

CONTROLLER INHIBITION OF AUTOMATED CONFLICT RESOLUTIONS IN A MAXIMUM NEXTGEN CONDITION

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Abstract

With the continued projection of increases in air traffic density, operations in the National Airspace System (NAS) are expected to exceed human capabilities in the near future [1]. In order to address the bottleneck of human workload capacity, highly automated safety-critical systems are under development to support air traffic controllers. However, the transfer of tasks and capabilities from a human agent to an automated agent is not without its pitfalls. Human controllers provide safe, efficient, and creative problem-solving in conflict situations—situations that often are outside the abilities of an automated system. In order for controllers to best use their creative problem-solving skills in safety-critical situations, automated agents must shoulder ‘routine’ activities contributing to controller workload in the current-day system, such as housekeeping tasks and basic separation assurance activities.

The detection and resolution of conflicts required for basic separation assurance is the primary contributor to current day workload, since it requires controllers have an awareness of all aircraft to produce effective solutions. However in high-traffic airspace (e.g., 30+ aircraft in a sector), full situation awareness becomes impossible without automated assistance. While research on the automation of conflict detection and resolution is fairly well established, questions remain concerning the give and take between the responsibilities of the human controller and those of the automated agent.

Discussed here is a portion of a larger human-in-the-loop experiment examining controllers’ transition through four hypothetical automation stages of the Next Generation Air Transportation System (NextGen). This portion, called Maximum NextGen, simulated a fully automated environment where the automation was responsible for detecting and resolving conflicts within simulation parameters in high-density airspace. The human moved to primarily a supervisory position: typically only assuming control over separation assurance tasks during U.S. Government work not protected by U.S. copyright

conflict situations deferred by the automation. While tasks were allocated a-priori between the controller and automated agent, controllers maintained authority to inhibit the automation from interacting with particular aircraft. This analysis focuses on the circumstances surrounding controller’s inhibitory actions upon the automation, postulating about their reasons for doing so based on contextual similarities, ultimately identifying preliminary trends for both further research and automation refinement.

Introduction

A key component in accommodating the expected increase in air traffic in the next 50 years is the allocation of work in the air traffic management system. While very safe, the current system for managing the NAS is constrained by the cognitive capacity of human air traffic controllers [1]. While human controllers remain valuable and necessary to the system for their flexible and creative decision-making, NextGen incorporates a number of agents, establishing a partnership between human air traffic controllers and assistive automation with decision-making capabilities [1]. While many of these automated agents are partially or fully developed, some debate remains about the appropriate allocation of functions between agents (human and automated) in NextGen.

A subset of this over-arching question focuses on what Miller and Parasuraman [2] explain as the difference between adaptive and adaptable automation. Adaptive automation describes an automated agent whose system design specifies its ability to acquire and execute tasks, and is not manipulable in real-time by other agents in the system. For example, automation in an air traffic management system may automatically acquire control over hand-off tasks when the number of aircraft in a controller’s sector exceeds fifteen. These boundaries are inflexible and are a feature of the system. Miller and Parasuraman [2], while citing the

value in this design principle, argue for the use of adaptable automation.

In adaptable automation the human agent uses their discretion in delegating tasks to or regaining tasks from the automation based on a predefined set of capabilities. For example, an air traffic controller may be notified they are controlling more aircraft than the recommended limits with the suggestion they allow the automation to take over hand-off tasks. In adaptive automation, the automated agent would seize control over handoffs, in adaptable automation, the automation can only request control, with the ultimate authority in the hands of the human agent. In adaptable automation, the automated agent may have default control over a number of tasks, like hand-offs, which the human agent can then inhibit, re-allocating control over the task to themselves, then allow the automation to regain control of the task later.

While both adaptive and adaptable designs have their merits, there is no hard and fast rule on which is most appropriate for each unique system. Certainly there are indicators and issues concerning responsibility and liability, workload, and situation awareness, as well as the consideration of the human agents within a system who may not wish to have tasks involuntarily ceded from their control. Which design is best for the safe and efficient management of the NAS is still under debate.

Adaptable Automation for Maximum NextGen

To better understand human-automation issues in the air traffic management environment, the Airspace Operations Laboratory (AOL) at NASA Ames Research Center examined elements of adaptable automation within the context of a larger experiment. The full experiment dealt with varying levels of automation assistance and intervention in the air traffic management system, from minimal automation in current-day operations, to a maximum NextGen condition where the majority of separation assurance tasks were the responsibility of the automated agent and not the human controller. The Maximum NextGen condition was the only opportunity to examine a feature of adaptable automation, as this was the only condition where the controller had the ability to inhibit the automated agent's actions upon aircraft. For information on the other conditions, the following publications discuss the experiment in detail: [3-8].

The purpose of this publication is to explore the conditions under which a human controller inhibited automated action upon an aircraft. The analysis encompassed data from five controllers who each acted to some extent independently. For this reason, conclusions are preliminary and are an interpretation of a rare and multi-purpose event.

Methods

Airspace

The test airspace (Figure 1) included five adjoining, high-altitude, en-route sectors of the Cleveland Air Route Traffic Control Center (ARTCC, ZOB). These sectors were divided into two areas of specialization (denoted by color in Figure 1), located in physically separate rooms. While the floor of each sector was set at 33,000 feet, each had a unique shape and traffic pattern.

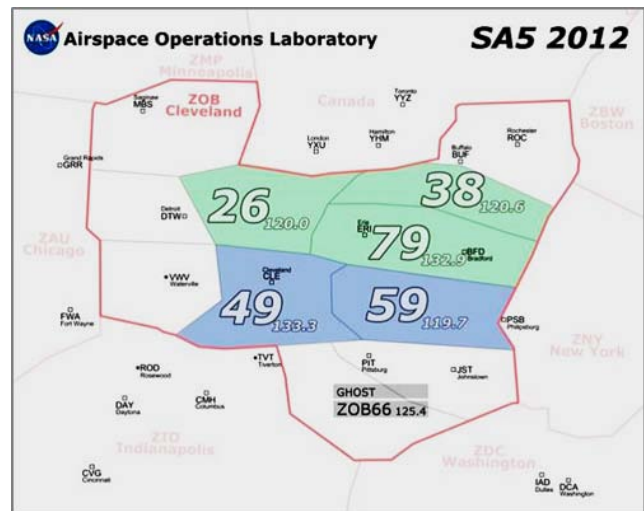


Figure 1. Test Airspace Based on the Cleveland ARTCC

Traffic

Live recordings of Cleveland traffic for the test sectors provided the basis for the simulated traffic. Traffic increased from the current day condition to the Maximum NextGen condition, where traffic was 100% over the current day baseline capacity for those sectors, with a Monitor Alert Parameter (MAP) value of 36 aircraft per sector. Traffic included a mixture of overflights and departures / arrivals from local airports. In the Maximum NextGen condition, all aircraft were able to receive Data Comm messages for frequency changes and control instructions.

Apparatus & Display

Operations were emulated using the java-based platform MACS (Multi Aircraft Control System) developed in the AOL [9]. Voice communications enabled live communications between participants with a VIOP system. Controller workstations were an emulation of the Display System Replacement (DSR), and consisted of the same monitor, keyboard and trackball used in operational facilities. As seen in Figure 2, aircraft were displayed as grey chevrons with a limited data block by default. The limited data block expanded to a full data block automatically in response to an automation detected conflict. Controllers could also manually expand the limited data block.

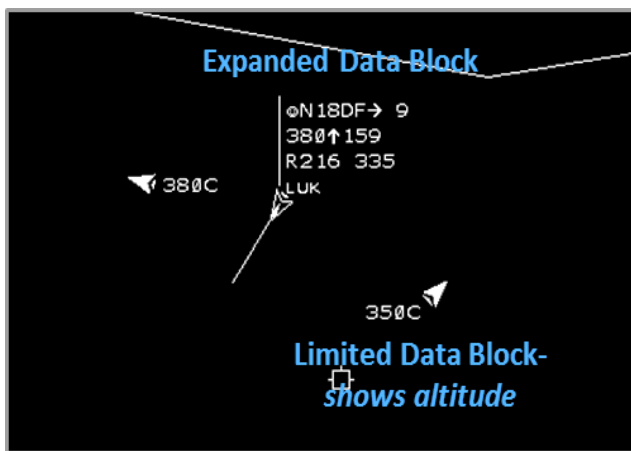


Figure 2. Display Screenshot of the Default Chevrons with a Collapsed Data Block and a Chevron with a Conflict Flagged

Participants

Two controllers worked each of the five test sectors: a radar controller (R-side) and an on-demand radar associate controller (D-side). Confederate or “ghost” controllers managed the surrounding airspace, while two controllers worked supervisory positions. The R-sides and supervisors served as test positions, staffed by six current and one recently retired front line manager from US ARTCCs. This analysis only includes data from the five test participants working R-side positions.

Maximum NextGen Roles and Responsibilities

All aircraft were Flight Management System (FMS) equipped for this condition, and could receive Data-Comm messages both directly from the controller and from the ground automation agent.

Similar to the automation, the majority of controller resolutions were issued via Data-Comm directly to the flight-deck; however, controllers retained verbal communication with their aircraft.

Automation

Based, in part, on the Automated Airspace Concept introduced by Erzberger [10], the ground automation was responsible for the safe separation of traffic, all conflict detection, and resolution, and automatically sending all necessary control instructions to aircraft via Data-Comm. Additionally, the automation was responsible for alerting the controller to any exceptional circumstances. The automation’s tools solved conflicts and provided resolutions similar to a human controller. However, the automation’s resolution authority for strategic conflicts (i.e., mid-term time horizon) included specific tolerance parameters. If the automation’s resolution exceeded the tolerance parameters, the automation flagged the conflict for the controller. For tactical conflicts (i.e., near-term time horizon), the automation calculated a heading change to be issued to one or both aircraft for separation [10].

Controller

While controllers retained authority over all the aircraft in their sector, their role shifted to primarily a supervisory capacity, managing any exceptions beyond the automation’s parameters. However, while they shared responsibility with the automation for losses of separation (LOS), they were not liable for a LOS if the conflict was not detected, not alerted to the controller, and / or not issued a separation assurance heading by the automation for tactical conflicts. When controllers needed to resolve a conflict themselves, they had interactive tools containing the same information the automation used for its resolutions, allowing them to interactively find solutions. In addition to interactive tools, controllers could inhibit the automation from up-linking any messages to multiple aircraft until they rescinded the inhibition.

Conflict Resolution Tools

Both the automation and controllers had access to a conflict resolution tool. The automation’s auto-resolver solved conflicts with resolutions not imposing less than: 90 seconds of delay, 60 degrees of heading change, 2200 feet of altitude change, and / or 50 knots of speed change. If a conflict was not

solvable within those constraints, the automation flagged the conflict for the controller, expanding the conflicting aircraft's data blocks and listing the conflict in the conflict list (Figure 3). The controller's tools included a trial-planner with integrated conflict-probe feedback that allowed them to test various maneuvers before sending clearances to an aircraft. Similarly, an altitude fly-out menu incorporated feedback from the conflict-probe, helping the controllers to evaluate potential maneuvers. Controllers then uplinked their resolutions to the flight deck via Data-Comm.

TSAFE

The Tactical Separation Assured Flight Environment (TSAFE) algorithm stepped in to

resolve conflicts with less than two minutes until LOS [10], issuing a lateral route amendment designed for immediate, short-term separation assurance. Prior to the uplink, TSAFE displayed the calculated heading change to the controller on the fifth line of the data block at three minutes until LOS (Figure 4). TSAFE was an automatic function; it always triggered unless the controller blocked the automation from interacting with an aircraft using the inhibition function. If the clearance was uplinked by the automation, a follow-up clearance was also sent to return the aircraft to its route.

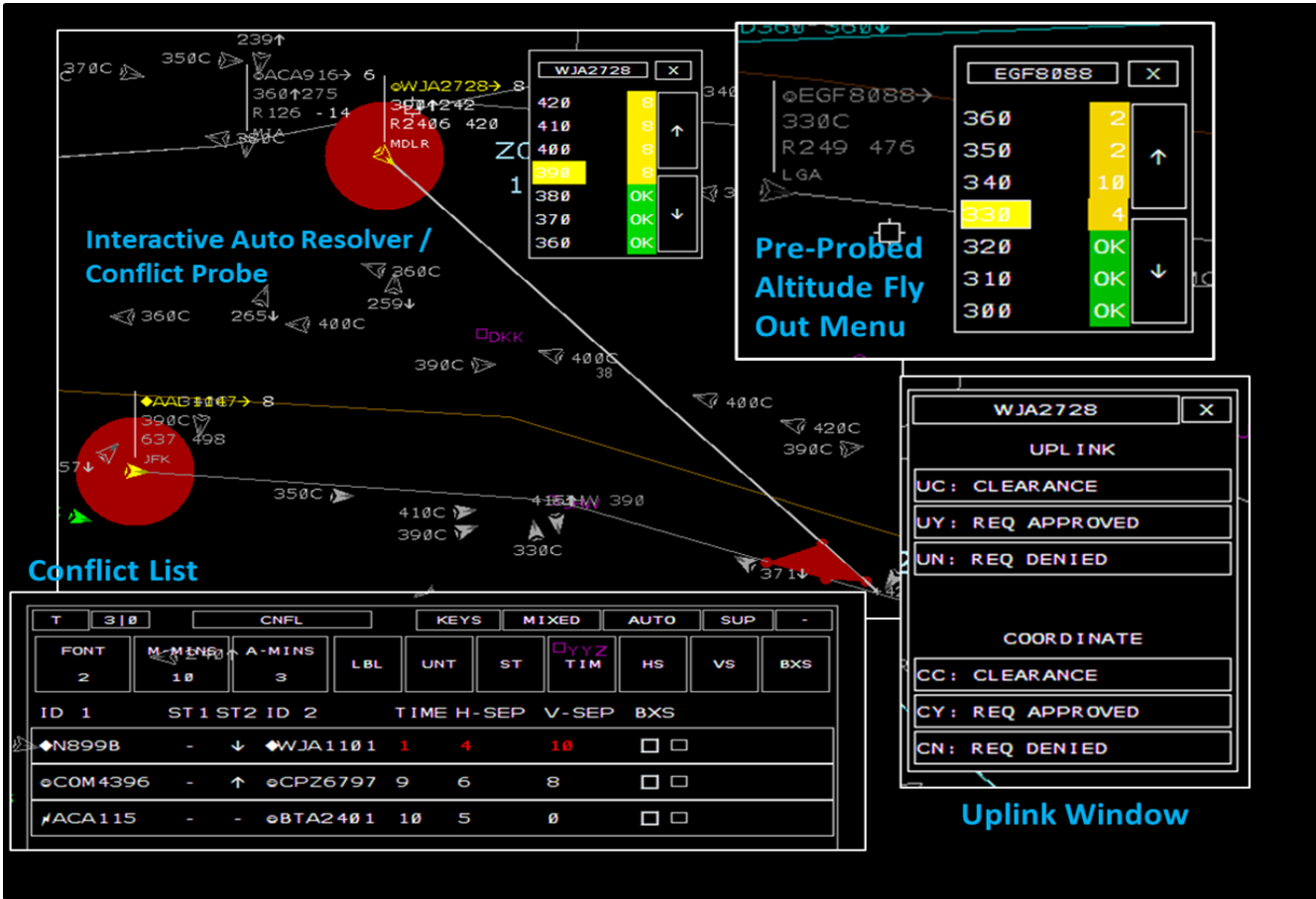


Figure 3. Interactive Conflict Resolution Tools Available during the Maximum NextGen Condition

Inhibition

Available to the controllers was the ability to inhibit the automation from sending any messages to

aircraft. This inhibition function, invoked by entering an 'NU' keyboard command, inhibited the automation from sending anything to an aircraft

(including routine tasks such as frequency changes). This inhibition remained in place until the controller removed it, using an ‘AU’ keyboard command. The NU function did not prevent the automation from showing the controller the TSAFE route amendments it would be issuing if not inhibited. For example, in Figure 4, both aircraft are inhibited [the pink box], but the automation still displays the TSAFE resolution for the controller’s reference.

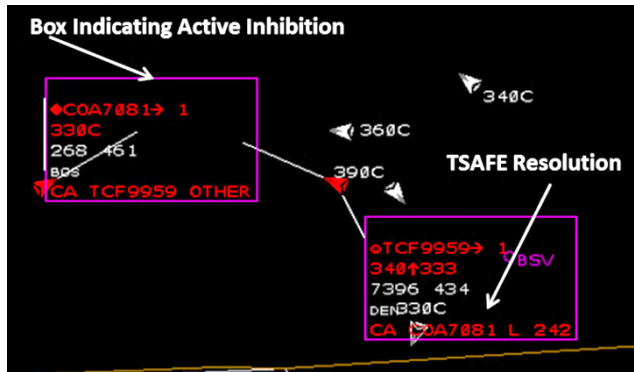


Figure 4. Inhibited Conflicting Aircraft Displaying a TSAFE Resolution

Procedures

As with all the study’s conditions, the Maximum NextGen condition consisted of two days in the laboratory: one day of training, followed by one day of data collection. The data collection consisted of six 40-minute runs of traffic with breaks in between and a lunch period half-way through.

Collected data consisted of various performance and subjective measures. MACS logged controller and pilot actions, flight path, aircraft states, losses of separation, time, and other metrics as well as a real time workload rating by participants. Camtasia recording software recorded all audio transmissions and screen recordings. Post-trial questionnaires collected subjective data.

Results

Whether or not the controllers inhibited the automation varied greatly by sector. Because of this, a traditional analysis was not available. Instead, controllers were grouped based on their use of the inhibition function. Each group was then examined as a case study, noting any trends. More specifically, frequencies counted the number of conflicts whose resolution included an inhibition event. A conflict is

an automation predicted loss of separation (LOS) between two or more aircraft. This analysis did not count the inhibitions themselves, since conflicts may have resulted in inhibition of one or both aircraft – whichever the controller preferred. Table 1 counts the number of times a conflict led to an inhibition action by the controller on one or both aircraft.

Table 1. Frequency of Conflict Resulting in Inhibition Events

	Sector				
Run	S26	S38	S49	S59	S79
19		3			1
20		3	2		1
21	1	2			2
22		4		1	5
23		5	1		5
24	1	4	4	1	5
Total	2	21	7	2	19

As shown in Table 1, two controllers inhibited the automation more frequently than the other three. The three who did not (sector 26, 49, and 59) are examined first; this analysis is limited to general observations about the circumstances surrounding the conflicts leading to the inhibitions. However, analyses of sectors 38 and 79 compare conflict situations that led to an inhibition, alongside conflict situations resolved without inhibiting the automation. This latter set of analyses characterize conflict situations across multiple parameters, as measured at the time of the last recorded active conflict state, intended to represent the moment just before an inhibition of the automation, or just before a controller issued a maneuver. The “sectors 38 and 79” section below reports those results.

Sectors 26, 49, and 59

As seen in Table 1, the controllers in sectors 26, 49, and 59 only inhibited the automation on a few occasions- 11 in total. As this was a new function for

the controllers, its rare use is understandable. Experimenters prompted the use of the inhibition function for four of these eleven conflict solutions. Specifically, during three conflicts for sector 49, and during one conflict for sector 59, the controller inhibited the automation based on suggestions from the experimenters. All four of these conflicts were tactical in nature, with less than three minutes to initial loss of separation, and in all cases, TSAFE would have issued a turn to one or both of the aircraft. Commentary available from the video recordings suggests that a priority of these controllers was to limit lateral maneuvers for these aircraft. For example, Sector 59 in run 22 said in regards to an inhibition, *"I'm trying it [Inhibition] right now because I don't want it to turn that guy whose climbing out there 10 minutes away..."* and sector 49 said in regards to an inhibition for a conflict involving two sets of aircraft, *"It would have been a lot of turns."*

In the same vein of turn limitation, in all but one of the seven conflicts leading to inhibitions

independent of experimenter suggestion, the controller either issued an altitude or waited a conflict out. In the cases where the controller waited, their behavior indicated they had identified a false alert by the automation. These false alerts are categorized as conflicts where, if nothing is changed, they fail to achieve a loss of separation [10]. None of the conflicts controllers inhibited and then waited out resulted in a LOS, indicating the controllers could correctly identify these situations.

Sector 49 especially preferred to wait out a conflict situation. For example, in Figure 5, sector 49 sees a conflict between COA7081 and TCF9959, promptly inhibits the automation from sending messages to either aircraft, sees the TSAFE resolution, and waits until the conflict disappears without issuing any changes to either aircraft. In this particular case, the controller apparently had confidence the climbing aircraft would safely ascend past the conflicting altitude. Concurrently, sector 49 was dealing with a different conflict in the sector that required more controller involvement.

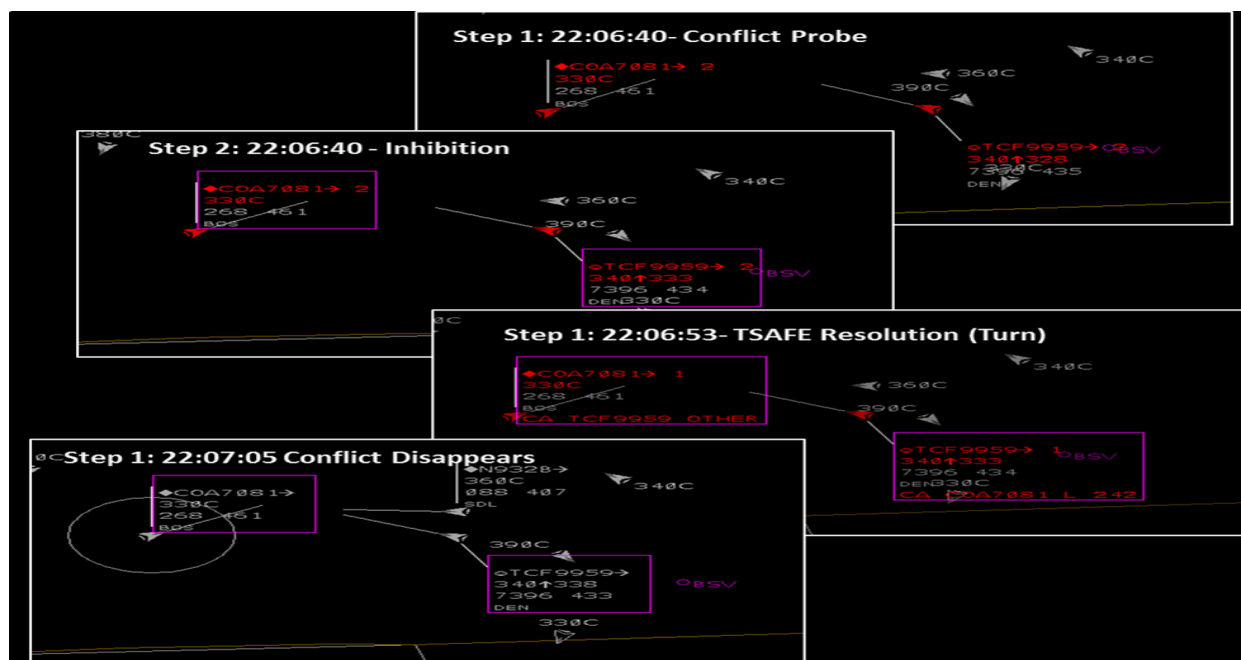


Figure 5. Step by Step process for Waiting Out a Conflict Using an Inhibition

Sectors 38 & 79

Of the five sectors, sectors 38 and 79 had the highest number of predicted conflicts leading to

inhibitions by the controllers, 21 and 19, respectively, with only three prompted by suggestions from the experimenters. All the conflicts for sectors 38 and 79 contain two parameters of interest: time until

predicted LOS and the predicted vertical states of the conflicting aircraft. These parameters may lead to insights regarding whether or not the controller would trust the automation to ensure separation when a LOS was imminent, and / or they may speak to controller's reaction to TSAFE advisories.

Conflicts with and without inhibitions were not paired observations, requiring an examination of trends instead of statistical inference. Figure 6 contains the distributions for time until loss of separations for conflicts with and without inhibitions, as well as a cumulative percentage line for each histogram. This line indicates the percentage of the overall data set reached by that point. Figure 6 shows the cumulative percentage line is much steeper in conflicts with inhibitions until six minutes than in conflicts without inhibitions, indicating a greater percentage of the data in conflicts with inhibitions lies in six minutes or less than in conflicts without inhibitions.

Time to Predicted Initial LOS

Figure 6 shows the distribution of conflicts with and without inhibitions across time to initial LOS. Both the overall distribution and the general time horizons (near, mid, far) are of interest. Near-term conflicts ranged from 0:00-3:00 minutes to LOS, mid-term conflicts ranged from 03.01-06:59 minutes to LOS, and far-term conflicts were 07:00+ minutes to LOS.

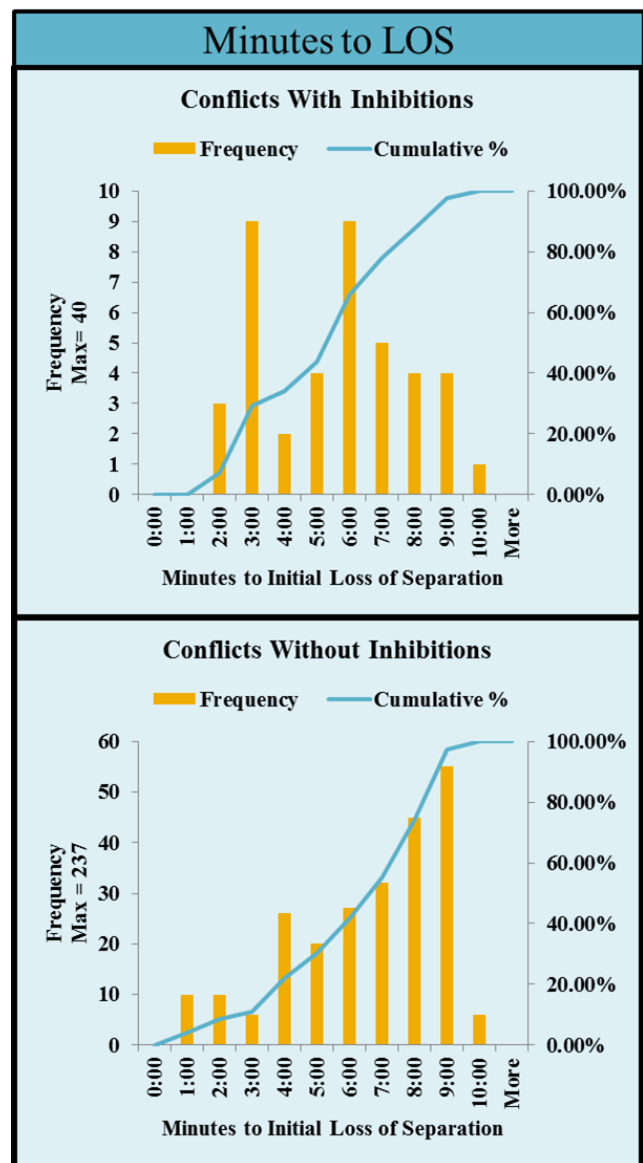


Figure 6. Minutes Until Predicted Initial Loss of Separation

Comparing the cumulative percentage line of both distributions identifies a trend where conflicts leading to inhibitions are more likely to be in the near and mid-term time frames (<06:59) than conflicts without inhibitions. Specifically, at the six minute bin, the cumulative percentage for conflicts with inhibitions is 65.85%, while for conflicts without inhibitions, it's 41.77%.

That the majority of conflicts with inhibitions occur in near-term and mid-term time horizons suggests these controllers may be motivated to intervene and inhibit the automation for conflicts with less time until loss of separation. Of the 40 total

conflicts with inhibitions, 20 fell into the mid-term time horizon group, nine near-terms had a TSAFE advisory posted (02:01 min-03:00 min) and three near terms triggered a TSAFE resolution (<02:00 min). Only eight fell into the far-term time horizon.

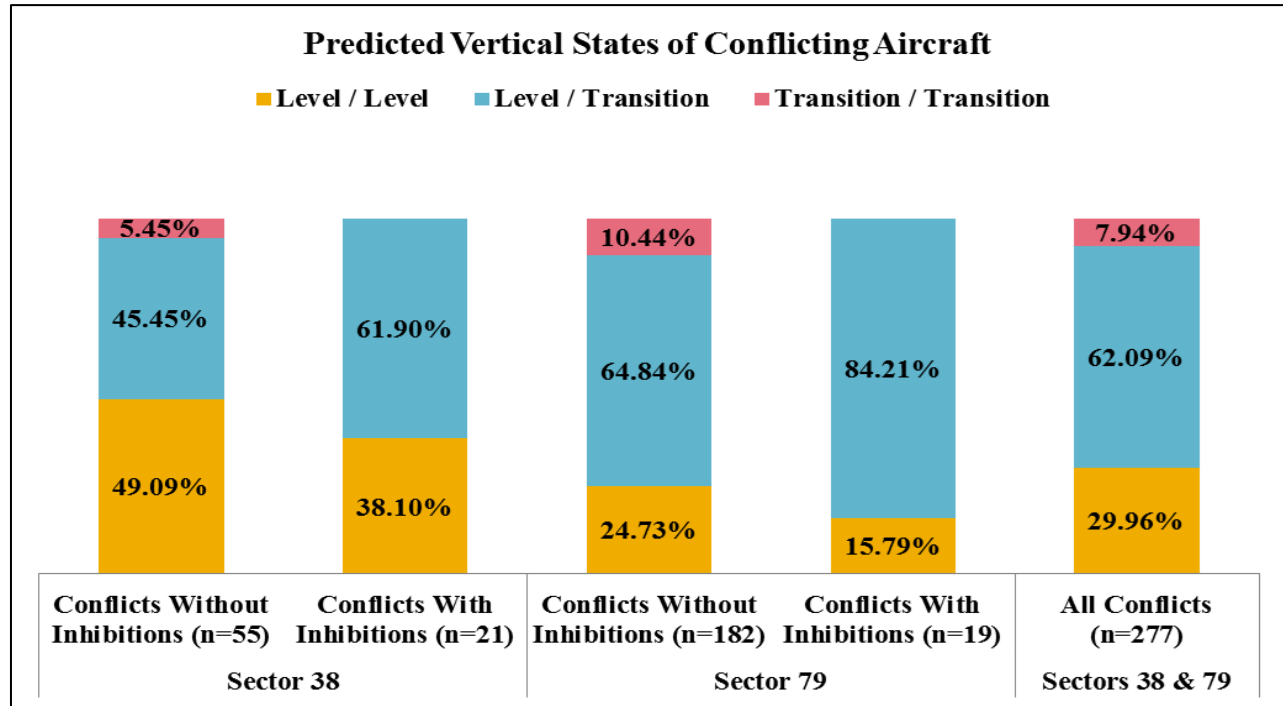


Figure 7. Predicted Vertical State for Conflicts with and without Inhibitions

Predicted Vertical Profile of the Conflict at Initial LOS

A conflict's vertical profile describes the predicted vertical states of the involved aircraft: level, climbing, or descending. An analysis of the data grouped the climbing and descending states into a single 'transitioning' state, in order to examine the likelihood that inhibitions occurred in more complex encounters. As seen in Figure 7, both sectors 38 and 79 inhibited Level/Transition conflicts the majority of the time, with the rest of the inhibitions for Level/Level conflict probes. Of note is that no inhibitions occurred on the few Transition/Transition conflict probes. Of the Level/Level conflicts with inhibitions, nine of 11 [82%] were solved by an altitude, and of the Level/Transition conflict probes, 17 of 29 [59%] were solved by waiting it out, with eight of 29 [28%] by altitudes. Six of those eight altitudes and two of three headings were for near-

term conflict probes, making an altitude or heading change predominantly a near-term solution for Level/Transition conflict probes.

Proactive Inhibitions

Like sectors 26, 49, and 59, there was also a trend in sectors 38 and 79 of proactive inhibitions-inhibitions the controller executed before TSAFE could display an advisory, or as part of a larger strategy beyond just the current conflict. These proactive inhibitions seem to have resulted from a desire to avoid multiple changes to aircraft, especially heading changes. Of the conflicts with inhibitions, 35 of 40 automation inhibitions resulted in either the controller issuing an altitude change [S38=8 of 21, S79=8 of 19] or waiting the conflict out (identifying a false alert) [S38=10 of 21, S79=9 of 19]. The circumstances around dealing with a false alert varied; controllers used inhibition to suppress

actions by the automation on false alerts, or to allow changes and / or plans by the controller time to take effect. For example, in Sector 79 the controller identified a false alert and inhibited a climbing aircraft with a conflict, saying *"I better NU him before it (the automation) does something"* and waited the conflict out. This behavior was especially notable for conflicts involving Level / Transition vertical states, which composed all but two of the waiting strategies related to false alerts.

Differently, Sector 38 had a conflict probe appear and then issued an amendment, which cleared the conflict for the time being. The conflict re-occurred a few seconds later, at which point the controller inhibited the automation, saying: *"Pretty sure that's the guy I just fixed, so now I better go and NU these guys before they do something different."* In this case, the pilot hadn't yet completed executing the controller's amendment, causing the conflict probe to re-alert. The inhibition suppressed the automation to allow the controller's change time to take effect.

Boredom

The controllers for sectors 38 and 79 each at one time verbally expressed having 'nothing else to do' as the reason for their inhibition of the automation. Controller 79 in run 21 said, *"Since I'm not doing anything, let me NU those"* and controller 38 in run 24 said, *"Oh, got something to do!"* at the appearance of a conflict which 38 then proceeded to inhibit. Both of these conflicts had more than three minutes remaining until the predicted LOS.

Discussion

The primary question of this exploration was why the controllers chose to inhibit the automation. Because each controller exhibited unique behaviors to some extent, and inhibition occurrences were few when compared to the overall number of conflict probes, more research is still needed in order to fully understand how, in more automated environments, controllers could incorporate automation-inhibition strategies into their overall work flow. However, this data did preliminarily reveal that: A) inhibition behavior more often happens when there is less time until loss of separation, B) conflicts with Level/Transition vertical profiles are more often inhibited, and C) participants primarily applied the inhibitions to conflicts they identified as false alerts,

and when it wasn't a false alert they preferred altitudes over headings as resolutions.

Inhibiting conflicts with less time until loss of separations leads to several possible considerations. First, controllers were identifying false alerts primarily in the mid-term time frame, which suggests the conflicts need to be closer to loss of separation to make this identification possible. Secondly, the controllers may have issues trusting the automation to resolve conflicts when there is not enough time left for a backup plan before the loss of separation. Thirdly, they may wish to avoid the lateral headings issued by the TSAFE algorithm at the two minute mark. A combination of motivations addressing the automation's false alerts and lack of time for a backup plan seem most likely since most (70%) of the inhibitions occurred before TSAFE posted the advisory at the three minute mark.

The controllers' penchant for identifying and inhibiting false alerts could be rooted in their desire to avoid lateral headings (turns) in this highly congested airspace. Level/Transition conflicts made up the majority of conflicts with inhibitions in this data set and were the most often identified as false alerts. The controllers rarely took any action on these Level/Transition conflicts, however, when they did issue an amendment, it was more likely to be an altitude change than a lateral maneuver.

Repetitive behavior on the part of the controllers such as this allows for an opportunity to refine the automation's behavior. When an aircraft is inhibited, the controller must delegate attention to monitor that aircraft, something the automation would normally handle. By refining the automation to identify and adjust false alerts so no inhibitory action is required by the controller, this workload on the human agent in the system can be alleviated.

The proactive use of the inhibition function was an additional insight not necessarily related to a potential conflict's characteristics. There was a trend, especially for sectors 38 and 79, of using the inhibition to manipulate the automation long before a conflict became a near term concern. This long range planning shows the use of inhibition as part of the controller's overall strategy for interacting with their traffic and the automation, as well as managing their workload and situation awareness.

Conclusion

The ability to inhibit the automation, thereby adapting the allocation of functions in real-time, allowed the controllers to customize their traffic management, workload, and situation awareness strategies. Some controllers did see the value of using the inhibition to re-engage in their sector management when they were bored or not doing something else; a concern when dealing with a highly automated environment. While this experiment condition only collected data for one day, it is reasonable to expect a higher occurrence of these engagement issues with longer exposure to such operations.

The actions on behalf of the controllers to inhibit the automation in this experiment lend to the idea that such interactions are a valuable tool for proactive planning, attention management and overall sector management strategy; giving credence to the adaptable automation scheme. However, the noticeable differences between the groups of controllers- those who frequently incorporated it and those who infrequently incorporated it- suggests that the proper use of inhibitions needs training like any other tool. Since adaptable automation only changes task function allocation at the controller's discretion, neglect on the part of the controller to take advantage of the feature may nullify its value, while an over use of the inhibition will increase their workload and potentially compromise safety. In either case, controllers properly equipped with knowledge on when and how to use an inhibition function will be more able to manage their traffic, workload and situation awareness effectively.

While interesting trends did surface, the data examined in this analysis was only from a handful of events drawn from a larger simulation, warranting further investigation of the circumstances surrounding inhibitions. Further studies should evaluate the automation's conflict thresholds, particularly for vertical trajectory segments, in an effort to reduce such false alerts. Additionally, a closer look at a larger sample of controllers' propensity to make use of the inhibition feature would be valuable, as well as more information on how conflict parameters and airspace characteristics affect inhibition behavior.

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