# THE EFFECT OF AIR TRAFFIC INCREASE ON CONTROLLER WORKLOAD

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The Federal Aviation Administration (FAA) has been increasing the National Airspace System (NAS) capacity to accommodate the predicted rapid growth of air traffic. One method to increase the capacity is reducing air traffic controller workload so that they can handle more air traffic. It is crucial to measure the impact of the increasing future air traffic on controller workload. Our experimental data show a linear relationship between the number of aircraft in the en route center sector and controllers' perceived workload. Based on the extensive range of aircraft count from 14 to 38 in the experiment, we can predict en route center controllers working as a team of Radar and Data controllers with the automation tools available in the our experiment could handle up to about 28 aircraft. This is 33% more than the 21 aircraft that en route center controllers typically handle in a busy sector.

The Federal Aviation Administration (FAA) predicted that air traffic will grow substantially in the coming years (FAA, 2006). To accommodate it, the FAA has planned to increase the National Airspace System (NAS) capacity by building new runways, modernizing hardware and software, and modifying existing procedures. With improved workstations, controllers can handle more aircraft, which will increase the NAS capacity. Recently we tested new concepts to improve controllers' workstation with various traffic levels. In this paper we report the effect of increasing traffic levels on controllers' perceived workload.

Controllers "coordinate the movement of air traffic to make certain that planes stay a safe distance apart. Their immediate concern is safety, but controllers also must direct planes efficiently to minimize delays." (Department of Labor, 2006). To achieve their goal, controllers monitor situations, resolve aircraft conflicts, manage air traffic sequences, route or plan flights, assess weather impact, and manage sector/position resources (Alexander, Alley, Ammerman, Hostetler & Jones, 1998). They perform these tasks concurrently and expeditiously in their own responsible airspace called a sector. They also convert the information about aircraft into three-dimensional space and sequence them to safely leave the sector within the constraints of written agreements. Automation and decision aid tools such as conflict probe (User Request Evaluation Tool [URET]) and traffic flow advisory (Traffic Management Advisory [TMA]) are available for controllers' use. Most of the information about aircraft for controllers to perform their task is presented on the controller's monitor screen.

Aircraft are displayed with a diamond symbol and have an attachment called a data block furnished with the critical information about the aircraft. Data block formats are domain specific and thus different in a Terminal Approach Radar Control (TRACON) and Air Route Traffic Control Center (ARTCC).

Since our experiments were run in the ARTCC environment that uses the Display System Replacement (DSR), we used the data block format shown in Figure 1. (See Table 1 for the description of the data block). In our experiment, the typical visual angle for the aircraft and data block with the shortest leader line was about 3.3 horizontal and 1.2 vertical degrees respectively assuming controllers sat about 24 inches away from the monitor. The lengths of the sector were about 32 degrees vertically and 28 degrees horizontally (Figure 1). From these visual-angle values, it is easy to imagine the cluttering effect from the increasing number of aircraft on the display.

Controllers need to direct the arrival aircraft to form traffic flows and hand off them to the next sector controllers (Figure 2). As the traffic volume increases, their data blocks are likely to overlap, and controllers offset them manually to read the information on them. Thus, with more aircraft, controllers need to perform more complex perceptual and motor tasks. This also increases the complexity of high-level mental tasks such as memorization and decision making which can increase workload.

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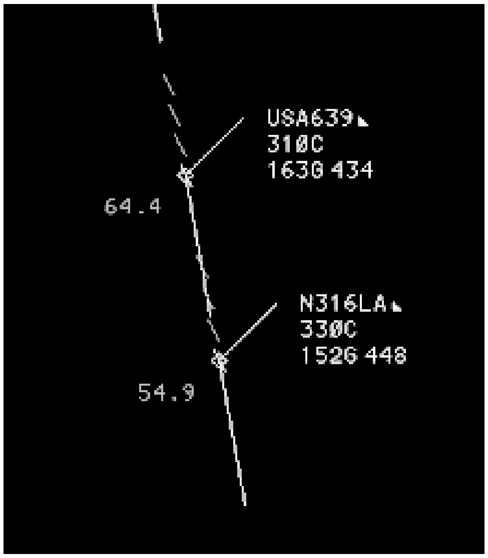


Figure 1. Data block. Controllers sometimes use the temporary fourth text-line to display temporary heading, speed, or free text.

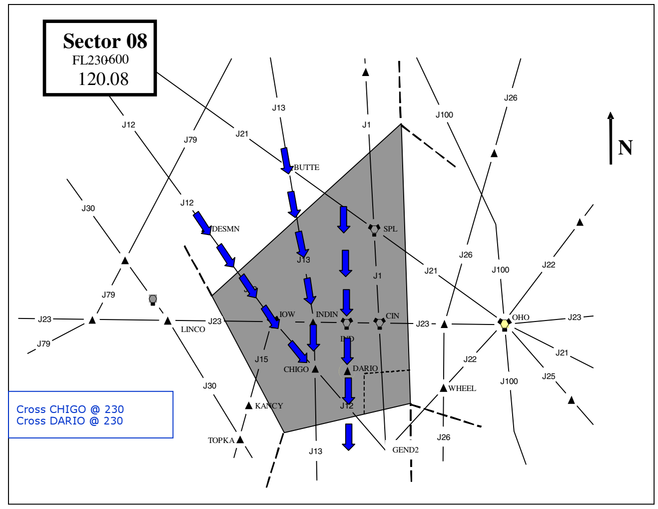


Figure 2. Airspace with the sector located in the middle (shown as shaded).

Table 1. Data block and other display elements about USA639 in Figure 1.

| Display Elements | Term | Description |
|---|---|---|
| Diamond symbol | Target / Aircraft | This symbol changes into a triangle if the aircraft deviates from the flight-plan path on the radar |
| USA639 | Call Sign / Aircraft Identification (AID) | Controllers usually refer to it when communicating with pilots and other controllers. |
| Solid triangle symbol on the first line | Data-link Symbol | If an aircraft is not data-link equipped, this symbol will not be shown. Seventy percent of the aircraft in the experiment were data-link equipped. |
| 310 | Altitude | Assigned altitude: 31,000 ft. |
| C | Altitude Profile Indicator | “C” stands for cruise or level altitude. |
| 163 | Computer Identification Number of the Aircraft (CID) | Controllers usually use it for keyboard entry pertaining to that aircraft. |
| G | Destination Symbol | This G stands for the destination airport, Genera Airport. |
| 434 | Ground Speed | Ground speed in knots. |
| Solid line from the aircraft to the data block | Leader Line | Controllers can adjust the leader line to one of three lengths. |
| Broken line attached to the aircraft | History Trail | History of the aircraft positions. |
| Solid line attached to the aircraft in the opposite direction to the broken line | Vector Line | This line shows aircraft’s heading and projected position. |
| 64.4 | Continuous Range Read-Out (CRR) | This shows the distance between the aircraft and a pre-determined fix a controller can choose. A fix can be waypoint, airport, etc., on the display. |

The number of aircraft in the sector is a major factor that contributes to air traffic control complexity. Some researchers did not identify it as a separate factor but used factors that were created by aircraft such as dynamic density. For instance, RTCA defined dynamic density as "traffic density, complexity of flow, and separation standards." (RTCA, 1995). RTCA suggested that for a short-term environment such as a sector, dynamic density could be used to measure air traffic control difficulty.

Most of the research on the effect of dynamic density or air traffic control complexity on workload has been based on interviews, surveys, or observers' ratings, and not on controllers' direct ratings while controlling traffic. (Note: There are numerous reports on this topic. Review papers by Mogford, Guttman, Morrow, & Kopakdekar [1995] and Hilburn [2004] have an extensive list of them.)

Recently, Lee (2005) argued that the relationship between aircraft count ranging from 6 to 26 and workload was nonlinear. His participant controllers rated their workload while controlling air traffic. He reported that an S Model described it better than a Linear Model, because the proportion of variance explained ($R^2$) by the S Model was larger than the one by Linear Model. Since he did not statistically test the $R^2$ difference, however, we do not know if the difference was significant. His results were also based on only three controllers' data.

We examined the effect of air traffic volume on controllers' perceived workload using an extensive range of aircraft count in the sector from 14 to 38. Based on the results from the high-end aircraft count, we also could predict controller workload for the future increased air traffic volume.

## METHOD

### Participants

Sixteen full-performance level controllers volunteered in our experiment. They worked as a team of Radar (R)-side and Data (D)-side positions. Our participants came from some of the busiest ARTCCs. D-side controllers assisted R-side controllers.
Due to computer problems during experimental runs for the first two teams, we used data of the remaining six teams for analysis. We also had 6 pilots, and each of them handled multiple aircraft.

### Equipment and Materials

We used two high-resolution 20x20-inch Barco LCD monitors (2,048 by 2,048 pixels), one for each position. An in-house real-time simulator emulated the Display System Replacement (DSR). The R-side had a TMA list as part of the Center TRACON Automation System (CTAS) and Controller Pilot Data Link Communication (CPDLC) Build 1A R-side interface. The D-side had Computer Readout Device (CRD), URET windows, and CPDLC Build 1A D-side interface. The FAA William J. Hughes Technical Center Target Generation Facility created aircraft target data.
For workload ratings, we used Workload Assessment Keypad (WAK) (Stein, 1985) that was a 4.25 x 8.5 inch instrument box located between the monitor and the keyboard and within an easy reach of the controller.

### Airspace

Our participant controllers used a generic air space that was easy to learn in a short time (Figure 2). They controlled traffic in a high altitude sector that metered three streams of traffic to low altitude sectors. Seventy percent of the aircraft were data-link equipped.
They used 1,000 ft as the vertical separation minimum and 3 miles for the lateral separation minimum that are similar to NAS separation standards in 2010 (RTCA, 2002). Currently the lateral separation minimum is 5 miles.

### Procedure

Each controller team participated in three experimental runs that used three different scenarios loaded with 21, 27, or 35 aircraft. However, the number of aircraft in each run fluctuated to some extent because of the dynamic nature of air traffic control.
We instructed controllers to press a button from 1 to 10 corresponding to their workload rating: "At the low end of the scale (1 or 2), your workload is low - you can accomplish everything easily. As the numbers increase, your workload is getting higher. Numbers 3, 4, and 5 represent the increasing levels of moderate workload where the chance of error is still low but steadily increasing. Numbers 6, 7, and 8 reflect relatively high workload where there is some chance of making errors. At the high end of the scale are numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished."

## RESULTS

There was a high correlation between R-side and D-side workload ratings ($r$ = .79). The D-side controllers' role was to assist R-side controllers. Thus, we analyzed only R-side workload ratings in this paper. There was a linear relationship between the number of aircraft and R-side controller's workload ratings ($t$ = 18.75, $p$ < 0.01, $R^2$ = 0.52) (Figure 3). The regression equation was *Workload Rating = 0.306 x Number of Aircraft - 3.373*. For both Quadratic and Cubic Models, $R^2$s were 0.53. But there was no statistical difference between Quadratic and Linear Models ($F_{1,326}$ = 1.83, $p$ >.05). Other models (Logarithm, Inverse, Compound, Power, S, Growth, Exponent, Logistic) explained less variance than Linear Model. For the aircraft count ranging from 6 to 26 that corresponded to Lee's aircraft count, there was also the linear relationship ($t_{211}$=2.63). However, the Linear Model had small $R^2$ (.03). Other models also showed the similarly negligible size of $R^2$.

There were large team differences in workload ratings as shown in Figure 4. Surprisingly some R-side controllers (Teams 1, 4, and 6) did not rate their workloads high even when they handled more than 30 aircraft in the sector and had difficulty in controlling traffic. (Note: The reason why ratings of 10 appeared in the scatter plot [Figure 3] but not in the line graph [Figure 4] is that in the line graph, ratings were averaged.)

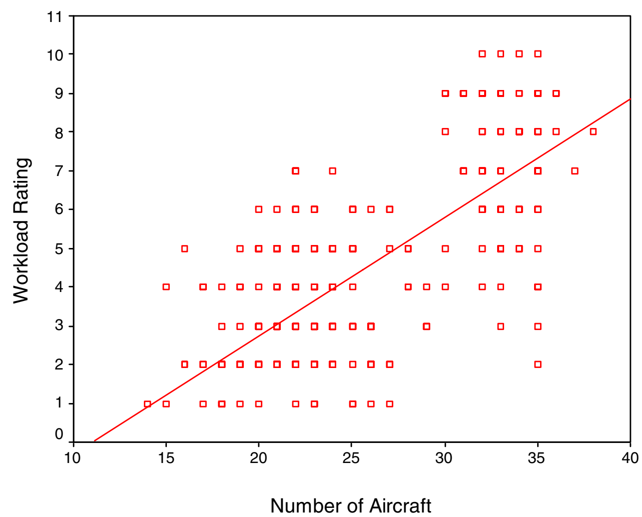


Figure 3. Scatter plot to show the linear relationship between the number of aircraft and R-side workload ratings.

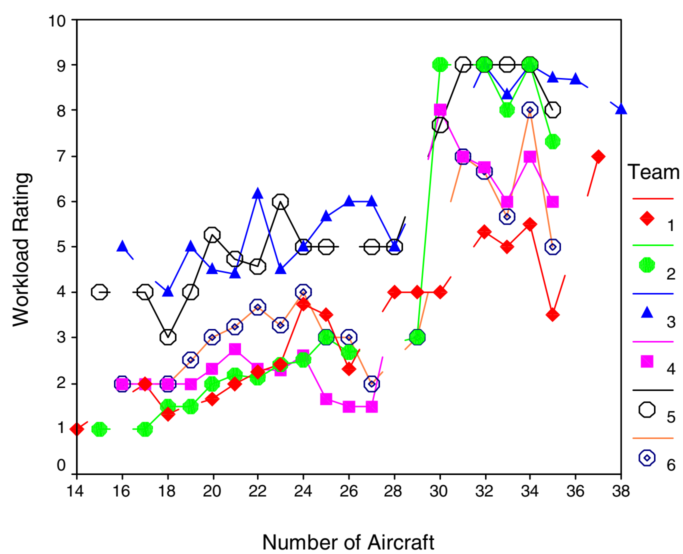


Figure 4. R-side workload ratings of individual teams.

## DISCUSSION

Our data showed that controller workload had a significant linear relationship with the number of aircraft in the sector, and this relationship described about 52% of their workload-rating variance. Even though the quadratic model had a slightly larger $R^2$, .53, there was no significant difference between them. Thus, for the sake of parsimony we consider the relationship as linear. Other models including the S Model did not describe the data as well as the Linear Model.

The aircraft count has been very robust in predicting about half of the controllers' workload variance: 52% by us, 53% by Hurst and Rose (1978) (quoted by Eurocontrol, 1998), and 60% by Stein (1985). The average of Lee's Linear Model $R^2$'s for three controllers (0.27, 0.54, and 0.77) was .53, which was not much different from our .52. This is very intriguing because all these experimental results showed similar $R^2$'s in spite of their differences in air traffic levels, experimental setups, and simulator configurations.

Our extensive range of the number of aircraft, from 14 to 38 aircraft, enabled us to predict controller workload for the future traffic level. Given moderate workload ratings of "5" in our experiment with low probability of errors, we can predict that controllers could handle up to about 28 aircraft using the DSR with CPDLC, TMA, and URET tools (Figure 3). This 28 aircraft is about 33% more than the 21 aircraft that ARTCC controllers typically handle currently where they do not have the three technologies optimized the way we accomplished it in this experiment.

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