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Effects of Information Availability on Workload and Situation Awareness in Air Traffic Control

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Abstract. To deal with the continous air traffic growth, air traffic controllers (ATCOs) are equipped with enhanced air traffic control (ATC) systems. The enhanced systems offer fully comprehensive aircraft information, such as plan view, speed, climb /descent rate, vertical information as well as the prediction of the aircraft parameters. Although increased information is often linked to the increase of situation awareness (SA), however, increasing the volume of information could also be detrimental to SA and workload. To what extend the aircraft information would benefit the ATCOs should be further investigated. This study aims to examine the effects of different information displays on ATCOs workload and SA. Thirty air traffic controllers (ATCOs) were divided into three groups corresponding to three display conditions: non-display, vertical, and trajectory display. The results revealed that the vertical display lowered ATCOs' workload and enhanced their SA as compared to other conditions. The workload and SA with the trajectory display were not different as compared to those in the existing ATC facility. It could be inferred that, on the one hand, with low information availability, ATCOs are required to interpret the airspace manually thus placing a cognitive burden on them. On the other hand, high information availability provided in the trajectory display condition, also hindered ATCOs from effectively using it due to the information overload. Here, the vertical display was found to provide sufficient information for ATCOs since it presents the information that was not depicted in the current radar system. Conversely, presenting information of all aircraft parameters was not necessarily valuable.

Keywords. Information availability, workload, situation awareness, air traffic control

Introduction

The continuous growth in air traffic has placed a challenge for air traffic control safety [1]. Given this increase, there will be a greater burden on ATCOs in performing the ATC tasks that include monitoring aircraft to obtain information about the call-sign, altitude, latitude, route and destination in ensuring that the aircraft are on the right path [2], as well as maintaing separation among aircraft.

To support ATCOs, a concept of additional display in ATC system has been proposed to provide more information about aircraft parameters such as plan view, speed view, climb/descent rate view, and vertical profile. On the one hand, the increase in information availability can be associated with the increase in SA. On the other hand, however, high information volume would also compromise SA [3].

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In this study, different levels of information display including vertical and trajectory displays were examined. The vertical display may be beneficial for ATC operations since it could help ATCOs in visualizing the 3D picture of the airspace that is important for safe and efficient traffic control. Moreover, ATCOs preferred vertical maneuvers for conflict avoidance [4]. In fact, almost all ATC facilities only provide aircraft altitude information in aircraft data-tag which is not intuitive in depicting spatial information.

In addition to the vertical display, trajectory display provides more comprehensive aircraft information. Detailed lateral positions, speed profile, and climb/descent rate as well as the prediction of these parameters are also available for ATCOs. These information may be valuable for ATCOs to meet air traffic and airspace constraints [5]. Furthermore, it could aid ATCOs in visualizing separation among flights.

A number of literature have suggested that displaying more information could enhance ATCOs' performance by reducing their mental computations thus lowering workload and increasing SA. However, the question "how much is too much" remains to be further investigated in determining appropriate volume of information in ATC.

Therefore, the main objective of this study was to examine how the presence of different information displays would affect ATCOs' workload and SA. In the experiment, the current ATC display (non-display condition) was constrasted with the vertical and trajectory displays. In each display condition, three conflict resolution aid (CRA) conditions were replicated. However, the effects of the CRA conditions were not the focus of this paper, hence, were not elaborated further. Two main hypotheses were tested in this study.

H1: The vertical and trajectory displays would generally reduce the workload relative to non-display condition. However, the workload would be further reduced with the vertical display.

H2: The vertical and trajectory displays would enhance the SA relative to non-display condition. However, the SA would be further enhanced with the vertical display.

1. Methods

1.1. Participants

Thirty (30) ATCOs from the Civil Aviation Authority of Singapore (CAAS) and the Republic of Singapore Air Force (RSAF) participated in the study. Their ages ranged from 24 to 62 years (Mean = 30.06 years) with the average work experience of 4.25 years.

1.2. Apparatus

A medium fidelity of ATC simulator, the NLR ATC Research Simulator (NARSIM) [6] was used during the experiment. It presented the standard instrument departure (SID) and standard arrival routes (STAR) of Singapore airspace. There were one ATCO's and two pseudo-pilot's positions set in the experiment. The ATCO participants were provided with four monitor screens that showed (i) the primary radar with short term conflict alert (STCA) feature warning ATCOs of a potential conflict (Figure 1), (ii) the flight progress strips, (iii) the vertical (Figure 2) or trajectory (Figure

3) display, and (iv) the CRA [7] that provides a resolution manuver to an ATCO two minutes prior to a conflict. The pseudo-pilots were provided with three monitor screens that display the primary radar, the blipper inputs, and the CRA feedback.

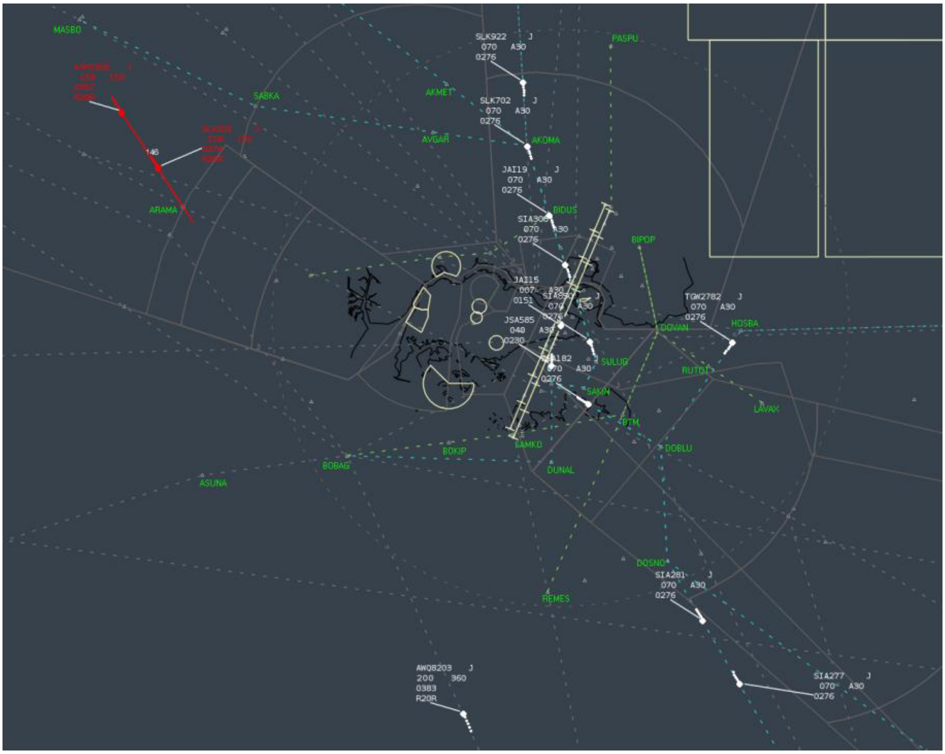

Figure 1. The Primary Radar Display. Dotted lines represent the airways.

1.2.1. The vertical display

The vertical display provides aircraft vertical profile showing the time and the flight level that will be achieved by the aircraft in every waypoint along its route. The aircraft profile was calculated based on the air traffic simulation (ATS) scripting in the NARSIM. A flight from the current radar position in the NARSIM was executed by following the route, constraints, and the script to its destination.

There are a few design features of the vertical display (Figure 2) used in this study. First, it shows the waypoints as indicated by the triangles to increase the cognitive linkage [8] between the vertical display and the primary radar display. Next, ATCO participants were able to only display the vertical profile of a selected aircraft. This "detail in demand" feature [9] allowed them to reserve their cognitive resources from other traffic aircraft that did not need immediate actions. To display the vertical information of a certain aircraft, ATCOs could select the aircraft call-sign on the display panel to activate the required information. They could reselect the respective call-sign to remove the information.

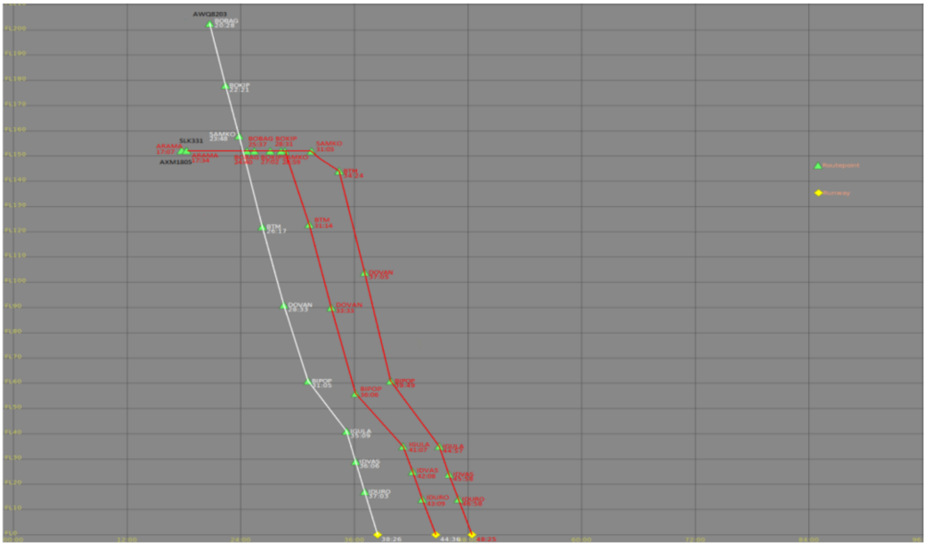

Figure 2. The Vertical Display.

1.2.2. The trajectory display

In addition to the altitude information as provided in the vertical display, the trajectory display (Figure 3) also showed other aircraft parameters in terms of heading and speed.

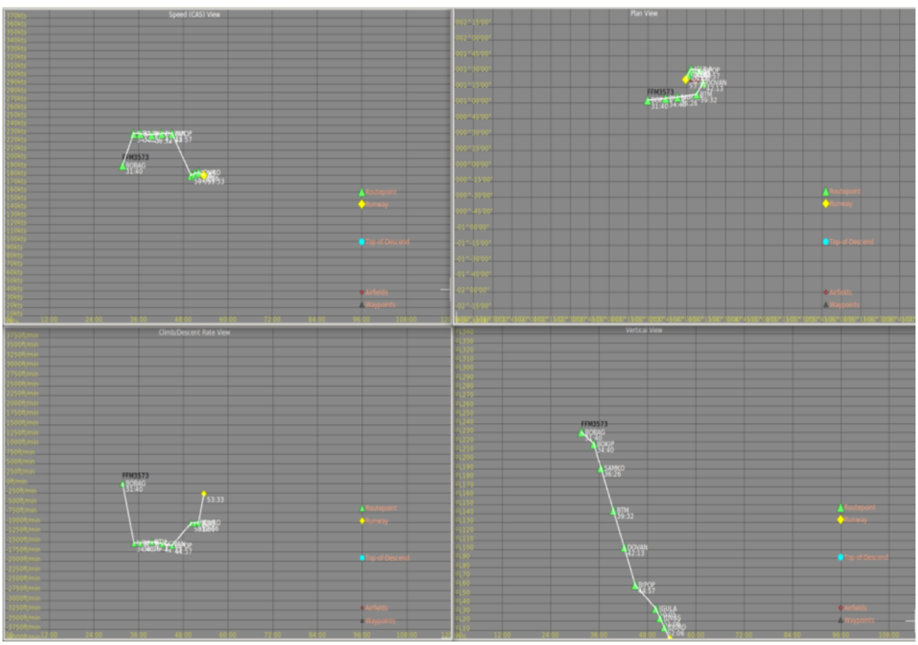

Figure 3. The Trajectory Prediction Aid.

Four aircraft paramaters were displayed along the waypoints. First, speed view was provided to display the aircraft speed profiles along the time axes (top-left corner). Second, plan view was displayed to show the aircraft lateral and longitudinal positions (top-right corner). Third, the climb/descent rate view was displayed to show the climb and descend courses in feet per minute (bottom-left corner). Lastly, vertical view was also displayed to provide the aircraft altitude information (bottom-right corner).

1.3. Experiment design

Two factors were examined in this study: CRA and display conditions. The CRA and display conditions were within- and between-subjects factors, respectively. The CRA conditions include three levels: reliable, unreliable, and manual conditions. The ATCO participants were assigned to three display conditions: trajectory display, vertical display, and non-display conditions.

In the trajectory display condition, the participants were provided with the four aircraft parameters information in an additional display. In the vertical display condition, only vertical profile information was provided. Whereas, no additional information was provided in non-display condition.

1.4. Procedure

The experiment consisted of a briefing and three experiment sessions. Participants performed ATC tasks including accepting and transferring the incoming and departing aircraft to and from their sectors, respectively, controlling the air traffic within their controller area, as well as maintaining separations among aircraft with the traffic density of 60 aicraft. In addition, participants were also requested to respond to the SA probes during the experiment. The CRA and the different displays could be utilized whenever available. The participants communicated with the pseudo-pilots verbally and the pseudo-pilots keyed in the respective commands to the ATC simulator. Moreover, the NASA-TLX questionnaire [10] was administered upon completion of each experiment session.

1.5. Analysis

A 3 (CRA conditions: reliable, unreliable, and manual) x 3 (display conditions: trajectory display, vertical display, and non-display) mixed-design ANOVA was performed for the workload and situation awareness (SA) measures, respectively. The mean (M) as well as the F and *p* values reflecting the significance of the factors are provided in Section 2 accordingly. Post-hoc comparisons were also performed to closely examine the effects of each display on the workload and SA. The effects of CRA were not reported since it was not the factor of interest in this paper. The workload measure was obtained from NASA-TLX rating (ranging from 0 to 100). The SA data were derived from the percentage of correct responses [11].

2. Results

2.1. Workload

In general, the workload was lower with the trajectory and vertical displays than without any additional information displays as shown in Figure 4, $F(2, 27)= 3.31$, $p=$

0.05. However, the post-hoc analyses revealed that there was no significant difference in the workload between trajectory (M= 67.36) and non-display (M= 73.69) conditions (*p*= 0.18), although there was a trend of lower workload with the trajectory display. However, the workload was significantly reduced with the vertical display (M= 61.89) as compared to the non-display condition (*p*= 0.02).

The trajectory display was beneficial only when the CRA was available [12] and it showed the same cost as the non-display condition when ATCOs worked manually. However, this interaction was not significant, F(2, 44)= 1.45, *p*= 0.23.

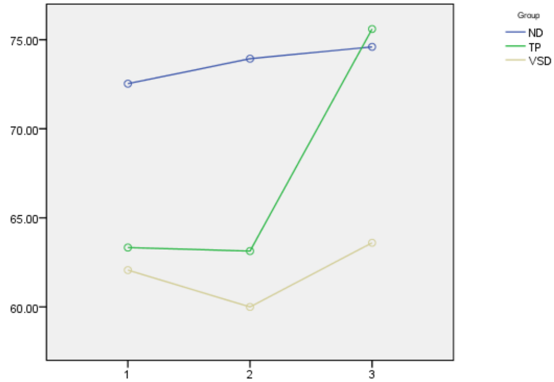

Figure 4. Workload Level across Conditions (1: Reliable, 2: Unreliable, 3: Manual Conditions; ND: Non-Display, TP: Trajectory Predictor, VSD: Vertical Display).

2.2. Situation awareness

There was a marginally significant effect of information display on SA, F(2, 23)= 2.79, *p*= 0.08. Furthermore, the post-hoc analyses (LSD) revealed that the SA was generally higher with the vertical display (M= 71.85%) than the trajectory display (M= 57.14%), *p*= 0.05 and the non-display (M= 58.80%), *p*= 0.06 conditions. No difference in SA between the trajectory display and non-display conditions (*p*= 0.82).

3. Discussion

In the existing ATC facilities, ATCOs mainly perform their work with the 2D primary radar display that provides aircraft status on the digital data-tag. Most of ATCOs would initially refer to the radar display and review the flight progress strips (FPS) to obtain required information. The process of checking and integrating the actual traffic information into the mental model is necessary for setting ATCOs' mental picture of current traffic conditions [13]. The maintenance of mental picture could enhance ATCOs' capability in efficiently controlling the air traffic [14]. To maintain their mental picture, however, ATCOs have to continuously perform accurate mental computations, including the updates for speed, altitudes, and headings changes, as well as the influences of the changes on the ATC operations.

In the present study, ATCOs were equipped with the additional displays that support them in obtaining the information of speed, altitude, and heading as well as the changes of every single aircraft along the flight paths. The displays including vertical display and trajectory display were evaluated using human-in-the-loop simulation and were contrasted with the current ATC facility. Prominently, our results generally showed that providing more information regarding aircraft status in a more intuitive format did benefit ATCOs.

The results revealed that workload was generally higher in the existing ATC setting as compared to the vertical and trajectory display conditions. Although the trajectory display led to lower workload than in non-display condition, the workload between the two conditions failed to reach significant difference. However, workload was significantly lower with the vertical display than the workload in the existing ATC setting, showing that H1 was upheld. These findings suggested that information displays could assist ATCOs in performing their mental computations thus lowering their workload.

Moreover, the SA was enhanced with the vertical display but not with the trajectory display. The ATCOs' SA was not different between the trajectory display and the existing ATC conditions, indicating that H2 was partially supported. This finding might be due to information overload [15] that could in fact hinder the ATCOs to effectively use the trajectory display.

Collectively, the vertical display did offer benefit for both workload and SA more than the trajectory display did. The vertical display was beneficial since it provides a contextual information [16] of vertical profile (Z axis) and updates that are currently not available on the primary radar display. It helps ATCOs to maintain their mental picture of air traffic situation without essentially burden their cognitive resources with high volume of information [3].

This derives practical safety implications in developing and using new ATC systems. A little information would require ATCOs to use higher cognitive resources to obtain aircraft and airspace information as well as to perform mental computations for the necessary information changes and updates. Yet, if too much information is presented to the ATCOs by new systems, ATCOs would also need more time and effort for interpreting the information [17]. An interactive display that presents "appropriate volume" of information and allows ATCOs to have control over the information interface would be recommended.

There are few limitations in this study. First, the environmental factors such as weather were not taken into account during the ATC simulation tasks. Next, longer training period should be allocated to make ATCOs more familiar with the additional displays. Yet, the findings of this study has outlined the display design principle for the development of new ATC systems in dealing with the air traffic growth.

4. Conclusion

This paper evaluated different information displays in ATC and provided an empirical evidence of the benefits of displaying appropriate volume of information. The findings also highlighted the provision of vertical display as a promising technology in ATC to provide sufficient information for ATCOs in dealing with the increasing air traffic. This display is also expected to support various concepts of future ATC operations such as continous climb and descent, user-preferred route, and trajectory based operations although it still deserves continually careful investigations. Particularly, scanning of the information display, flight delay, advance conflict notification time, communication time between pilots and controllers, and aircraft fuel consumption may be quantified in future research to validate the display use for the future ATC operational concepts.

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