoring and Control

Unlike paper strips, an electronic provides better monitoring of the system status. This is because all the data is electronic and can be displayed in various forms to identify patterns and various events. Conflict avoidance is much better achieved by the electronic system too. This is because any changes made on the electronic strips (or any other part of the system) are immediately propagated into the rest of the system therefore making more accurate predictions of events to come. For example, the information snapshot at a specific time could tell whether a controller will have heavy airspace an hour hence, therefore leading to re-routing some of the aircrafts to balance off the load.

Discussion

A striking difference between the results in this user study and results obtained in other studies is that most users interviewed preferred the electronic system. This difference could be attributed to various things.

First, this could indicate shifting attitudes of users based better products that have the user experience in mind. Whereas previous research looked at replacing the functionality of paper strips in digital strip, current systems have sought to do more than this. They have added functionality not able to be met by paper strips. This includes tools for prediction and pattern recognition.

Secondly, the fact that few of the subjects interview expressed interest in augmented flight strip could be attributed to the fact that they were not well exposed to the same. All the information they had about augmented strips is based on the information I gave them, and this clearly does not capture the whole picture. It is possible that had they have seen a video of augmented paper strips being used, or maybe had a chance to use it themselves, their attitude towards augmented paper strips would change.

Thirdly, most of the user studies referenced in this paper happened in Europe. It is possible that the presence of stronger Air Traffic Controller Unions their gave controllers a stronger voice as far as resistance of changing work habits is concerned. The equivalent here in the USA is the National Air Traffic Controllers Association (NATCA).

This being said, virtually all the subjects in the study wanted to continue having paper flight strips in case of emergency periods. Although they accepted that paper is more reliable, the benefits provided by an electronic strip far outweighed the benefits of paper. It is clear to see that one shortcoming of this could be unfamiliarity with the paper strips after prolonged times of using the digital system hence defeating the whole purpose of the exercise. A possible solution to this dilemma could be regular training (real or simulated) on the use of paper strips. Most of the users were confident about the availability of the electronic system and did not seem overly concerned about events such as power outages. However, as pointed out earlier, the subjects saw recovering from outages as a major drawback of the electronic system. Being a new system, many of the practices are still being refined. In the event that an outage occurs, paper strips together with the flight strip bays have to be quickly replaced and strip markings updated to conform to the actual status of the aircraft.

Although the subjects' age or experience as controllers was not collected and recorded in this study, it was generally observed that older controllers were less receptive to changing the system from paper-based strips to digital strips. On the other hand, the younger controllers showed more enthusiasm in adopting the electronic system. This could be due to the expected reluctance by long-time users to change their time-proven work habits.

Contrary to my initial expectations, the tower supervisors were more positive about the deployment of a digital display system than the controllers. They saw and better understood the benefits such a system would provide. Specifically, they were impressed by the fact that one controller could control more airspace with the digital system. This would result in less administrative work as far as combining and de-combining airspace sectors is concerned. In addition, a digital system offered them better

control, monitoring and visualization of the entire system. One of them spoke about a new messaging system still in development that would provide an email link between the towers and the pilots. This would drastically cut down on the radio communications and eventually replace many of the actions the controllers do in its fully automated deployment. The drawback on this is that aircrafts would have to be fitted with the equipment to communicate with the new system.

Conclusion

The information obtained from this study paints a different picture from most of what has been referenced material. The study indicates that a combination of the electronic system and the paper strips is what the users want. Previous research has focused on providing one or the other and therefore ending up in concluding in favor of paper strips or digital strips. Based on the findings of this study, it is suggested that more work be done streamline the process of returning back to paper strips in the event of system outages. Presently, more work is being done to assure the availability of the digital system than ensuring a smooth crossover between the two systems. It is generally accepted that the current state where both systems are kept in parallel to each other is temporary, and the eventual goal is to totally get rid of paper flight strips.

As part of future work, I would like to develop a prototype augmented flight strips and have controllers get a feel of them, in addition to watching videos of the same. Hopefully, this will provide them with a better understanding of how these work and enable them to make better comparisons. If the same results are obtained in such a study, then it would be acceptable to claim that most controllers now prefer digital strips than paper strips.

References

1. The Coordinative Functions of Flight Strips:Air Traffic Control Work Revisited
Johan Berndtsson,Linne Group, Maria Normark,Royal Institute of Technology, Sweden

2. An Interactive Electronic Flight Progress Strip Prototype
Nathan A. Doble,R. John Hansman, August 2002

3. Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control
Wendy E. Mackay, University of Aarhus

4. Visual re-representation of database information: the flight data strip in air traffic control
Shapiro, Dan Z.; John A. Hughes; David W. Randall; And Richard H. R. Harper

5. Reinventing the Familiar: Exploring an Augmented Reality Design Space for Air Traffic Control
Wendy E. Mackay, Anne-Laure Fayard, Laurent Frobert and Lionel Médini Centre d'Études de la Navigation Aérienne

6 .An Augmented Stripboard for Air Traffic Control
Lionel Médini, Wendy E. Mackay

7. The ERIDS Project, Computer Sciences Corporation (CSC) and Lockheed Martin, Rockville, MD

8. The Myth of the Paperless Office
Sellen and Harper [MIT Press], 2002

9. User Request Evaluation Tool (URET) Project
Lockheed Martin, Rockville, MD