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Reduced Flight Progress Strips in En Route ATC Mixed Environments

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16. Abstract

Currently, en route control of high altitude flights between airports uses computer-augmented radar information available on the Plan View Display (PVD), Computer Readout Device (CRD), and flight information printed on Flight Progress Strips (FPSs). The FPS contains thirty-one fields that supplement data available on the PVD. While an aircraft is in a controller's sector, control instructions, changes to the flight plan, and other contacts with the aircraft are written on the corresponding strip. This report describes an experiment that compared the effects of using a standard-sized (1 5/16" x 8") FPS and an FPS reduced both in size (1" x 5") and information on the performance and workload of controller teams. The teams, from Minneapolis ARTCC, controlled simulated air traffic in a mixed radar-nonradar environment. Overall, the 1" x 5" reduced strip yielded deficits in the control of nonradar flights but not radar flights. This was evidenced in subject matter experts' evaluation of nonradar separation, strip processing and board management, and, to a marginal extent, in the efficiency of traffic movement through the sector. The radar-side (R-side) controller's awareness was also rated lower when using the smaller strips. Interestingly, the controllers' evaluation of their own performance did not reflect a difference between smaller and normal-sized strips. This may help explain why controllers did not compensate for the smaller strips to any great extent. Only R-side controllers exhibited compensatory behaviors and reported increased workload. R-side controllers also pointed to the PVD more often. Although there was little compensatory activity, R-side Controllers thought workload was greater with smaller strips. R-side controllers also felt it was more effortful and more frustrating working with the 1" x 5" strips. Despite the self-reported heavier workload, controllers nevertheless were able to perform secondary tasks, such as granting pilot requests, as often and as quickly using smaller strips as they did using standard strips. This study also described specific air traffic activities likely to be affected by a reduction to a 1" x 5" FPS. Strip marking, speed of strip processing, and some aspects of board management seemed especially affected. Inferior strip marking was evidenced in the on-line expert evaluation and controllers often reported that the size of the 1" x 5" strip prevented writing. The ability to locate a particular strip and find the information on it seems to suffer with a reduction in size as tested in this study. On-line expert evaluations and controller opinions echoed this problem. Locating strips might have been especially difficult for the R-side, thus leading to large differences in self-reported frustration. Controllers also noted specific problems with the strip display, including the use of shading to replace information typically presented in red. Of board management responsibilities, considered by controllers as generally inferior with 1" x 5" strips, removal of deadwood seems less likely to be negatively affected by reduction in strip size. The on-line expert evaluation rated the 1" x 5" strips negatively and the subject matter experts recorded more negative comments about removal of deadwood under that condition. Overall, this study does not permit recommendation of the 1"x 5" reduced strip as designed for this study. Suggestions for improving a less than standard size FPS are provided.

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Executive Summary

Currently, en route air traffic control depends on computer-augmented radar information available on the Plan View Display (PVD), Computer Readout Device (CRD), and the flight information available on the Flight Progress Strip (FPS). Thirty-one fields for information are printed on the strips. This information supplements the data available from the PVD. While an aircraft is in the controller's sector, the controller writes on the corresponding strip to reflect the control instructions, any changes made in the flight plan, and other contacts with the aircraft.

This report describes an experiment that compared the effects of using a standard-sized ($1^5/_{16}$" x 8") FPS and a smaller (1" x 5") FPS containing less information on the performance and workload of controller teams. The teams, from Minneapolis ARTCC, controlled simulated air traffic in a mixed radar-nonradar environment. Overall, the 1" x 5" reduced strip yielded deficits in the control of nonradar flights but not radar flights. This was evidenced in the subject matter experts' evaluation of nonradar separation, strip processing and board management, and, to a marginal extent, in the efficiency with which traffic was moved through the sector. The R-side controller's awareness was also rated lower when using the smaller strips. Interestingly, the controllers' evaluation of their own performance did not reflect this difference between reduced and normal strips. This may help explain why controllers did not compensate for the smaller strips to any great extent.

Only the radar-side (R-side) controller exhibited any compensatory behaviors and only the R-side reported increased workload. R-side controllers pointed to the PVD more often. Although there was little compensatory activity, the R-side controller felt the workload was greater with the smaller strips. The R-side controller felt it was more effortful and more frustrating working with the 1"x 5" strips. Despite being under a self-reported heavier workload, the controllers nevertheless were able to perform secondary tasks, such as granting pilot requests, as often and as quickly using the smaller strips as they did using standard strips.

This study also supplied information about the specific air traffic activities likely to be affected by a reduction to a 1" x 5" FPS. Strip marking, speed of strip processing, and some aspects of board management seemed especially affected. Inferior strip marking was evidenced in the on-line expert evaluation and the controllers often reported that the size of the 1" x 5" strip prevented writing. The ability to locate a particular strip and to find the information on the strip once it was found seems to suffer with a reduction in the size of the strip used in this study. The on-line expert evaluation and the controller opinions echoed this problem. Locating strips might have been especially difficult for the R-side, thus leading to the large difference in self-reported frustration. The controllers also noted specific problems with the strip display, including the use of shading to replace information that is typically presented in red. Of board management responsibilities—considered by the controllers as generally inferior with 1" x 5" strips—removal of deadwood seems less likely to be negatively affected by reduction in strip size. The on-line expert evaluation rated the 1" x 5" strips negatively and the subject matter experts recorded more negative comments about removal of deadwood under that condition.

Overall, this study does not permit recommendation of the 1"x 5" reduced strip as designed for this study. Suggestions for selecting a less than standard size FPS are made in this report.

Reduced Flight Progress Strips in En Route ATC Mixed Environments

Introduction

The Federal Aviation Administration (FAA) has been engaged in an intense effort to modernize the equipment that controllers use to help ensure the safe and expeditious movement of the nation's air traffic. For reasons detailed elsewhere, attempts to completely modernize the system have met with only partial success. Plans for the Initial Sector Suite System (ISSS) have been revised significantly. The state-of-the-art common-consoles that were the technological underpinnings of ISSS are available and will be placed in the field soon.

Unfortunately, the efforts to automate the presentation of flight data have been less than successful, and the common console is no longer planned to incorporate electronic renditions of aircraft flight progress strips. Thus, the problem is to take maximum advantage of the functional aspects of the common console, while providing controllers with the flight data information they need to separate aircraft.

Currently, en route flight progress data are presented on 1 5/16" x 8" strips of paper called Flight Progress Strips (FPSs). The FPS includes 31 fields in which information about a particular flight is presented by the computer or entered and modified by the controller. A figure of the current FPS, together with an explanation of the fields, can be found in FAA Order 7110.65 and is reproduced in Figure 1 of this report. The FPS is placed in a plastic strip holder and these holders are sequenced and manipulated in vertical bays next to the radar scope or plan view display (PVD). If the 8" FPS is retained, a bay of these strips will quickly cover the radar associate's side of the common-console, making access to the console's technology difficult, if not impossible.

The 1" x 5" Flight Progress Strip

One solution to this problem is to present controllers with flight progress data in much the same way that it is currently presented, but to reduce the size of the FPS so that more of the new equipment is accessible by the controller. However, the functionality of the FPS could be threatened by reducing its physical size or by eliminating some of the 31 information fields. The FPS not only supplies information to the controller, it is written on and modified by the controller. Thus, a smaller strip and its concomitant reduction of constituent information could affect both the controller's ability to locate and extract information about a flight and the ability to find enough space to update and modify information on the strip. Some writing space can be gained by eliminating

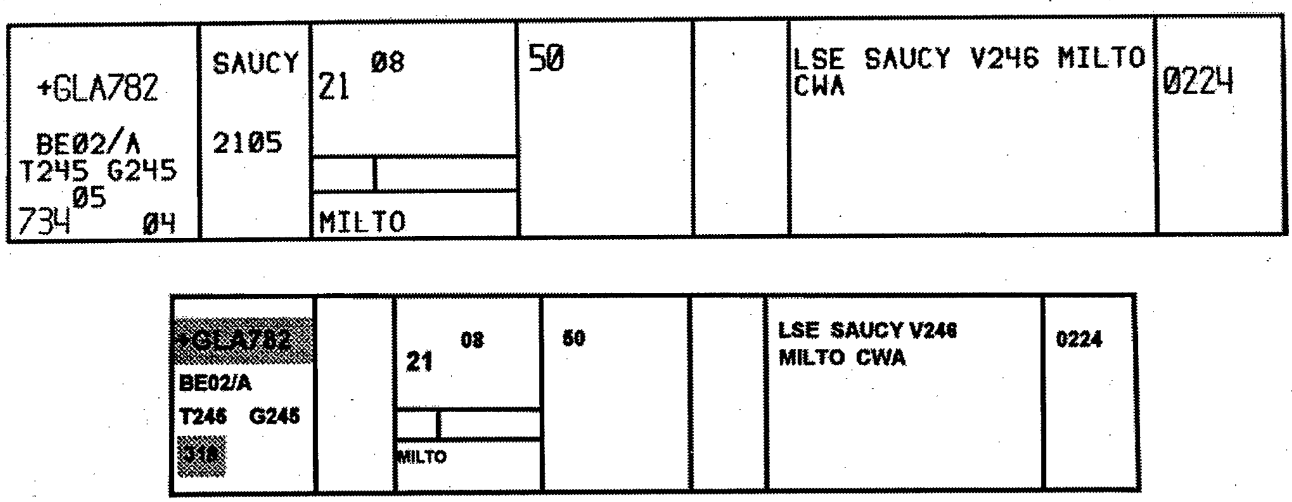

Figure 1. Examples of flight progress strips used in this study. On top is the flight progress strip (FPS) used today. On the bottom, is the 1" x 5" reduced flight progress strip (RFPS), which has the call sign and computer ID in bold.

fields that are no longer of value to the controller— and this was done in the current study. It is important to ascertain whether controllers can effectively control traffic when the FPS is physically reduced in size and some of the fields typically found on the FPS are no longer present.

There is some evidence that removal of information on the FPS would not necessarily hurt ATC performance (Albright, Truitt, Barile, Vortac, & Manning, 1994; Vortac, Edwards, Fuller, & Manning, 1993; Vortac, Barile, Albright, Truitt, Manning, & Bain, 1996). Vortac and colleagues have shown that, at least in some types of sectors and situations, the amount of information on the strip can be pared considerably (Vortac et al., 1993; 1996) or in some cases research suggests that the strip may be eliminated altogether (Albright et al., in press). Although the controller was often forced to compensate for the lack of an FPS (e.g., by doing a Flight Plan Readout (FPR)) there was not necessarily an increase in workload or decrease in performance. In fact, in some cases, the controller was able to spend more time looking at the PVD (using FPRs in lieu of strips) than was the case with full FPSs. In another case, with only a one-line 5-field strip and no permitted strip-marking, some aspects of ATC were actually superior to a full FPS condition in which the controllers were required to mark the strips. Finally, the Air Traffic Rules and Procedures Service has recently given en route facilities some latitude in the use of strips. Thus, it is not unreasonable to assume that removal of information from the current FPS may be a benign modification of the way flight data are presented.

One caveat to the above argument is that, to date, efforts to test the limit of FPS information have used only sectors in which the flights are continually tracked by the radar. In mixed environments, where some flights are never under radar control, and where others enter and leave radar control, the role of the FPS and its constituent fields seems especially critical.

Our team was charged with determining the effects of reducing the size of the current FPS. We began by consulting with air traffic specialists at the FAA Academy and then with specialists and National Air Traffic Controller Association (NATCA) representatives at the Minneapolis Air Route Traffic Control Center (ZMP). All consultants were intimately familiar with controlling traffic in mixed environments. The purpose of these consultations was to determine what information, if any, could be eliminated from the FPS. Final determination of the information to be presented on the reduced FPS (RFPS) was left to the controller consultants, who as a body tended to be conservative in what information was removed. For example, although only one controller felt that groundspeed was important, groundspeed was, nevertheless, retained on the RFPS.

The blank RFPS was identical to the current en route FPS but was reduced proportionately to 1" x 5" dimensions. Thus, all line demarcations were retained on the RFPS. However, a number of fields in which computer-generated information typically appeared were left blank on the RFPS. Specifically, the RFPS no longer contained the verification symbol, revision number, sector number, revised ground speed, strip number, previous fix information (including estimated time), and next posted fix. Font size was also reduced.

Finally, we were instructed to indicate information that currently appears to the controller in red (e.g., CID, special routing, and callsigns) with shading. Although from a human factors point-of-view, if shading reduces contrast too dramatically it is unlikely to be a viable candidate for increasing the readability of critical information, the printer targeted to print the RFPS that will be used with the common console will be incapable of printing color. Nevertheless, to preview one finding of the report, we recommend that any monochromatic highlighting of critical information use a method other than shading (e.g., bolding or boxing).

The 1" x 5" RFPS with eliminated information, and with shading replacing "red information," appears in Figure 1. The FPS for the same flight is reproduced for comparison. The current experiment compared the efficiency and effectiveness of air traffic control using the full FPS with the efficiency and effectiveness of the RFPS.

Method

Site

The study was conducted at the Minneapolis Center (ZMP), one of 20 Air Route Traffic Control Centers (ARTCCs) in the United States. ZMP is responsible for airspace from the Canadian border to northern Kansas, and from eastern Michigan to the western Dakotas. ZMP has a number of mixed sectors: Air traffic is under both radar and nonradar control. The nonradar volumes of airspace exist because of a lack of radar sites throughout the center's airspace and not, for example, because of geographical impediments to radar coverage.

Participants

Twenty pairs of controllers participated in the study. Thirty-nine were full performance level (FPL) controllers and one was a developmental (checked-out for the sector). Mean time as an FPL at ZMP was 7.43 years, and ranged from 0 to 21.0 years. The controllers had worked in their current area for 8 years (range .58 - 13.25). All teams except one comprised controllers who had worked together operationally as Radar-side (R-side) and Data-side (D-side) teams prior to the experiment. For the experiment, one member of each team served as R-side and one served as D-side for both scenarios. The participants decided who would perform which duties.

Airspace

Two sectors from ZMP were used in the study (Sector 1, Area 1; Sector 5, Area 2). Both sectors have substantial amounts of nonradar traffic, in addition to flights under radar control. The sectors were chosen in consultation with our subject matter experts (SMEs), one from Area 1 and one from Area 2.

Ten teams were from ZMP's Area-1; for the purpose of this experiment, they controlled simulated traffic in the Pellston (Sector 1) sector.

The official sector 1 description

Sector 01 works all performances of aircraft from the ground to 12,000 feet MSL. At Pellston (PLN) it is nonradar 5,000 feet and below. South of PLN this increases to 7000 Feet MSL and below, and to the north of PLN this increases to 10,000 feet MSL and below. The sector becomes active in the summer months with a large amount of recreational traffic. The complexity of this sector becomes evident with the numerous overlapping approaches coupled with the nonradar areas. Controllers work with two Approach Controls, Saginaw (MBS) and Collins (APN). MBS is ARTS equipped for automated hand-offs and flight plans are passed via computer. APN requires manual coordinations of flight plans and manual hand-offs. Sector 01 is bordered on the north and east by Toronto Center (YYZ), to which (the controller) must coordinate manually both for flight plans and radar hand-offs. Sector 01 is bordered on the south by Cleveland Center, Flint Sector. Sector 01 is bordered on the west by Minneapolis Center sectors 02 and 03. (Taken from the facility's sector narrative, ZMP7220.1).

Ten teams were from ZMP's Area-2; for the purpose of this experiment, they controlled simulated traffic in the Eau Claire (Sector 5) sector.

The official sector 5 description

Sector 05 is a low altitude sector (0 to 23,000) involved in handling a broad array of traffic. Though generally small in area, sector 05 is a fast moving sector. The two airports generating the most traffic are Eau Claire (EAU) and La Crosse (LSE). EAU has 4 IFR approaches. The BC Rwy 4 and ILS Rwy 22 are the most commonly used and vectors can be provided for the final approach course at the BC Rwy 4. Radar coverage west of EAU is generally 3000 to 4000 feet MSL, while east of the VOR coverage below 6000 feet is marginal at best. Thirty to 40 miles southeast of EAU coverage does not exist below 8000 feet. At LSE, there is a part-time VFR control tower. The ILS Rwy 19, VOR Rwy 13, and the VOR Rwy 36 approaches are most commonly used. Radar vectors are provided to the VOR Rwy 13 and VOR Rwy 36 final approach course while radar coverage north of LSE makes vectoring for the ILS Rwy 18 approach very difficult. Coverage below 5000 feet north of LSE is very limited. In addition, approach services are provided for numerous small airports scattered throughout the sector. Sector 05 works closely with Rochester (RST) and Waterloo (ALO) approach controls located in the southwest corner of the sector. RST Approach owns 8000 feet and down while ALO owns 10,000 feet and down. A part-time GCA unit operates at VOK field just east of the sector 05 boundary. They own 10,000 feet and down. There is also a part-time VFR control tower located at the Fort McCoy (CMY) airport. Two restricted areas and 2 MOA's are used within the sector. The traffic flow is generally east to west consisting of all types of aircraft. Sector 05 remains open all of the time. All other sectors within the area combine at Sector 05. (Taken from the facility's sector narrative, ZMP7220.1).

Design

Each team controlled air traffic during two scenarios, once using full FPSs and once using the 1" x 5" RFPSs. Order of the scenarios, order of the strip-condition (FPS or RFPS), and assignment of strip condition to scenario were counterbalanced across the teams, such that each scenario appeared equally often as first or second, each type of strip was used equally often first or second, and each scenario was controlled using each type of strip equally often.

Scenarios

Scenarios were constructed and tested by the area SME. Two 50-minute scenarios, comparable in difficulty and realism, were constructed for each area. The scenarios were intentionally designed to exercise the use of the flight strips, sometimes including situations experienced in the field, but at a somewhat higher rate. For example, departures from small airports make use of the flight progress strips, but their typical occurrence in the field was less frequent than in our experimental scenarios. When asked about the realism of the scenarios, 53% found nothing unrealistic about the scenarios. The only differences between the simulated scenarios and their typical live traffic mentioned with any frequency (>1) were busy small airports (9) and more nonradar traffic (5).

The scenarios were tested and modified by the SMEs until they appeared comparable in difficulty, realism, and complexity. Characteristics of the 4 scenarios appear in Table 1.

On-line Production of Reduced Strips

Plastic strip holders for the RFPSs were created by removing the middle 3" from the strip holders used in terminal facilities. The strips used by terminal controllers are only 1" in height, neatly fitting the requirements for the current study. Similarly, the paper used to print terminal strips was used to print the RFPS. The paper, perforated every inch, was the same color as current en route FPSs, and was blank on one side, allowing us to create the RFPS on the blank side of the strip. A wooden strip bay with metal dowels was constructed to permit the sequencing and manipulation of the smaller RFPS.

Because it was not possible to interface directly with the HOST to produce the RFPSs, we utilized a program (i.e., STRIPS) written by the staff at ZMP explicitly for the purpose of quickly translating full FPSs into the RFPSs. An experimenter sat next to the HOST's printer and removed FPSs as they were made available. This experimenter identified the call sign to another experimenter operating the STRIPS program. The call sign was used to retrieve the relevant strip from a database of potential strips. The experimenters then changed the computer identification number (CID), any times (hours and minutes) on the strip, and the flight's beacon code. Because the CID, time, and beacon code depended on the time period during which the problem was presented, it was necessary that these pieces of information be entered for each execution of the scenario. For reroutings made by controllers during the scenario, the experimenters either pulled up a strip from the database, anticipating that rerouting, or modified an existing strip in the database to accommodate the route change. Obviously, the process of removing strips from the HOST printer, translating them, and then printing them on the terminal forms took longer than simply removing strips from the HOST printer. This delay was reduced considerably by having the SMEs indicate which of the several strips printed for a particular flight was, in fact, one that a controller would use for the flight. Nevertheless, it is undeniable that controllers received strips more slowly in the RFPS condition of this experiment than they would when a dedicated printer is interfaced directly to the HOST. Finally, the translated RFPS was printed on an EPSON laser printer and handed to a ZMP developmental who placed the RFPSs in holders and delivered the strips (i.e., A-side) for the simulations.

Dependent Measures

We collected several dependent measures during the course of the experiment. The measures fall under 4 categories: Performance, Controller Behaviors, Workload, and Controller Opinion.

Table 1. Characteristics of the 4 scenarios used in the experiment.

	Sector 01 Scenario A	Sector 01 Scenario B	Sector 05 Scenario A	Sector 05 Scenario B
Length of scenario (min)	50	50	50	50
Total aircraft	41	41	41	40
Overflights	14	9	8	12
Military flights	3	4	0	1
Departures	14	19	20	17
Arrivals	13	18	17	15
Primarily or exclusively nonradar flights	6	7	11	9
Aircraft needing manual coordination	12	12	13	10
Communication Frequencies	8	8	5	5
Other sectors, approach controls, and centers	11	11	10	10
Active military airspaces	5	5	2	2

Performance

Two instruments were used to assess controller performance. One was a version of the standard OJT evaluation form (FAA Form 3120-25) modified to focus more precisely on strip activity; like an OJT evaluation, this On-line Expert Evaluation (OLEE) was performed by expert controllers while the participant controller was engaged in the scenario. The other was the Post-scenario analysis we developed previously to assess the number of remaining control actions (Vortac et al., 1993). In addition, 2 alerts from the controller's system were recorded when they occurred.

On-line expert evaluation. The SMEs assessed controller performance "over the shoulder" while the team was controlling traffic in the scenario. Each SME had the OLEE form, as shown in Appendix A. The SME from the relevant area of specialization always observed the D-side, while the SME from the other area observed the R-side. This was for 2 reasons. First, an FPL from a different area can more easily evaluate mistakes apparent on the radar than mistakes on the D-side. Second, the focus of the study was on changes in flight data utilization, suggesting the more knowledgeable controller should evaluate D-side performance. Of course, the SME observers might differ in how they used the OLEE form, but because scenarios were counterbalanced across strip condition, such differences cannot affect the results systematically. Each observer indicated whether each performance category was Satisfactory, Needs Improvement, or Unsatisfactory. Observers also kept a tally of the mistakes controllers made within each of the OLEE categories.

Post scenario analysis. At the end of each scenario, the 2 SMEs consulted in completing the post-scenario analysis. The post-scenario analysis is a quasi-objective measure of performance that we developed for an earlier set of studies. The SME determines, for each flight, those controller actions still remaining that will successfully remove the flight from the controller's sector. Assuming the same starting point, and the same amount of time allowed for controlling traffic, a condition that leaves fewer remaining actions can be thought of as one that supported more efficient control. Finally, because FPLs typically agree on the actions necessary to transit an aircraft out of the sector, we believe the remaining actions measure makes a strong appeal to objectivity.

Conflict alerts/MSAWs. Finally, we recorded 2 measures that may be indicative of performance difficulties. The current system alerts the controller when it predicts that loss of separation or violation of altitude minimums is imminent. Although such alerts do not mean that separation was lost, or even that it will ultimately be lost, a larger number of such occurrences in one condition compared with the other may again suggest that the controller is performing less effectively.

Controller Behaviors

The behaviors in which controllers engage can provide valuable clues to the potential effects of a new system on their performance. Some of the behaviors are likely to compensate for an inferior display. Other behaviors are relevant to performance and suggest poorer performance in one situation than another. All the behavioral observations described below were obtained on-line by observers seated behind the controllers during the scenarios. The experimenters used a tally-sheet, and, where appropriate, a stopwatch, to record the relevant data. One experimenter observed the behavior of the R-side and another the behavior of the D-side. For those behaviors involving communication between the controller and pilots, other facilities, or other sectors, the data were gathered following completion of the scenario from a multitrack tape recorder that captured the radio and telephone communications of the controllers.

Compensatory Behaviors

In order to maintain an acceptable level of performance, controllers may need to compensate for information not present on the RFPS, or not easily seen or retrieved from the RFPS. Such compensatory behaviors are not necessarily negative, but they are certainly informative. For example, in the Albright et al. study using field controllers from Atlanta ARTCC, controllers without strips compensated by performing more flight plan readouts. Replacing strip inspection with FPRs had interesting consequences. Controllers could spend more time looking at the PVD when performing FPRs, and using the quick action keyboard (QAK) to obtain other flight data, than when he or she obtained those data from the strip bay. Thus, compensatory behaviors often painted a complex picture that must be evaluated carefully.

In the current study, we recorded several different controller behaviors that could serve as compensatory mechanisms.

FPRs. If the controller cannot easily access needed information from the strips, he or she may choose instead, to request the information from the computer via the system's quick action keyboard (QAK). The QAK can be used to deliver the flight plan to a small screen, the computer readout display (CRD). Such a behavior could occur for either the R-side or the D-side, and thus we kept separate tallies of these QAK activities for the two team members.

Time on strip bay. If it is difficult to see or find information on the smaller strips, the controller may spend more time viewing the strip bay. For the R-side controller, this of course means that he or she is spending less time monitoring the PVD. Time-on-strip-bay for the D-side is, on the other hand, not a compensatory behavior. Thus, we recorded this behavior for the R-side only.

Time in aural R—D communication. A smaller strip may be a less valuable aid in communicating between the two members of the controller team. This deficit could manifest itself in more R—D aural communication. For example, the R-side may not be able to access the information from the RFPS quickly and subsequently, may verbally request assistance from the D-side. Thus, for each scenario, we recorded the cumulative amount of time that the team members spoke to each other.

Pointing. If a smaller strip is difficult to locate by one controller, it may require the other controller to point to it. This form of nonverbal communication is quite common, but sharp increases in its occurrence could be indicative of a problem in searching the strip bay and detecting the target.

J-rings. J-rings are multisided polygons that the controller can place around a flight displayed on the PVD. These rings aid the controller in discerning lateral separation between flights that are at the same altitude. Disproportionate use of J-rings in one strip condition could suggest that the controller is pushing separation standards more in that condition than in the other.

Route displays. Another compensatory operation available to the controller is displaying the route of a flight across the PVD. Again, if smaller strips make discerning routes more difficult, we may see controllers choosing to obtain route information by requesting a route display. We recorded the number of route displays requested, regardless of which controller requested them.

Coast tracks. For flights not under radar control, the controller can initiate a Coast track on the PVD. Such tracks can move according to the filed flight plan or the controller can move the data blocks manually. A controller may choose to initiate more Coast tracks when insufficient information is available from the strips. We recorded the number of Coast tracks displayed for each scenario.

Controller queries. If the controller cannot easily retrieve the information from the strip, or if the strip proves to be an unsuitable medium to record important information, the controller may simply choose to query the pilot about the missing data. We recorded all radio and telephone communications during the scenarios and subsequently tallied the number of such queries made by the R-side and D-side controllers.

Writing. Finally, we recorded the number of times that a controller, either R-side or D-side, wrote on the strips. Writing on the strips is a central part of board management, and as we have shown previously, an integral part of the behavioral sequences that characterize ATC (Edwards, Fuller, Vortac, & Manning, in press; Vortac, Edwards, Jones, Manning, & Rotter, 1993; Vortac, Edwards, & Manning, 1994). However, the effect of smaller strips on the frequency of writing, while important, is not easily predicted. One possibility is that, because of the absence of information, controllers may choose to write more on the smaller strips. On the other hand, because the strips are physically much smaller and have less room on which to write, the controllers may choose to neglect or postpone strip marking that they might otherwise perform. Thus, although the frequency of writing is clearly important and worth observing, this measure alone will not be indicative of the viability of the smaller strips.

Workload

It may be the case that comparable performance can be maintained by the controllers, but at a cost in the amount of effort the controller is required to expend. We assessed workload in 2 ways. One was a relatively direct query of the controllers of their effort using a standard instrument. The other measure was a more complex, less direct, but more unobtrusive measure of workload.

TLX. We used a modified version of the NASA TLX form. The NASA TLX (Hart & Straveland, 1988) is an instrument that allows the assessment of several dimensions of the workload construct: mental demand, temporal demand, physical demand, effort, frustration, and performance. Subjects placed an "x" on a line ranging from "low" to "high" to indicate their perception of the workload when controlling traffic with FPSs and RFPSs.

Granting requests. As part of their job, controllers are often asked to respond to requests made by pilots, other sectors, and other facilities. Although the frequency with which controllers grant such requests and the time it takes them to grant these requests clearly involves more than workload (e.g., the particular traffic situation, feasibility of the request), it is clear that workload would be one factor influencing the frequency and speed with which requests are granted. Thus, communication between the controllers and the pilots, other sectors, and facilities were recorded. Requests *of* the controller were identified and the number of those granted and the time taken to grant them were analyzed.

Controller Opinion

Finally, the opinions of the experts employed to operate any new system are a vital part of its assessment. Thus, we interviewed each controller to determine overall opinions of the 2 strip formats. We queried them using continuous-line scales to determine how well they liked the formats, how easy they were to use, how useful they were, the quality of information, their perceived efficiency in controlling traffic, and their perceived efficiency in board management. Subjects placed an "x" on a 9.6 cm line to indicate their opinion on each of the scales. We also included a number of open-ended questions designed to explore their particular concerns, if any, with the reduced strip, including their opinion as to how it could be improved.

Procedure

All teams of controllers were tested during a 2-week period in January 1995. After giving informed consent and completing a short biographical questionnaire, the team decided on who would serve as R-side. The participants then took their respective places and were allowed to view and interact with the system and the strips for up to 5 minutes before the problem started. During that 5-minute period, the participants received a short briefing from the SME from that area. The briefing included idiosyncrasies of controlling simulated air traffic on the DYSIM and an overview of current traffic parameters, including "hot" airspaces, ILS approaches, VOR problems, and so on. The first of the two 50-minute scenarios then began.

During the scenario, an A-side controller placed the FPSs (or RFPSs) in the strip holders. The primary specialist stood over the shoulder of the D-side participant and the other SME stood over the shoulder of the R-side. Each SME completed an OLEE for the controller they were observing. Behind and further to the sides stood the 2 observers responsible for recording R-side and D-side activity. An observer monitoring our audio-recordings of interfacility communications was plugged-in overhead and sat behind the SMEs. During the reduced strip conditions, a pair of experimenters sat off to the side next to the HOST printer that produced the FPSs. FPSs were removed from the printer and translated into RFPSs.

At the end of 50 minutes, the controllers completed the modified TLX instrument and were given a 20 to 25-minute break while the second scenario was set up. During this time, the SMEs completed the post-scenario instrument. When the participants returned, the procedure was repeated for the second scenario.

At the end of the second scenario, the participants were separated and interviewed about their experiences and opinions, using the post-experimental questionnaire. The participants were then thanked and asked not to discuss the details of the study with other controllers until the study was completed.

Results

For the analyses in this report, we chose to compare the FPS condition with the RFPS condition using uncorrected Student t-tests at a test-wise alpha of .05. We made this decision not only because of the temporal constraints placed on the production of this report, but also because such a statistical strategy will be liberal in rejecting the null hypothesis, a bias not without its benefits when exploring for potential differences.

Performance

We analyzed 2 instruments to assess performance: the Subjective OLEE form and the Remaining Actions form. The OLEE form contained overall ratings from the SMEs and a count of the number of negative occurrences or comments by the SMEs. Overall, the frequency of negative comments was a more sensitive instrument than the simple ratings of "satisfactory," "needs improvement," and "unsatisfactory."

OLEE Analysis

Although ratings tended to be less sensitive to differences between FPS and RFPS than were frequency counts, the 2 sets of data were quite clear in their overall agreement that the RFPSs had negative effects. The mean ratings (Satisfactory = 1; Needs improvement = 2; Unsatisfactory = 3) and the frequency of mistakes noted by the SMEs are shown in Tables 2a (R-side) and 2b (D-side).

Both R-side and D-side evaluations were poorer for the RFPS than the FPS condition in the separation of nonradar (but not radar) flights, in effective strip marking essential for control, and in locating the strips within the bay. In addition, using the 1" x 5" strip resulted in an increased number of negative comments about the R-side controller's awareness of the situation. For the D-side, the small strip not only affected the ability to locate the strip within the bay, but also the ability to scan information on a particular strip. Finally, the D-side's board management responsibility of removing deadwood (but not sequencing) was affected by the smaller strip. Overall, the smaller strips seemed to interfere with separation of nonradar traffic and with the R-side's awareness of the situation. This deficit may be due to difficulty in locating the strip or finding information on it, marking essential information on the strip, and removing strips for flights no longer under control. Interestingly, radar control was apparently unaffected and there was no indication that nonverbal communication between the members of the pair was hindered.

Remaining Actions

Results from the Remaining Actions form showed no overall difference between FPSs and RFPSs for the total number of aircraft still under consideration, or for the number of proposals remaining in the bay (See Table 3). We then used the remaining actions data from the post-scenario analysis to analyze flights under

Table 2a. OLEE: Ratings (left) and Frequency of Negative Comments (right) for R-side.

RATINGS	FPS	RFPS	*t*
SEPARATION			
Radar	1.60	1.70	ns
Nonradar	1.90	2.30	ns
STRIP MARKING			
Essential for control	**2.35**	**2.75**	**2.18**
Nonessential	**1.80**	**2.15**	**2.30**
STRIP PROCESSING SPEED			
Locating	**1.20**	**2.30**	**5.77**
Strip scan	1.00	1.05	ns
R-D COMMUNICATION			
Nonverbal communication	1.00	1.05	ns
AWARENESS			
Awareness	*1.15*	*1.40*	*1.75*
BOARD MANAGEMENT			
Removal of deadwood	1.25	1.40	ns
Effective sequencing	1.00	1.10	ns

FREQUENCIES	FPS	RFPS	*t*
SEPARATION			
Radar	.40	.45	ns
Nonradar	**.55**	**1.20**	**2.16**
STRIP MARKING			
Essential for control	**11.25**	**16.70**	**2.66**
Nonessential	7.3	9.15	ns
STRIP PROCESSING SPEED			
Locating	**3.15**	**7.65**	**5.35**
Strip scan	.05	.20	ns
R-D COMMUNICATION			
Nonverbal communication	.85	.50	ns
AWARENESS			
Awareness	**.95**	**1.80**	**2.43**
BOARD MANAGEMENT			
Removal of deadwood	3.65	4.30	ns
Effective sequencing	.30	.60	ns

Italics = p < .10
bold = p < .05

Table 2b. OLEE: Ratings (left) and Frequency of Negative Comments (right) for D-side.

RATINGS	FPS	RFPS	t
SEPARATION			
Radar	1.00	1.00	ns
Nonradar	*1.25*	*1.80*	*2.07*
STRIP MARKING			
Essential for control	**1.65**	**2.15**	**2.24**
Nonessential	1.10	1.25	ns
STRIP PROCESSING SPEED			
Locating	**1.00**	**1.70**	**4.27**
Strip scan	1.00	1.10	ns
R-D COMMUNICATION			
Nonverbal communication	1.00	1.10	ns
AWARENESS			
Awareness	1.30	1.40	ns
BOARD MANAGEMENT			
Removal of deadwood	*1.30*	*1.60*	*2.04*
Effective sequencing	1.15	1.20	ns

FREQUENCIES	FPS	RFPS	t
SEPARATION			
Radar	0.00	0.00	ns
Nonradar	**.15**	**.75**	**2.45**
STRIP MARKING			
Essential for control	**2.95**	**4.95**	**2.89**
Nonessential	3.20	3.00	ns
STRIP PROCESSING SPEED			
Locating	**.85**	**3.75**	**6.10**
Strip scan	**.10**	**.65**	**2.24**
R-D COMMUNICATION			
Nonverbal communication	.25	.90	ns
AWARENESS			
Awareness	1.20	1.30	ns
BOARD MANAGEMENT			
Removal of deadwood	**3.75**	**6.60**	**2.86**
Effective sequencing	2.00	1.50	ns

Italics = $p < .10$
bold = $p < .05$

Table 3. Remaining actions analysis.

REMAINING ACTIONS	FPS	RFPS
Total aircraft	14.9	15.15
Proposals	3.65	3.25
RADAR		
Aircraft remaining	7.05	7.05
Route changes	.90	1.15
Altitude changes	3.40	3.50
Approach clearances	2.50	2.55
Accept hand-off	0.00	0.00
Initiate hand-off	3.95	3.40
Communications	6.95	6.80
NONRADAR		
Aircraft remaining	*4.05*	*5.10*
Route changes	1.25	1.75
Altitude changes	2.60	2.95
Approach clearances	1.35	1.40
Accept hand-off	0.05	0.00
Initiate hand-off	2.25	2.55
Communications	4.05	4.90
Italics = $p < .10$		

radar control and flights not under radar control separately. For flights under radar control, no performance differences were observed. On the other hand, nonradar flights tended to be less efficiently controlled with RFPSs than FPSs, $t(19) = 1.88$, $p < .10$, with 5 flights remaining in the RFPS and only 4 remaining in the FPS condition. This deficit seemed to be divided across a number of remaining actions including route changes, altitude changes, hand-offs, and communications, although none of these constituent categories showed a statistical difference. Thus, smaller strips affected nonradar flights more than radar flights, although even here, the effects were marginal. Thus, what remained to be accomplished by the end of the controller's 50-minute scenario, although not nearly as dramatic as the OLEE analysis, again favored the normal strips. Overall, the OLEE and the Remaining Actions analysis raise concerns about the ability of controllers to perform as competently with reduced strips, especially in the control of nonradar flights.

Alerts

Conflict alerts and MSAWs are, at best, gross measures of controller performance, because they could occur even when no problem is imminent. Consistent with Table 4, there were no reliable differences in the frequencies of these alerts between the FPS and RFPS conditions.

Table 4. Frequency of alerts.

Alerts	FPS	RFPS
Conflict alerts	2.70	2.41
MSAWs	2.30	2.61

Compensatory Behaviors

Of the 12 behaviors we tallied from the R-side that could reflect compensatory behavior, including some communications events (e.g., requests of pilots for current speed), only the frequency with which they pointed to the PVD evidenced any difference between RFPSs and FPSs, $t(19) = 2.79$: When using reduced strips, the R-side pointed to the PVD 48% more often (6.07 vs. 4.10) than he or she otherwise did. Notice that pointing to the PVD more was *not* because the controller was pointing to the strips less. Of the 5 behaviors tallied for the D-side, none were significantly affected by the type of strip. The frequencies of compensatory behaviors appear in Table 5.

Table 5. Compensatory behaviors for R-side and D-side, R-D communication, and performance related controller behaviors.

BEHAVIORS	FPS	RFPS
R-SIDE		
Coast tracks	4.00	4.13
Flight Plan Readout	1.65	1.62
Route display	8.00	8.91
Point-to-PVD	**4.10**	**6.07**
Writing	174.9	165.2
Point-to-Strip	34.25	37.36
Offset strip	3.00	3.86
View strips (sec)	1057.00	1091.30
Vector line	5.30	5.40
Range of PVD	4.15	3.07
Pilot requests	19.40	19.90
J-rings	1.30	1.35
D-SIDE		
Flight Plan Readout	1.65	2.16
Point-to-PVD	10.80	11.73
Point-to-Strip	25.15	26.97
Offset strip	12.55	10.82
Writing	147.80	134.85
R-D COMMUNICATION		
Time (sec)	193.55	198.07
Italics = p < .10		
Bold = p < .05		

Workload

TLX

Workload, as assessed by the modified TLX, was analyzed separately for R-side and D-side. The D-side controller reported experiencing comparable workload, regardless of whether the FPSs or RFPSs were used. For the R-side, however, the RFPSs produced greater self-reported effort, $t(19) = 2.17$, and frustration, $t(19) = 2.79$.

Granting requests

Another less direct, but more objective measure of workload, is the number of pilot requests granted and the time required to grant them (see Table 6). Controllers granted the same percentage of requests, and granted them in approximately the same amount of time. Although the mean grant time for FPSs appears considerably longer than the mean grant time for the RFPS, this 22 second difference is due primarily to one team's exceptionally long latency.

Opinion

When the controllers were asked to evaluate the 2 strip formats, the results were quite clear (see Table 7). On the 6 scales, the controllers showed a significant preference for the current FPS on each scale.

Additional open-ended responses about the RFPS were tallied. Controllers were allowed to make as many or as few comments as they wished; thus, the following summary, unless indicated, over-represents those controllers who offered more suggestions. When asked what they liked about reduced strips, 55%

Table 6. Two measures of workload. Direct TLX reports and indirect frequency and delay of granting pilot requests.

TLX	FPS	RFPS
R-SIDE		
Mental demand	75.60	79.55
Physical demand	59.00	69.70
Temporal demand	64.75	71.50
Effort	**67.20**	**77.25**
Frustration	**51.45**	**70.25**
Performance	48.40	49.50
D-SIDE		
Mental demand	69.55	76.65
Physical demand	53.70	62.30
Temporal demand	64.95	69.20
Effort	62.70	71.55
Frustration	49.95	61.15
Performance	55.60	48.05
GRANTING REQUESTS		
Percent Granted	94.92	95.40
Time to grant	60.27	38.96
Bold = p < .05		

Table 7. Controller opinion about strips.

OPINION	FPS	RFPS	t
Ease of Use	**10.18**	**2.45**	**14.02**
Usefulness	**9.88**	**3.10**	**14.38**
Like	**2.66**	**1.58**	**2.32**
Quality of information	**10.28**	**5.04**	**8.64**
Efficiency of control	**8.95**	**4.23**	**7.27**
Efficiency of board management	**8.73**	**3.53**	**6.85**

Bold = p < .05

found nothing. Negative comments were: hard to see, had to write smaller, less room, better than no strip at all, good excuse for not using them. Positive comments were: fit in the bay, less time to sequence, less space/room used, didn't have to reach as far, convenient for the left handed person, eye-level, less clutter, less paper.

When asked how reduced strips impaired performance, the majority of responses fell into comments about information retrieval and about board management. Comments about information retrieval included: hard to scan (22), hard to read (16), CID (12), altitude (2), route (7), departure/arrival arrows (1), east-west bound indication (1). When explicitly asked if the RFPS board was hard to scan, 98% opined that it was harder to scan than the normal bay. Many of the information retrieval concerns also revolved around the use of shading, rather than color, to indicate direction of flight and CID. Shading is not, ergonomically, a good method for highlighting critical information, and several controllers commented on this impact of shading; CID seemed especially affected by appearing in shading, rather than color. Only 3 comments revolved around the excluded information, previous/next fix. When asked if there was enough room on the reduced FPS, 75% said no.

Comments about board management included strip marking problems: writing difficult (11), no room for altitude (5), hard to write on cocked strip (2), need a fine tipped pen (1), wrote less (1); and manipulation problems: hard to manipulate (11), hard to remove deadwood (1). There were also comments about trying to encode written information: hard to read D-side writing (2), cannot see when R-side's hand is in the way (1). Sixty-five percent of the controllers stated they did not write all required markings and 10% were unable to write nonmandated information. Resequencing was also viewed as more difficult with the reduced strip (40%) or the same (48%), with 12% of the controllers not performing any resequencing.

When asked what information they would remove from the reduced FPS, 70% said nothing. Only shading was suggested by more than one controller. When asked what information they would add to the reduced FPS, 48% said nothing. Other comments were: color (13), previous/next fix (8), CID-modifications (4), nonradar indicator (2), size of arrival/departure arrow (3), move beacon code (2), larger altitude (2). Previous fix/next fix information was mentioned by a significant minority. These concerns often dealt with flights transiting from Canada; for such flights, information about time appears nowhere else on the strips. Thus, when previous/next fix was removed, strips for Canadian flights had no temporal information.

When asked to identify circumstances that needed normal strips, controllers indicated: multiple altitude changes (10), approach/departure indicators (10), nonradar environment (8), preplanning (8), holding (7), scanning (6), none (5), vectoring arcs (4), when busy (4), and resolving conflicts (3). Finally, we asked controllers if they could safely control more, less, or the same amount of traffic with the reduced strips. None projected an ability to control more traffic and 60% believed they would be able to control less.

Conclusions and Recommendations

We compared the performance and workload for controllers controlling air traffic in a mixed radar-nonradar environment using the standard sized FPS (1 5/16" x 8") and an FPS reduced in both size (1" x 5") and the amount of information it presented. The results from 20 teams of field controllers from Minneapolis center are summarized in this report. Overall, the 1" x 5" strip yielded deficits in the control of nonradar flights, but not in the control of radar flights. This was evidenced in the subject matter experts' evaluation of nonradar separation, strip processing and board management, and, to a marginal extent, in the efficiency with which traffic was moved through the sector according to the remaining actions analysis. Furthermore, the R-side controllers' awareness was rated lower when using the smaller strips. Because the problems occurred only with nonradar flights, such measures as conflict or MSAW alerts or the number of J-rings used would not be expected to, and did not, vary with condition.

Interestingly, the controllers' evaluation of their *own performance,* as indicated on the TLX, did not reflect this difference between reduced and normal strips. This may help explain why controllers did not compensate for the smaller strips to any great extent. In order to compensate for the reduced strips, controllers made only one reliable change in their behavior: The R-side pointed to the PVD more often. This behavior was not because the R-side pointed to the small strips less often. Perhaps the small strips engendered more nonverbal communication overall, but this nonverbal communication was not the type that alerted our subject matter experts to any problem in intra-team communication.

Although there was little compensatory activity, the R-side controller, but not the D-side controller, felt the workload was greater with the 1" x 5" strips. In particular, the R-side controller felt it was more effortful and more frustrating working with the small strips. Despite being under a perceived heavier workload, the controllers nevertheless were able to perform secondary tasks, like granting pilot requests, as often and as quickly using small strips as they did using standard strips.

This study also supplied information about the specific air traffic operations likely to be affected by a reduction to a 1" x 5" FPS. Strip marking, strip processing, and some aspects of board management seemed especially affected. Inferior strip marking was evidenced in the OLEE analysis and the controllers often reported that the size of the strip prevented writing.

The ability to locate a particular strip and to find the information on the strip once it was found seems to suffer with strip reduction. The OLEE and the controller opinions echoed this problem. Locating strips might have been especially difficult for the R-side, thus leading to the large difference in perceived frustration. The controllers also noted specific problems with the strip display, including the use of shading to replace information that is typically presented in red.

Of board management responsibilities—considered by the controllers as generally inferior with small strips — removal of deadwood seems to be most likely to be affected by strip reduction. The OLEE evaluation rated the 1" x 5" strips negatively, and the subject matter experts recorded more negative comments about removal of deadwood under that condition. Because few controllers complained about handling the small strip holders, the deficiency is likely to lie in an inability to locate those strips ready for removal.

Overall, it seems clear that the 1" x 5" strip tested here was inferior to the current FPS, especially in the control of nonradar flights. Thus, based on these data, we cannot recommend that the 1" x 5" strip, as designed for this study, be considered as a design option. This, of course, does not mean that the current FPS is the only method of presenting flight data. A smaller strip may be feasible. Toward this end, it seems clear that some method of highlighting critical information, other than shading, should be used. Although several controllers offered suggestions about the display characteristics of the reduced strip, there was less concern about the substantive information removed. However, previous/next fix information was requested by a significant minority. Much of this concern was in regard to flights transiting from Canadian airspace. For these flights, important time information is routinely available only in the fields used for fix postings. Thus, while display characteristics should undoubtedly be changed, this study also suggests that, at least in some cases, valuable information was removed.

The problems with the smaller size tested here were both in terms of finding relevant information quickly and with writing on the strip. Obviously, a strip larger than the test version would alleviate many of the problems found here, but it is unclear what size such a strip should be, short of using the current FPS. A larger strip would allow more space for writing and, together with optimally formatted information, may be sufficient. This might be especially true once the controller gains some experience with smaller strips; the controllers in this study obviously had had no prior experience with the 1" x 5" strip.

It is also apparent that the reduction will have its greatest impact on nonradar flights. In fact, other work by this research team has suggested that in sectors under radar control, strip marking might be eliminated completely, and the strip size and information reduced substantially. However, the current study suggests that this is not the case with nonradar flights. Thus, one solution involves a change in procedures: Required strip marking could be eliminated and controllers could be given the option to retain only those strips needed to control nonradar flights. This procedural change could also be combined with a smaller strip, although it is unclear from this study what the size and characteristics of the reduced strip should be. This study does indicate, however, that a 1" x 5" strip with the characteristics described in this report will be unlikely to allow controllers to perform their job at the current levels of efficiency and workload.

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APPENDIX A

Sample On-Line Expert Evaluation Form

S	NI	U	
			Separation
			Non-radar
			Radar
			Essential Srip Marking
			Essential for effective control
			Mandated by 7110.65
			Speed
			Difficulty locating strips
			Slow strip scan
			Non-verbal communications (done verbally which can be done non-verbally)
			Awareness
			Board Management
			Additions to active bay
			Removal of deadwood
			Effective sequencing

Sample On-Line Expert Evaluation (OLEE) form used by subject matter experts (SMEs) to rate the effectiveness of controller activities involving strip usage. SMEs rated R-side activities separately from D-side activities.
S = Satisfactory, NI = Needs Improvement, U = Unsatisfactory.

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