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Assessing Cognitive Processing and Human Factors Challenges in NextGen Air Traffic Control Tower Team Operations

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Abstract. Previous research of Terminal Radar Control Facilities and Standard Terminal Automation Replacement Systems interactions by the authors examined how combined NextGen digitized technology affects air traffic controller functions. Applying their updated SHELL model, human factors implications on the Tower Team before and after implementing NextGen technology were examined, focusing on cognitive loading and automated functions affecting each team member. A survey examined where cognitive difficulties occur when controllers are responsible for multiple screen views, remote airfields or helipads, and digitized cameras and blind spots. Scanning challenges were identified where local traffic, ground operations, and data converge onto one screen, and when attention is diverted to distant screens. Also studied were automatic aircraft handoffs and potential for missed handoffs, and, assessing changes from voice communication to text messaging for human error. Findings indicated a necessity for controllers to manage balanced tasking, vigilance pacing, and resource management.

Keywords: SHELL · Human Factors · NextGen · Control tower · Cognitive load

1 Introduction and Intent of the Study

The Next Generation (NextGen) air traffic control system for the United States (U.S.) is continuing to implement new technology to accommodate growth of the aviation industry. New control tower equipment and operations by the Federal Aviation Administration (FAA) may affect the airport environment and invites closer examination. This study assessed the FAA Tower Team concept [1] and how air traffic controller cognition is affected in relation to the new technology. Intended gains in safety and efficiency for tower teams could be offset by human error relative to cognitive loading. This is evident in national runway incursion data indicating that tower controllers are the primary cause of runway incursions 18% of the time [2]. Controller incursion error can lead to deadly aviation accidents like at LAX in 1991 when a USAir Boeing 737 landed on a SkyWest commuter on an active runway at night destroying both aircraft and fatally injuring 12 people [3].

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2 Tower Team Analysis Before Computer Automation

The SHELL model by Hawkins [4] used a simple block layout. The tower controller is represented here by the L (Liveware) in the center and surrounded by four other human factors interfaces: S (Software), H (Hardware), E (Environment) and L (Liveware).

The model for the tower control team in Fig. 1 had four working positions where each job encompassed a SHELL component. The data controller's main job in the S-L and H-L connection was to complete flight strips with departing aircraft information. The E-L interface required controllers to update the flight strips with new information. The task was completed in the L-L team linkage by passing the flight strips to ground controllers. In the S-L interface the ground control position had jurisdiction over all aircraft taxiing for takeoff. The H-L connection required that ground control use line of sight and could be aided by ground radar in low visibility. Critical radio communications in clearance directions between ground control, aircraft and ground vehicles were the key to situational awareness in the E-L linkage. Once the aircraft was near the runway, the ground controller would coordinate through radio in the L-L team interface for the aircraft to switch to local control. The tower local controller followed procedures in the S-L interface to safely direct all aircraft for takeoff and landing. This included standardized phraseology and adherence to separation distances for wake turbulence. Regarding the H-L interface, the local controller depended on clear, concise radio communications through the tower radio with all aircraft and line of sight visual contact to the aircraft. This required a high degree of situational awareness in the E-L interface with the local controller constantly scanning the airspace and runway. In the L-L team connection, the local controller needed to be aware of ground control and incoming traffic from approach control. The tower supervisor was responsible for the actions of each position in the S-L interface. This included oversight of shift changeovers and backing up inexperienced controllers. In the H-L connection the tower supervisor listened to all radios and backed up all taxiway and runway operations. In the E-L interface the supervisor managed traffic flow and unexpected emergencies. The supervisor led the team by employing effective communications in the L-L team connection. With different tower positions and limited technology, teamwork and training were essential. Several tenants similar to aircraft CRM (Crew Resource Management) were employed to ensure the team remained connected in the L-L team relationship. Teamwork was an FAA priority. Good communication consisting of standardized aviation phrases and careful listening supported the teamwork. Assertiveness was valued in promoting each team member to speak up. Most importantly, the tower team remained focused on ensuring good situational awareness. The old model relied on training that was supported by a progressive hierarchy starting at the data controller position and moving up to supervisor. The training mandated that each tower position first had to qualify as an instructor at that position before moving up. In this system a model airport was set up and supervisors used model aircraft to physically simulate aircraft moving about the airfield while trainees learned the controller positions.

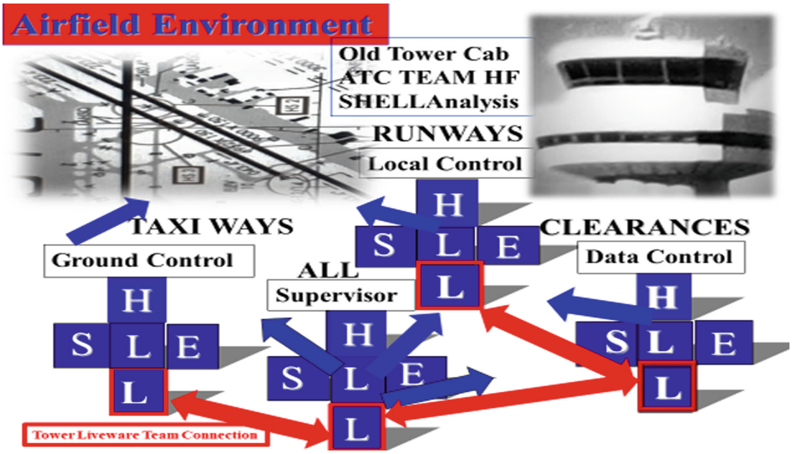

Fig. 1. Tower Controller Human Factors (HF) SHELL analysis based on the model by Hawkins [4] modified to depict the Liveware-Liveware team interface.

3 Tower Team Analysis After Computer Automation

In 2020 the ATC tower has been transformed with digital information and automation for the NextGen system. In Fig. 2 the SHELL 2016 model [5] is updated to account for digitization and crowded interfaces filled with technology. In doing so the previous SHELL model of separate tower positions from Fig. 1 becomes one SHELL as the technology causes all four tower control positions to superimpose upon each other. The same tower positions exist, although technology is transforming the positions into a tighter overlapping team. The automated systems create clouds of technology to replace the direct SHELL linkage interfaces in Fig. 1, thus causing all four linkages of the SHELL to become concatenated. The impact of these technologies on the four tower controllers starts with the S-L interface cloud employing an automated information device known as VIDS (Visual Information Display System). This computer houses all the information relative to tower operations and each controller has their own VIDS to access the same information. The data controller uses it to input the aircraft flight strip data into the National Airspace System while also updating the ADIS (Aviation Data Integration System) information regarding weather, wind data, airfield status, and detailed airfield operations data. Lastly, it has a digital feed from the airfield lighting system and digital video cameras systems that monitor the airfield blind spots and remote airfield operations. In the H-L connection the main hardware in the cloud is the STARS CTRD (Certified Tower Radar Display) and keyboard. A crucial approach control system for NextGen, STARS (Standard Terminal Automation Replacement), has been added to the control tower displays. Visible to all tower controllers, it depicts flight information of aircraft near or in the control tower's airspace. With STARS, the TRACON (Terminal Radar Approach Control) controller can hand off aircraft automatically to the tower local controller. The STARS display increases situational awareness and enables the tower to reduce wake turbulence separation minimums. This enables controllers to expedite takeoffs and landings and reduce aircraft fuel cost. Other hardware in the H-L cloud includes the FIDO (Flight Data Input Operation) flight strip printer, the airfield lighting system and the digital video camera system. The E-L interface now incorporates technologies that overlap from H-L and S-H clouds allowing controllers to manage the environment better. The STARS screen enables all controllers to be situationally aware of aircraft and to locate them visually. The digital video cameras can be monitored by any controller on the VIDS. Through the lighting system certain taxiway lighting or runway lighting can be adjusted. The L-L cloud also feeds into the E-L interface. The Enhanced Terminal Voice Switch (ETVS) creates a tighter overlapping team of tower controllers. All four controllers have an ETVS terminal. Each controller uses one frequency and monitors other controllers' frequencies with touch screens. This enables ground and data controllers to work on the primary ground frequency while monitoring the local controller on the tower frequency. The tower supervisor monitors ground and tower frequencies and has overriding authority. Team members can talk freely, but the final radio call outbound is always recorded.

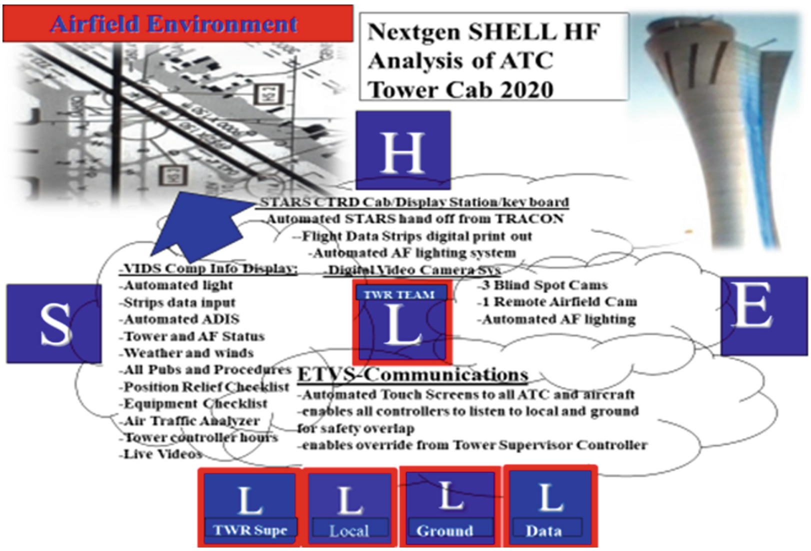

Fig. 2. NextGen Tower Controller Human Factors SHELL Analysis 2020 based on the SHELL 2016 [5] updated for computer information and automation.

4 Other Factors Influencing the Tower Team in 2020

Technology maximizes gains in CRM teamwork from better communications, assertiveness and increased situational awareness. These precepts are further enhanced in a more realistic case study training environment by recordings of incidents from other towers. The training method of qualifying as an instructor in each position has helped ensure that controllers thoroughly understand the different technologies. The most dramatic shift in training from the past is use of a high-fidelity tower simulator. All the positions are equipped with a similar layout of equipment found in the operating tower. The difference is that the simulator tower windows are a realistic virtual view of the airfield.

5 The Next Big Step in NextGen Tower Controller Development

Future elements of the NextGen system in the form of ASSC (Airport Surface Surveillance Capability), CPDLC (Controller Pilot Data Link Communications) and more remote digital videos are coming. The ASSC currently is being tested in the form of ASDE X (using ADS-B out) at 35 major U.S. airports. It would allow the Tower Team to know exactly where all aircraft and ground vehicles are and provide oral warnings of potential runway incursions or ground collisions, however, it adds another display screen to monitor. CPDLC already has proven an effective way to text Departure Clearances to aircraft, but it raises a concern that when used with current communications it may prove distracting for controllers. Digital videos now are used by controllers to monitor blind spots and remote airfields, but the concern remains as to how many extra videos controllers can monitor before their critical scan of the airfield is compromised. These human factors issues invite evaluation from a human cognition perspective.

6 Cognitive Processing Challenges

As seen with the evolution of air traffic control and incorporating new technologies, different behaviors and tasks have modified the cognitive processing challenges for operators. Currently in many air traffic centers, controllers are working simultaneously with existing legacy systems and newer NextGen systems [6]. The cognitive requirements to sustain reliable performance become complex and exclusionary. The authors previously have examined ATC TRACON and STARS functions and discovered cognitive processing limitations and potential areas for closer study that address attention, distraction, and cognitive overload [7]. The Tower Team concept, as established by the FAA [1], further increases situational awareness and cognitive loading. With increasing traffic loads, and tower involvement in runway incursions, concentrated attention on these and other concerns bears immediate assessment for feasible remedies.

Explained earlier, the FAA Tower Team performs three separate, interrelated functions as an integral unit. Team controllers work with the VIDS displaying four separate screens depicting local air traffic, ground environment, data and communications, and remote cameras on the airfield, runway crossings, and helipads. In some locations, controllers direct air traffic operations at multiple remote airfields. Although a controller is not responsible for all the activity seen, they are exposed to it in their continuous scan of VIDS. Controllers also are aware of blind spots in the vicinity that are not captured by cameras or sensors [8]. In addition, they monitor all other transactions conducted by controllers with different assigned tasks. Combined, these engage substantial cognitive processing resources. Consequently, while scanning displays, something that distracts attention and delays their scan can disrupt a train of thought. The potential for conflict or confusion is evident and invites possible overload, even in nominal conditions. A major potential for distraction is when controllers must move to view the large screen mounted above them displaying STARS information.

7 Cognitive Overload

Given the operating environment within the Tower Team, several potential overload situations can arise. With each controller visually scanning all functions, when an unanticipated event occurs they may be uncertain which controller takes the lead. Or, if an anomaly is detected in one of the remote locations, that can disrupt the scan and prospective memory or deferred actions awaiting execution. Where action requires intervention of the supervisor (who can override a controller at any time), this might draw the immediate attention of remaining controllers and divert their scans. Where conditions are nominal, operators can usually function effectively. It is when an emergency or unanticipated event occurs, for example an unauthorized runway crossing, that cognitive overload is likely [9]. Consequences can seriously degrade controller performance.

To assess the potential for cognitive loading issues, a convenience survey (10 items) was administered to 20 Tower Team controllers. Complete results will be published separately. Preliminary findings indicated sometimes or often 75% needed to shift attention, 60% required added time to assess status when re-engaging, and 40% found monitoring digital videos (e.g., remote airfields, helipads, blind spots) intruded upon attention to other tasks. When encountering a diversion from their primary screen, 75% experienced confusion, and, experienced stress in the team environment. However, 85% believed automation did not add to their workload. In a different vein, 85% indicated an automated ground display with warnings of potential collisions or incursions would be of value. Expecting additional NextGen technology regarding digital texting to aircraft, 45% indicated they prefer texting to radios, although 75% believed it would be of benefit as support. The survey results indicate two clear outcomes - first, that there are substantial opportunities for distraction and confusion in the Tower Team environment. And second, controllers are confident in their abilities to manage growing technology applications and they welcome added functions to improve communications. In part, this confidence may be attributed to the advanced training simulators and requirements to operate in each of the positions on the Team. However, the obvious disparity lies in the juxtaposition of these two findings.

As NextGen progresses, new functions and technology, including expanded texting, will arrive. Although limited in practice currently, the use of ADSE-X when implementing ASSC and CPDLC are prime examples of advanced technologies added to controller scan. To achieve balanced tasking and to maintain vigilance of critical functions, implications for CRM tailored for the Tower Team environment are evident.

8 Summary

In the transition from legacy tower operations to continuing development of the Next Gen Tower Team, the potential for disrupted cognitive processing and eventual cognitive overload become clear. As indicated, the functions of local traffic, ground operations, and data transfer and communications are successively building the cognitive processing demands and suggesting thresholds for cognitive overload. As more NextGen functions are implemented, a close examination of effects on controllers is apparent. Likewise, the positive results of superior training and equipment needs to be assessed for possible lessons learned that may apply to other aviation functions.

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