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Many recent initiatives involving social psychology applications in the aviation world have redoubled the interest in the concept of teams and teamwork. The importance of teamwork in airline cockpits, hailed as cockpit (or crew-) resource management (CRM), has been recognized for a relatively long time. It is also widely agreed that extensive and effective interaction among participants in the National Airspace System (NAS), pilots, air traffic controllers, and airline operations personnel, is tantamount to the daily successes of the nation's air transportation industry. Team aspects in air traffic control (ATC) are, however, much more convoluted than intra-cockpit teams or top-level teamwork between NAS elements. The ATC system involves a complicated network of facilities, technology, and personnel, which all must interact synergistically, often under time pressure, to ensure safe, efficient, and orderly flow of air traffic. It is perhaps due to this complexity that there has been a significant deficiency in research activity relating to teamwork in ATC. Yet, inadequate coordination between controllers has been considered a causal factor in a substantial proportion of low to moderate severity operational errors. Furthermore, automation tools developed for controllers are primarily focused on supporting the individual controller, while many, if not all of ATC functions are a team effort. In this paper we review the literature relevant to the team concept in the ATC domain, identify and characterize the different teams controllers belong to either simultaneously (e.g., intra- and inter-facility teams) or in different operational environments, and catalog the results from research literature as they pertain to the aforementioned teams in ATC and their specific characteristics. Our principal focus is on concepts such as taskload, workload, and situation awareness. Within this framework, we also map recent automation applications to ATC teams, hence highlighting their impact on the team dimension of human factors in ATC.

Introduction

It may be argued that the global air traffic control (ATC) system forms the largest singular team in aviation. It involves a complicated network of facilities, technology, and personnel which all must interact synergistically and often under severe time pressure to meet the ultimate objectives of ATC: safe, efficient, and orderly flow of air traffic from one location to another. Despite these inherent characteristics of the National Airspace System (NAS) in the U.S. and its international constituents, air traffic management (ATM) research with respect to automation-supported team decision-making has been fairly sparse. In fact, there has been a significant deficiency in objective scientific measures of ATC teamwork alone (Bailey & Thompson, 2000). Although this area is novel and still emerging, its further study in operational environments would potentially enhance the effective use of automation to aid team decision-making. Lapses in decision-making, coordination, and planning have been implicated in accidents and incidents alike and identified as latent problem areas in the NAS. According to a study by Rogers and Nye, coordination between controllers was considered a causal factor in 15% of low to moderate severity operational errors from 1988-1991 (Bailey, Broach, Thompson, Enos, 1999). Fortunately, a newfound interest has recently blossomed in this area due to the strong infusion of new technology into the ATC system and the foreseeable impact of automation on controllers' performance individually as well as on their interactions as members of various teams.

Implementation of automation in the worldwide ATC system's team of personnel to create safer and more efficient traffic management is easier said than done. There are many different members within the ATC system that have different and even conflicting strategic and tactical goals. Supporting these occasionally incongruent goals will require interfaces tailored to each position and job responsibility. Evaluating such a design has been described as a suitability assessment. A suitability assessment is the third part of a three-stage progressive assessment process geared towards systematic evaluation of system usability and task suitability of the system. Suitability assessments focus on the match between the system design and the user's task. A system is considered suitable if design features and functions support users well as they perform their tasks (Sanford et al., 1993). In this case, it is appropriate to evaluate a system in the context of the controllers' individual task of managing traffic while maintaining established team responsibilities.

However, there is a pervasive tradeoff between individual and team suitability assessments. Optimal automation for an individual is not always ideal for team performance (Hopkin, 1995). Tantamount in implementing automation as a 'team player' is a system that allows members of teams to maintain the best possible shared situation awareness (SA) and mental models. The importance of shared SA and mental models is forcefully explained by Wickens et al. (1998) and specifically in a study by Salas, Stout, and Cannon-Bowers (1994). This literature strongly asserts the need for shared mental models and SA as a linchpin for optimal team decision-making. In this paper, optimal team decision-making will be considered a function of a team's performance due to the interdependent nature of personnel and equipment in the NAS.

Current Automation Applications in ATC

We will discuss ATC team decision-making primarily in the context of the latest ATC automation tools: the Center-TRACON Automation System (CTAS) and its components. The User Request Evaluation Tool (URET) and Surface management System (SMS) are not part of the CTAS toolbox, but will also be discussed. More specifically, we will examine how these systems present information to the individual controller to support the underlying goals of the NAS and the more immediate objectives of the controller. CTAS is highly functional in that it features specific tools and interfaces for each control position. Such features, however, may conflict with established team norms and could undermine team performance (Hopkin, 1995). Furthermore, the automation that reduces team norms and standards will also disguise weakness or inconsistencies in team performance. This relates to actions of a controller troubleshooting being less visible to someone who might share the same problem. Thus, a significant aspect of implementing automation in the ATC domain would be evaluation of these consequences and their relationship to safety. These safety consequences currently are not directly apparent, however. Issues with automation in ATC include the extent to which team functions should be preserved and the importance of better identifying these functions so they aren't discovered to be necessary after the means to fulfill them have been automated out of the system (Hopkin, 1995). The tradeoffs of shared situational awareness with team and individual performance will be discussed for each component of the CTAS and their associated control positions.

CTAS

CTAS is a sophisticated system that consists of three major automation tools: the Traffic Management Advisor (TMA), Descent Advisor (DA), and the Final Approach Spacing Tool (FAST). On the Sheridan and Verplank (1978) scale, CTAS represents level 3 automation, where the controller is advised of action to take but has the option to disagree. In general, CTAS is primarily concerned with downstream flow and arrival traffic. As the name implies, it is utilized by both TRACON and en route center controllers. The TMA uses an interactive, menu driven timeline and a plan view display for Graphical User Interfaces (GUIs). The DA and FAST use graphical advisories and work in conjunction with the TMA kit.

SMS

Ground control of aircraft and scheduling of departure runways and times is handled by tower and ground controllers who are assisted by the SMS. The SMS advises and informs these controllers with runway balancing and departure schedule optimization (Walton, Quinn, & Atkins, 2002). The SMS features four types of displays at the controllers' disposal: maps, timelines, load graphs, and tables. The map display shows the location and direction of aircraft. The timeline predicts when an aircraft will be at a specific location (gate, runway etc), but does not show current aircraft position. Load graph displays show the current and forecast demand on airport resources. Meanwhile, the Flight and status tables provide flight-specific information (e.g., OUT and OFF times and departure runway; Atkins et al., 2004).

URET

The en route sector teams are assisted by the URET. This particular tool, which is independent of CTAS, allows these controllers to test scenarios of rerouting without having to mentally extrapolate the flight paths of numerous types of aircraft traveling at different speeds and altitudes. This tool takes into account, among other factors, aircraft performance and weather conditions to create a 4-dimensional flight profile of all aircraft. This is built into a human-computer interface, which is in textual and graphical format. The display provides the controller the ability to view aircraft routes and altitudes, predicted conflicts, and trial plan results. In addition, the point-and-click interface affords expedient entry and evaluation of trial plan route, altitude, or speed changes. Any changes made to the aircraft's flight plan are automatically updated in the central Host computer, which holds all flight plan information. (Walker et al., 2000). On a strategic and tactical level, this tool has the potential to reduce workload significantly and will potentially allow en route sector teams to effectively manage a larger taskload as traffic levels increase.

A Hypothetical Case Study

We will next discuss the implications of these automated tools on team aspects of ATC performance by a hypothetical case study, by following a generic flight from point A to point B through the NAS. The role of automation in coordination and collaboration between individual controllers will be highlighted.

Departure

After receiving their departure clearance from the clearance delivery controller, a commercial airline flight will typically be pushed back from the gate. At this point, the pilots' journey begins by talking to a ground controller, who will issue safe taxiing instructions to an active runway. At major airports, this is a complex job, as the intersections of taxiways and runways and sheer volume of traffic creates an intricate labyrinth of pavement and airplanes. Once the flight is at the intersection of a taxiway and the active runway, it is handed off to a tower controller, who issues the take-off clearance and is responsible for the initial departure sequencing. A human Traffic Management Coordinator (TMC), or supervisor, ensures smooth flow. Coordination demands concern appropriate assignment of runways to departing flights for least restricted climb-outs and to minimize the delays between successive departures, which are necessary for safe separation and wake turbulence avoidance.

Control of aircraft on the ground at the airport is augmented by the SMS. A simulation study by Walton, et. al (2002) has revealed several points to note in how the controllers who control departures utilize this system to make decisions and handle aircraft. This particular automation system has potentially negative effects on shared situational awareness, however. The root cause for this could be a result of different goals and displays that support these goals. The TMC has strategic goals, while the ground and local controllers have predominantly tactical goals (Walton et. al, 2002). Therefore, ground and tower controllers will allocate their attention to the information available to them in order to suit their tactical goals, while the TMC is looking at the big picture and a different display to make strategic decisions. The consequence is a decrease in shared situation awareness. Walton et al., (2002) reported controllers experiencing information overload and over-redundancy, which may cause cues to become selectively filtered and processed according to salience (Wickens & Hollands, 2000). Also, when workload increases, controllers will further channel their actions and attention to support their job responsibilities (Hopkin, 1995), thus decreasing teamwork. This teamwork detriment could result in action decisions being made with suboptimal SA. More specifically, the controllers' ability to perceive a change in the environment, understand it, and predict the future state will be compromised. In such an unforgiving field as air traffic management, making decisions based on suboptimal SA carries potentially dangerous consequences.

To compound the situation, the simulator study revealed reliability problems in the advisories, which were partially due to algorithm problems (Walton et al., 2002). Essentially, the same information with different meaning to certain personnel is going to have implications for how controllers in charge of departure flow interact with those who actually manipulate the airplanes to create that flow. This situation is further complicated by less than acceptable user ratings of automation reliability.

Enroute

Once the aircraft is airborne, it is handed off to the departure controller, who will place the airplane on a departure procedure to route them out of the terminal airspace and into the en route structure of the NAS. Next, the aircraft will be handed off to a controller in an air route traffic control center (ARTCC, or center). Most of the flight will be spent interacting with a series of center controllers who control a 3-dimensional block of airspace known as a sector.

Typically, sectors in ARTCCs are controlled by a team of two controllers, a radar controller, or an "R-side" controller, while and a flight data controller, or "D-side" controller. The R-side controller is typically charged with maintaining separation of the airplanes in the sector, and this controller is the one who communicates verbally with aircraft over the radio. The D-side controller is responsible for coordinating the transfer of control of aircraft to other sectors or facilities, as well as providing a second opinion and safety mechanism for the R-side controller (Bailey & Willems, 2002).

The primary automation tool available for en route sector teams, URET, fosters solid team decision-making within the team. The R-side controller receives a re-routing request from an aircraft and gives the information to the D-side controller, who has access to the URET. After testing the scenario or creating a more acceptable one, the D-side controller will inform his or her counterpart of the situation (Wickens et al, 1998). This system fosters a shared mental model because the D-side controller can only work with the information he/she is given by the R

Side controller, which is a manifestation of their understanding of the situation.

One potential issue for further investigation in this case is the compatibility of the URET with the CTAS's Traffic Management Advisor (TMA). This tool augments the enroute and TRACON traffic management controllers. The TMA develops a plan for each individual aircraft and sequences multiple aircraft arrivals in relationship with each other (Wickens et al, 1998). If the en route sector teams are routing aircraft in a manner contrary to the TMA or supervisors' plan, the TMA when combined with the URET could reallocate workload for the users. On different levels, this idea has been expressed consistently in the literature (Wickens et al, 1998, Sanford et al, 1999, Sanford et al, 1993). Essentially, the operators of the URET and TMA would have to effectively communicate to ensure their goals and SA is consistent.

The last sector to handle an aircraft before it re-enters the terminal environment works with the Descent Advisor (DA) CTAS tool. This tool assists controllers by structuring advisories to create a seamless transition from the en route phase of flight to the arrival. There is often a bottleneck at this point in the system, and this automation is an effort to mitigate the arrival bottleneck.

The DA advisories include fuel-efficient top-of-descent (TOD) points, speed profiles, altitudes, and vectors. Conflict resolution and management conformance advisories are supported automatically or semi-automatically through scenario planning (Sanford et al, 1999). This system contributes to team decision-making in that its primary objective is to integrate the notoriously separate tasks of en route control to arrival sequencing. Also, it adds a third dimension by ensuring the traffic management personnel's policy is being implemented in the system's output. In theory, the system integrates all involved parties' goals to create common solutions.

Despite the commendable goals of the DA tool, it is not free of automation-related human factors concerns. A primary concern in the evaluation literature is that of redistributing workload. The DA essentially reallocates the human's role in the system by forcing them to perform primarily strategic control action as opposed to the tactical control they exercised previously (Sanford et al, 1999). Further problems with reallocating workload lie in the new tasks required of the human operator. In the case of the DA, the system performs all tactical decisions in the form of a level 3 automation advisory. As the human's role shifts to performing strategic tasks, their mental model is now sub-optimal due to the inherent fact that automation represents data in terms of a direct visualization (Pea, 1993; Salomon, 1993; Wickens, 1992). The operators are less informed about how the tactical decisions were made, thus their mental model is degraded because they are not actually thinking about the situation. Because effective strategic decision-making is comprised of numerous tactical decisions, fully optimal strategic decision-making may possibly be hindered by the DA. An automated system such as the DA is consistent with the assertion that positive automation attributes of low workload and good prediction have implications for a good mental model (Wickens, 1992).

Arrival

As the airplane transitions from the en route phase of flight to the arrival, the aircraft control is handed over to the TRACON controller. These controllers primarily sequence aircraft for approaches and issue landing clearances. Once the airplane is clear of the active runway on a taxiway, the control is once again passed to the Ground controller for the taxi clearance to the gate.

Efficient aircraft arrival is aided by the Final Approach Spacing Tool (FAST) component of CTAS. Currently, a passive level 3 automation version of FAST is used, referred to as pFAST. The pFast utilizes advanced logic and algorithms to sequence aircraft by advising the controller. It also performs runway allocation tasks. This tool aids a task that is notorious for very high workload and even has made a significant impact on improving throughput. Dallas-Fort Worth reported a 9-13 % increase in throughput as a result of pFAST implementation (Quinn & Robinson, 2000). Proper flow management by supervisors should enhance the effectiveness of pFAST.

The interdependent nature of air traffic control teams and automation's effect on their performance is quite evident. From a review of automated systems in ATC, there are many positive attributes associated with their operational implementation. There are also positive aspects in the design and evaluations of these systems, as experienced air traffic controllers are highly involved in the design and evaluation processes (Quinn & Robinson, 2000; Harwood, 1993; Sanford et al., 1993,1999; Walton et al., 2002). The overall system benefits are not without cost to shared SA at some point in the system. This shared SA is the linchpin in effective and optimal decision-making with automated traffic management tools.

Discussion

The current automation interventions to aid the air traffic controller have caused the ATC teamwork concept to evolve and adapt. Although each system is lauded for key positive technological and task-driven features, several factors indicate a guarded approach to automation implementation should be followed.

The positive aspects of innovative automation approaches to ATC are the benefits for documented throughput and alleviation of some time-pressured, high-workload problem solving tasks which controllers would find increasingly difficult in the ever-growing volume of future air traffic. Some automation, such as the URET, actually does foster strong team decision-making on account of both individuals utilizing the same information to compose a mental model and conduct action decisions with the same information at their disposal.

However, the drawbacks to some automated approaches suggest more work will need to be accomplished in determining optimal automation suitability for the individual and the team's task environment. This involves a strong foundation of understanding more precisely how air traffic control teams interact and how automation can best support this interaction. More specifically, differences in strategic and tactical goals between two different tiers in the ATC system can invite difficulty in sharing SA. Also, this type of situation could result from the interaction of two independently designed automation systems. Other issues include the redistribution of workload among the various ATC specialists and managers. Furthermore, automation supporting direct visualization can hinder a controller's problem-solving skills (Pea, 1993; Salomon, 1993; Wickens, 1992). On the technological side, unreliable automation can produce an entirely separate set of human performance problems, particularly involving trust and reliability issues.

Despite the drawbacks, automation and advanced technology implementation has much potential to assist controllers and improve safety. However, this safety improvement potential can be realized by constructively analyzing the strengths and weaknesses of automation in the context of the concept of ATC as a single large team.

Conclusion

Areas for future research include the cost-benefit analyses of automated tools and the specific effect of their implementation on controller workload and team decision-making. It is a realistic possibility that future air traffic demands will dictate that controllers and traffic managers must operate with a certain amount of a decrease in shared situational awareness in order to meet the demands. These studies performed in the context of future air traffic demands will be beneficial in ensuring excessively severe latent issues will not manifest themselves later. Given the complexity of the ATC system, these evaluations are difficult but necessary in preparing for the future air traffic demands.

The task of managing traffic in the NAS is certainly a daunting one, as air traffic is projected to continue to increase in the near future. Effective understanding of how ATC teams function and how to best support team coordination with team-centered automation approaches will improve shared situational awareness of all team members and will consequently enhance the safety and efficiency of operations.

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