33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ATCO STRATEGIES IN TACTICAL TBO: A SIMULATOR STUDY

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Abstract

Trajectory based operations will be an important concept in tomorrow's Air Traffic Management. The concept is a complex puzzle that includes both strategical and tactical aspects to achieve increased predictability and efficiency. However, research related to trajectory based operations has been focusing on strategical or technical perspectives, thus not addressing how it effects, and is affected by, the air traffic controllers work situation. In this study, we conducted real-time simulations with air traffic controllers to explore how the introduction of a tactical trajectory management tool affects the controllers' work strategies for conflict resolution. A tool for tactical trajectory management was developed and integrated in an Air Traffic Control simulator, and tested with realistic traffic scenarios. The results showed that by using tactical trajectory management, it was possible to reduce the need for the air traffic controllers to monitor implemented conflict solutions. The tool was incorporated by the controllers in their current work strategies for conflict resolution rather than changing their strategies. However, it also highlighted the need for more advanced support tools for trajectory management in solving vertical conflicts and using temporal constraints.

Keywords: Trajectory based operations, air traffic controller, work strategies, simulator study

1. Introduction

Trajectory Based Operations (TBO) has been suggested as an important technological and operational change to meet future demands on capacity and efficiency in Air Traffic Management (ATM) [1, 2]. One of the most important gains expected from implementing TBO is increased predictability that allows for better strategic and tactical planning. Regardless of the improved planning, there are still uncertainties that affect the aircraft, e.g. weather and wind, as well as factors that are unknown to the ground system, such as aircraft weight and cost index. These uncertainties create deviations from the planned trajectories, creating conflicts between aircraft which requires tactical interventions from the Air Traffic Controllers (ATCOs). Depending on traffic situation and other factors such as airspace design, surrounding traffic, and even personal preferences based on previous experience, ATCOs may chose different work strategies for how to solve the conflicts. Thus, conflict resolutions implemented by the ATCOs introduces new uncertainties and further reduces predictability. This is particularly true for open loop clearances (Fig.1), for example assigning a heading to an aircraft until it is clear of the conflict. One way to mitigate this problem is to use tactical trajectory management, or 4D trajectory management (4DTM) [3], where the ATCO makes updates directly in the trajectory and sends it to the pilot using datalink. The trajectory is then entered into the aircraft flight management system (FMS), thus maintaining closed loop navigation (Fig.1). Tactical interventions will still be needed in ATM as long as the air traffic is not fully deterministic, and working on tactical basis with aircraft trajectories will be an important enabler in future ATM automation.

Even though some basic functionality for tactical trajectory management already has been adopted in operational air traffic control systems, surprisingly little research can be found on how this new

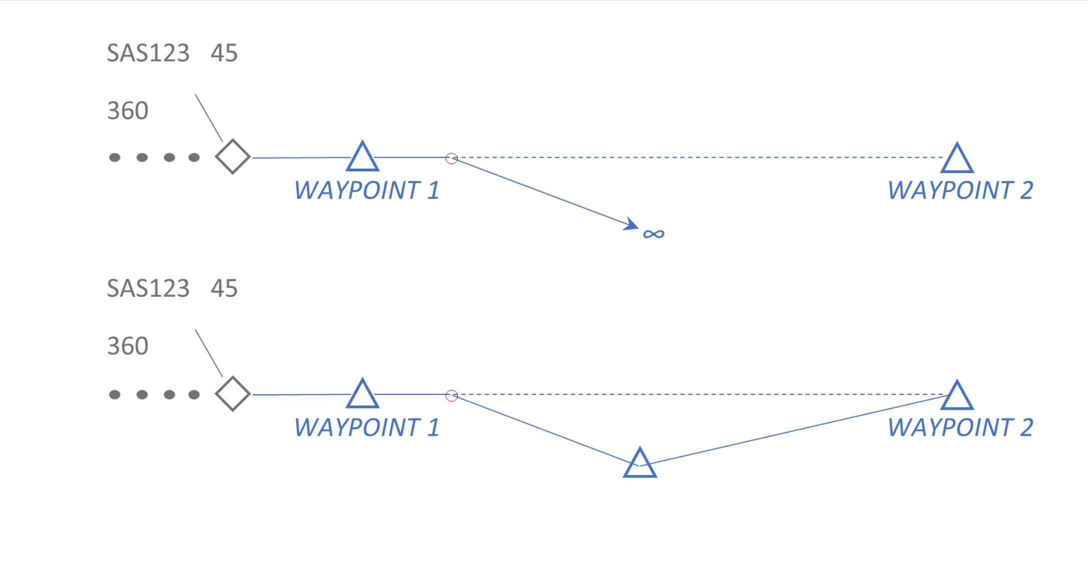

Figure 1 – Open versus closed loop clearances. When the aircraft in the upper figure reaches the point indicated bu the small red circle, it is cleared to turn right on a magnetic heading. Since it is not defined when it shall return to its original route, this is an open loop clearance. In the lower figure, the aircraft is cleared via a new, temporary waypoint at which the aircraft shall turn back to its original route — a closed loop clearance. By using the closed loop clearance, the trajectory is kept intact, and the system can predict the future trajectory with higher certainty.

methodology affects the work strategies of the ATCOs. TBO as a concept is a puzzle with many pieces that needs to be in place to reach the full potential of TBO. For example, there must be system support in airborne and ground systems, trajectory predictions must be reliable, it must be possible to exchange trajectory information ground-ground and ground-air, operational procedures and regulations must be in place, and the operators must have sufficient knowledge about the concept to utilize TBO. A review of present research in TBO and 4DTM showed a focus on the initial optimization problem, and strategic TBO for flow management, as well as various technical aspects of the message exchanges. However, studies on how the ATCOs work strategies are affected when shifting towards a trajectory-based methodology is, to our knowledge, largely missing and new issues and risks may be introduced.

To approach this gap, a series of internal workshops using a set of traffic scenarios were conducted, which resulted in a design of a tactical TBO tool. The tool was implemented in a real time air traffic control simulator and tested in a real-time simulator study.

The expected effects of tactical TBO on the ATCOs' strategies were that it should lead to less time spent on monitoring implemented conflicts resolutions and that the resolutions should be implemented earlier. It was also expected that it would be possible for the ATCOs to include the use of the tool for conflict resolution after just a short period of training.

2. Related Work

The TBO concept [1, 2] covers both the strategic planning and the tactical use of trajectory management during the execution of a flight. The strategic phase of TBO focuses on flow management and pre-departure flight planning [4, 5, 6] in which the goal of TBO is to optimize the use of the airspace from an Air Traffic Control (ATC) perspective as well as the perspective of airspace users before the aircraft leaves the ground. Even though improved pre-departure planning can reduce the conflicts in the airspace it cannot remove them entirely. Delays due to technical and logistical problems will affect the flights, and weather and winds which are difficult to predict, impacts the flight trajectories [7]. We can also conclude from the literature that the notion of trajectory prediction in research is often limited to mathematical and physical aspects only, not taking into account tactical human interventions and the resulting effects on predictability.

Tactical TBO provides the tools needed to maintain the benefits of TBO when the ATCO must make interventions due to conflicts or sequencing needs, as well as accommodate changes in the requirements from the pilots. The research found about tactical TBO and trajectory management was mainly focused on technical aspects related to the details of the trajectory negotiation and synchronization process, both ground to ground and ground to air [8, 9, 10]. Some studies was also found where TBO was used in a limited case, e.g. i4D [11, 12] which aims to sequence traffic flows by assigning time restrictions on waypoints and managing of trajectories for ground movement [13].

Even though the main focus has not been on tactical management of trajectories and how ATCOs should interact with the trajectories, there are some studies that relates to these perspectives. The SESAR Emergia project [14][15] highlighted the need for connecting the strategical and tactical perspectives on TBO and the ATCOs' roles for short- and medium term conflict resolutions. However, it only contained Monte Carlo simulations where the main ATCOs parameters studied were response times for implementing resolutions and possible number of interactions per minute. The importance of including the human perspective, and not only a technological perspective, was emphasized by Fernandes and Rebello [16]. They performed a focus group study on the use of TBO to enhance efficiency for oceanic flights through in-flight trajectory re-negotiation. The focus group though consisted of pilots, not ATCOs.

A concept for dynamic rerouting using TBO for avoidance of severe weather was demonstrated by Guerreiro [17]. It was considered feasible by the ATCOs participating in the demonstration. However, the constraints, the definitions of new routes, should be created by the Traffic Management Unit and the ATCOs should only take care of the implementation of the constraints — a less active role for the ATCOs. How the development of future concepts within ATM could change the role of the ATCO was addressed by Rohacs, Jankovics, and Rohacs [18]. Though not focusing specifically on TBO, trajectory based airspace was listed as one of the factors that was foreseen to affect the role of the ATCO, and a future role of trajectory manager was mentioned. An ongoing TBO related project is the SESAR project PJ18, 4D Skyways [19]. It has a wide scope which include improved trajectory prediction, exchange of complex CPDLC for air-ground synchronization including increased automation for ATCOs and pilots, trajectory exchange between ATM actors, and the development of a common architecture for trajectory management within Europe. The project includes large scale real-time simulations.

Even though research where TBO is related to how it affects the work of the ATCOs and their strategies for handling the air traffic can be found, there is an overweight of research on technical aspects and strategic use of TBO. There is a lack of research about how ATCOs should handle tactical trajectory management, what tools are needed, and how this interaction affects the ATCOs' work. If these tactical interventions by ATCOs are not taken into account, and if the affect on the ATCO situation and work strategies are not considered, there is a risk that the possible benefits of TBO as a concept may not materialize.

3. Methods

Based on the outcome of a series of internal workshops, a tool for tactical trajectory management was developed and tested in Narsim [20], a real-time human-in-the-loop ATM simulator, placed at the Swedish Air Navigation Services (LFV) research simulation facilities. The tool allowed the ATCOs to modify the trajectory laterally by inserting new waypoints anywhere along the lateral route, or move or delete existing waypoints. Each waypoint could also be given altitude, time, and speed restrictions. Communication with the aircraft was performed via a simulated voice communication system and Controller Pilot Data Link Communication (CPDLC). CPDLC datalink message UM79 was used to send updated trajectories. The Narsim simulator at LFV has a graphical user interface (Fig.2) that is aligned with the operational system used in Sweden, with the same colour scheme and main tools implemented, such as a Separation Monitoring tool and a Mid Term Conflict Detection system with associated graphical user interface. The tool was designed in accordance with the existing graphical user interface to focus on functional aspects rather than tool design. Aircraft performance in Narsim is based on the Eurocontrol Base of Aircraft Data (BADA) models, and the aircraft were controlled by pseudo pilots.

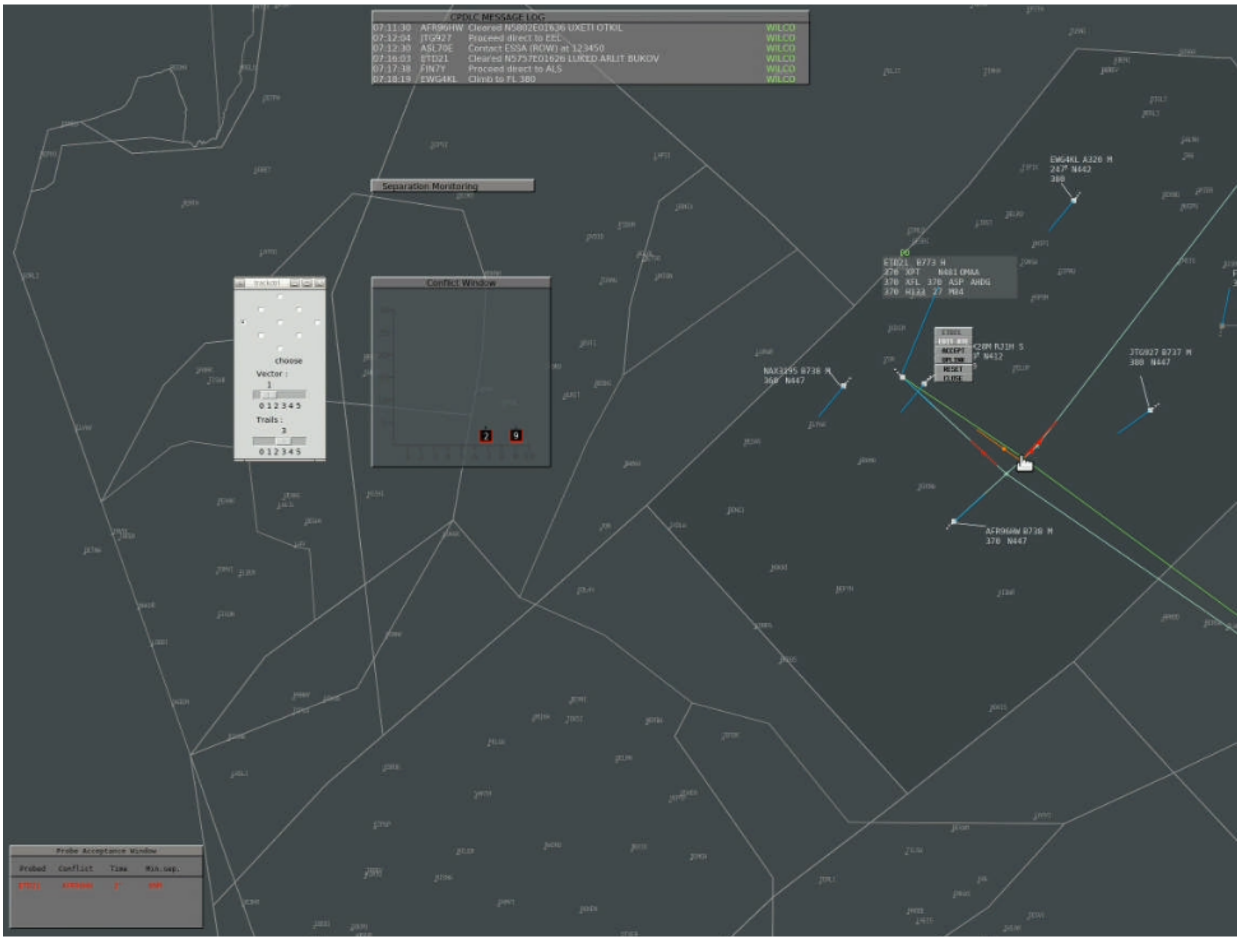

Figure 2 – Screenshot from the Narsim simulator with the tactical trajectory management tool. The trajectory of an aircraft is being edited by the ATCO. Trajectories for both aircraft in the conflict is shown, the conflicting sections of the trajectories are highlighted in red. The Conflict Window (slightly upper left of the middle) with distance on x-axis and time to conflict at the y-axis, visualizes the same conflict where one of the red/black boxes represents the conflict as is, and the other box represents the conflict if the new trajectory is implemented.

The traffic scenarios used in this study consists of five different scenarios with low traffic in synthetic sectors (scenario 1-5) and two realistic scenarios based on real traffic and in a real sector (scenario 6 and 7). The scenarios were developed together with subject matter experts in cooperation with a related project. For the purpose of this project the first five scenarios were used for training and scenario 6 and 7 were used for evaluation.

Two senior en-route ATCOs with valid ratings were recruited to act as controllers in the simulations where the TBO tool was used. The participants were recruited through LFV and participated at office working hours as part of their ordinary work. The same scenarios were run by 15 ATCOs in the related project without the TBO tool and the results from that project were used as baseline for comparison. Every scenario was run once by each ATCO in both projects.

When each ATCO had completed the simulation exercises, a debriefing was held to gather their experiences of how the tactical TBO tool affected their work. All interactions with the system were logged and eye gaze data was recorded with a Smart Eye Pro eye-tracking system consisting of four small infrared cameras mounted on the 43” air situation display screen. The eye-tracking system also provided screen capture of the air traffic controller display. The setup and procedure was the same for the related project.

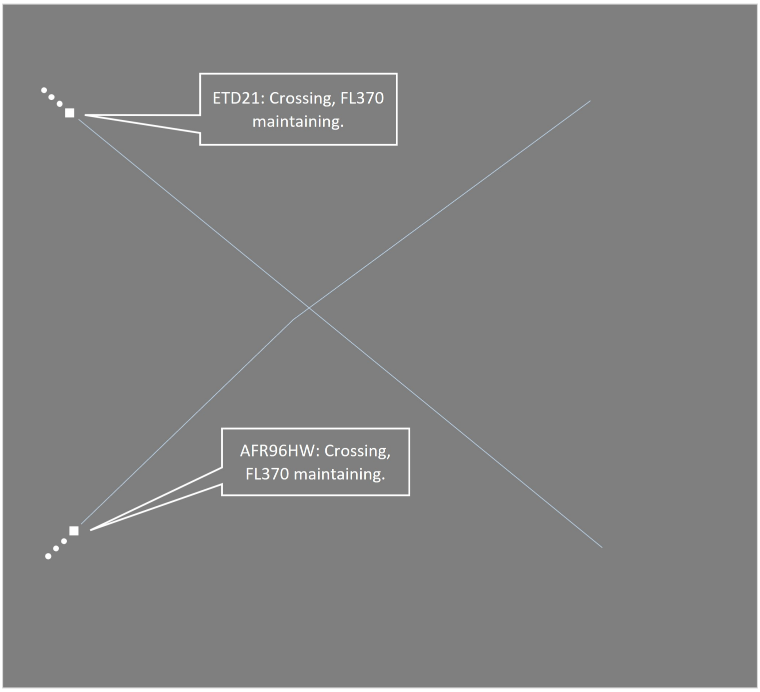

Figure 3 – Illustration of the simple conflict (not to scale). ETD21 and AFR96HW are both overflights, have crossing trajectories at the the same altitude. Traffic not directly involved in the conflict is not shown here.

The resolution of two conflicts where the tactical TBO tool was used was chosen for a detailed analysis, one conflict in scenario 6, which was conflict of low complexity, and one, more complex, conflict from scenario 7. Both these conflicts were conflicts by scenario design, and not results of previous ATCO interventions, and therefore comparable. The simpler situation consisted of two crossing aircraft at almost right angle maintaining the same altitude (Fig.3). The more complex situation (Fig.4) consisted of two departing aircraft, one aircraft behind another, initially climbing to flightlevel (FL) 290. (A flightlevel is 100 feet and is used when flying on standard atmospheric pressure altimeter setting at higher altitudes.) Their trajectories crossed each other at an acute angle and the trailing aircraft was slightly faster and requested a higher cruise level than the leading aircraft. Added to this, another aircraft was crossing their trajectories while descending towards its destination. The solution space was more limited than in the simpler situation due to sector borders close to the trajectories and surrounding traffic that blocked early descend alternatives for the crossing aircraft.

The analysis of each of these two situations was done by looking at the screen recordings where visualized eye gazes and system interface interaction were be observed. It was noted at which time different actions were taken and it was estimated when the participants worked actively with the situation and when they were monitoring the situations. The actions were then grouped into different solution types and a comparison was made between simulations with and without the TBO tool. The notes from the debriefings with the ATCOs were compiled and then clustered to find themes in the answers and then compared with the analysis of the recordings.

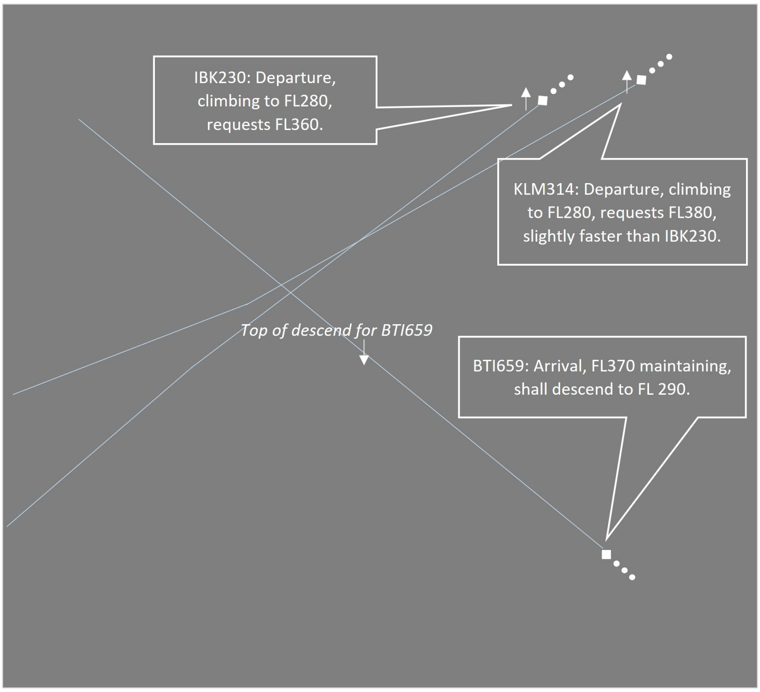

Figure 4 – Illustration of the complex conflict (not to scale). Two aircraft (IBK230 and KLM314) are climbing on routes that will cross each other at an acute angle. IBK230 is lower, but has requested a higher cruise level and is slightly faster than KLM314. BTI659 is crossing both KLM314's and IBK230's tracks and shall descend through their profile. Hence, there are three aircraft that must be separated towards each other. The possible alternatives are reduced by sector borders and additional traffic not shown in this figure.

4. Results

A first observation from the analysis was the ATCOs only used the TBO tool for lateral solutions to replace open loop clearances if the form of magnetic headings. Manual methods were preferred to solve conflicts using altitude or speed control. The reason given for this in the debriefings was that the TBO tool was to complex to work with in these situations. The results presented here is therefore limited to this use case.

The expected reduction of time needed for monitoring implemented conflict resolutions was confirmed by the ATCO feedback as well as the analysis of the eye gaze recordings. In the scenario with the simple crossing (Fig.3), the ATCO that used the TBO tool spent less time monitoring the separation of the involved aircraft and also didn't have to monitor the situation for a suitable time for the aircraft to resume its own navigation. This effect was even more prominent in the solution of the complex conflict (Fig.4) when the TBO tool was used to solve the conflicts between BTI659 and the two climbing aircraft, KLM314 and IBK230. In this case the ATCO spent less time monitoring these crossings than the ATCOs that did not use the TBO tool.

The expectation that conflicts could be solved earlier when the TBO tools was used was refuted by the analysis of the recordings. Conflicts were generally detected long before the aircraft entered the sector and the ATCO's had to wait for at least one of the involved aircraft to come under its control before a solution could be implemented. This was inline with the feedback during the debriefings where the ATCO's claimed that earlier implementation of solutions *may* be possible in some cases, but other factors such as size and shape of the airspace sectors and lack of technical means to communicate system-wise with upstream sectors were considered limiting factors. Another factor that seemed to affect when the solutions were implemented was the predictability of situation. The conflict in the less complex scenario was solved earlier. Since the two crossing aircraft were in level flight and the crossing trajectories were almost perpendicular, it was easy to predict the outcome of any actions. In the complex scenario the conflict was solved later, and with additional follow up actions to maintain separation, due to the difficulty of predicting changes in vertical speed and the changes in ground speed during climb or descent.

The analysis of the recordings showed that the ATCOs used different solutions for the same traffic situation, indicating, differences in preferred work strategies for solving conflicts. For the less complex conflict, the work strategy for all ATCOs was to implement a simple solution early. The solutions implemented could be grouped into distinct types, such as left turn, right turn, or climb, and were generally implemented soon after the aircraft had been transferred to the ATCO. In the complex conflict, the work strategy was to implement solutions incrementally as the situation developed. The individual differences were larger and it was more difficult to group the solutions. Even if the solutions consisted of the similar elements, the combination of them was unique for each ATCO. It could be seen that small differences in the initial actions had effects on how the conflict evolved and upcoming actions had to be be adapted to take this into account. Whether the effects were to the better or to the worse depended on the timing and order of the actions. Within the limits of this study we could not see any difference in the preferred strategies between simulation runs with and without the TBO tool. See Appendix A for details on issued clearances.

As expected, it was possible for the ATCOs to use the tactical TBO for conflict resolution with just a short period of training, in this case five 10-20 minutes long simulation exercises. A learning effect was observed during the first few training runs, thereafter the TBO tool was used efficiently by the ATCOs. The ATCOs also confirmed in the debriefings that they felt comfortable using the TBO tool, but they also suggested some improvements to make the tool more efficient. The first suggestion was to make the interaction with the trajectory easier by increasing the zone around the trajectory which registers mouse clicks, the narrow zone used made it slightly difficult to add a new way point. This was a usability issue related to our implementation. Secondly, they made some suggestions on how to reduce the number of graphical user interface inputs needed to send the trajectory. Finally, explicit representation of distance between conflicting aircraft in the tool when implementing a solution was requested to eliminate the need for gathering information from different support tools.

In addition to the observations and findings from the recordings, there was also some more general feedback on the tool as such, with emphasis on the importance of having a tool that is easy and efficient to use. As is today, aircraft equipment and capabilities differ, except for mandatory equipment. Hence, it is likely that technology that supports uplink and implementation of full 4D trajectories will happen step-wise. Some concerns were raised that a mixed environment, where only some aircraft support tactical trajectory changes, would affect the ATCOs overview of the traffic situation negatively since the temporary waypoints were not displayed unless the flight leg was lit up. Hence, it was not obvious when an aircraft would reach a turning point, while when on a heading, an aircraft would continue on that heading until otherwise told. However, the opinion about whether mixed equipment environments would be a problem differed, it was not expressed to have been an issue during the simulations, and nothing related was found in the recordings.

5. Discussion

The time spent on monitoring implemented solutions was reduced when using the TBO tool. However, most monitoring was needed for the conflict which included to climbing aircraft and when that should descend through their trajectories. Contrary to the lateral trajectory, there was no visualization that showed the vertical trajectory. And, even if there had been possible to visualize the vertical trajectory, there are a lot of unknown factors that may affect it, such as the actual weight of the aircraft, wind layers, and company specific operational procedures. The trajectory is better known by the aircraft flight management system and sharing this data with the ground systems is crucial to overcome these issues. If this could be successfully addressed, there is potential for substantial decrease in the need for monitoring vertical conflicts. The assumed earlier implementations of solutions did not materialize. The main explanation given for this was that other factors are limiting it, such as the airspace design. The assumption that the tool would be quick to learn as it was designed in line with the existing graphical user interface was confirmed, both from the feedback of the debriefings and the observed use of the tool, though the interaction with the tool left some room for improvements, for example to reduce the number of inputs needed.

The results showed more clear work strategies for the less complex situations. However, also in the complex situation, the basic strategies were often similar. What differed a lot between different simulation runs was the timing of the interaction and the result thereof. Depending on when certain instructions were given, the situations developed differently, and the subsequent instructions diverted. For example, if the plan was to let the trailing aircraft (KLM314) in the IBK230/KLM314 conflict (Fig.4) cross IBK230's trajectory before climbing through IBK230's altitude, then it was better to give KLM314 direct exit point (a slight right turn) as early as possible. Contrary, if the plan was to let KLM314 climb on a heading parallel to IBK230 until KLM314 had climbed above IBK230, then it was much better not to give KLM314 a direct route to exit point but keep it on its original route. The timing of the interaction was also affected by the response time from the pilot. If the instructions had been trajectory based, separation could have been guaranteed in the first place, reducing monitoring needs. However, it remains an open question whether it would result in more distinct solutions, or if the complexity in the situation would still result in a more diverse palette of solutions.

Time restrictions were not used, mainly because focus was on lateral and vertical aspects as the scenarios did not include sequencing and spacing of aircraft in an arrival flow. However, there are also factors that reduce the possible gains from time constraints. Like for vertical trajectory based solutions, they need aircraft derived trajectory data to be reliable. If two crossing aircraft shall be separated by giving time constraints, it must be known where both aircraft will be at the most critical moment. This works if they are passing the same waypoint, even though time must be translated into distance to be meaningful as radar separation, but it is more complicated if they have crossing trajectories that do not cross at a common waypoint, as times in the trajectories are only calculated for waypoints. Furthermore, this should possibly need a more elaborated visualization that provides not only times over waypoints, but times related to the separation distance. Added to this, the possible changes in speed to achieve separation in time for a crossing is limited by aircraft performance at high altitudes. Due to this, and unless a more developed representation of time-based separation for crossing aircraft is available, time-based solutions should probably be reserved for arrival sequencing and spacing and point merge operations where aircraft join common trajectories at a certain point.

Regardless of which strategy the ATCOs choose, it can be concluded that a tactical TBO tool must be carefully designed to reduce the impact on the work load when using it. The analysis of the recordings showed extensive system interaction, and this should be reduced rather than increased. Especially important is the integration of support that visualizes the effects when probing a solution. To some extent this was implemented in the prototype by visualizing the conflict in the probe flight legs (Fig.2). Despite this, the ATCOs needed to complement this information, primarily by looking at the figures presented in the separation monitoring tool. It would be beneficial for the ATCOs to have a more sophisticated system support that could reduce the need for this manual compilation of multiple data sources. Preferably that should be integrated into the TBO tool.

5.1 Future Work

Both the debriefing feedback and the simulation runs showed a clear preference for using the TBO tool for lateral solutions only. At the same time, vertical solutions proved to require more monitoring and thus larger potential for reduction of monitoring time if the TBO tool was used to control the vertical profiles. The system support for implementing vertical solutions must be improved, both with respect to available data and how it is visualized. The limitations for earlier implementations with respect to airspace design should be further investigated; could tactical trajectory management affect how we should design future airspaces? Some of these limitations may also be related to the capacity of human with respect to the amount of traffic that it possible to handle simultaneously. How can the introduction of sophisticated artificial intelligence (AI) based tools, and even AI based agents working together with the ATCOs, take advantage of working tactically with trajectories? Finally, we would advocate larger studies with tactical TBO tools where larger data sets can be quantitatively analyzed.

6. Summary and Conclusions

We performed a real-time, human-in-the loop simulation study where we analyzed how the introduction of a tool for tactical modification of aircraft trajectories affected the Air Traffic Controllers (ATCO) strategies, focusing on conflict resolution. By investigating how it affects the users, it complements previous research on Trajectory Based Operations (TBO), which primarily focus on strategic use of TBO, or only address technical aspects and trajectory prediction. A tool was designed and integrated into the Narsim simulator at LFV. The setup also included a Smart Eye Pro eye tracking system for collection of eye gaze data. Two ATCOs were recruited and performed one day each of simulation runs, five simplified scenarios for training and familiarization of the tool, and then two scenarios with traffic based on real traffic samples. After each day, a debriefing was held with the ATCOs. The recordings from the simulator runs were compared to recordings from another project where with 15 other ATCOs performed the same scenarios, but without the tool.

From the results we can see that by using tactical trajectory management, the monitoring time for implemented solutions was reduced and that the tool was possible to use after only a short period of training. These effects confirmed two of the expected outcomes. The third expected outcome, that the use of the tactical trajectory management tool should lead to earlier implementations of solutions was refuted. The main reason was that other factors were limiting *when* a solution was possible to implement, such as:

- Airspace design
- Uncertainties in the trajectory prediction, especially for the vertical profile during climb and descent, including effects on ground speed
- High conflict complexity
- Lack of sufficient system support to coordinate TBO clearances with upstream sectors

Overall, no significant effect on the ATCO work strategies could be observed by the introduction of the tool in its current form, rather the ATCOs incorporated the use of the tool in their current work strategies. However the analysis of the recordings clearly shows that the ATCOs uses different solutions for the same traffic situation, indicating, differences between ATCOs in preferred strategies for solving conflicts, which must be considered in an operational implementation and training to obtain the expected benefits of tactical TBO.

Even though this is a relatively small study, we can see that the results provide new knowledge by providing important parts to the TBO implementation puzzle, and we saw positive effects for the ATCOs' work in the form of monitoring need reduction. However, even if the effect on the ATCOs' work from using the tactical trajectory management tool should only be neutral, the fact that the trajectories are kept intact is an improvement since it reduces uncertainties in the ATM system trajectory prediction. This in turn will provide the ATCOs with a more robust and reliable system support with respect to trajectory prediction, used in conflict detection and sequencing tools. Working with closed trajectories will also ensure that the ATM systems on the ground and the airborne flight management systems has a common and detailed view of the expected trajectory for the aircraft.

To conclude, the results from this study shows that using tactical trajectory management is a feasible way for ATCOs to solve conflicts in the following ways:

- It reduced monitoring needs, especially important for vertical conflicts,
- could be incorporated in current work strategies, and

- was possible to use after only a short period of training.

However, solutions for better system support for implementation of vertical or temporal solutions must be developed. This would require better vertical trajectory predictions, for example by the use of downlinked aircraft flight management system data. For future studies, we recommend a more comprehensive simulation study with variations in airspace sectors to make a quantitative analysis to find what ATCO strategies provides the most optimal benefits in terms of predictability, while maintaining operational safety, when performing tactical trajectory management. Finally, we also think that tactical trajectory management will be important in future AI-based, highly automated ATM support systems.

7. Acknowledgement

The research was funded by the Swedish Transport Administration through the projects F AUTO (TRV 2018/41347) and AI-assisterad flygledning (TRV 2019/36272).

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9. Copyright Statement

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Appendix A Clearances Issued to Aircraft in the Analyzed Conflicts

This appendix contains a visualization of logged clearances issued to the aircraft involved in the analysed conflicts (described in Fig.3 and Fig.4). The clearances are shown in Fig.5 and Fig.6 using the following notation:

- **DCT**: Direct route to a future waypoint
- **Alt**: Altitude
- **Heading**: Magnetic heading
- **Speed**: Fixed speed
- **TBO LATERAL**: Lateral update of route with the TBO tool using a temporal waypoint
- **TBO DCT**: Direct route to future waypoint already in the route using the TBO tool

On the *x*-axis the time relative to the start of the exercise is shown in hours, minutes and seconds. On the *y*-axis the scenario run number is shown. In both diagrams, run 1 and 2 are the runs where the ATCO had the possibility to use the TBO-tool.

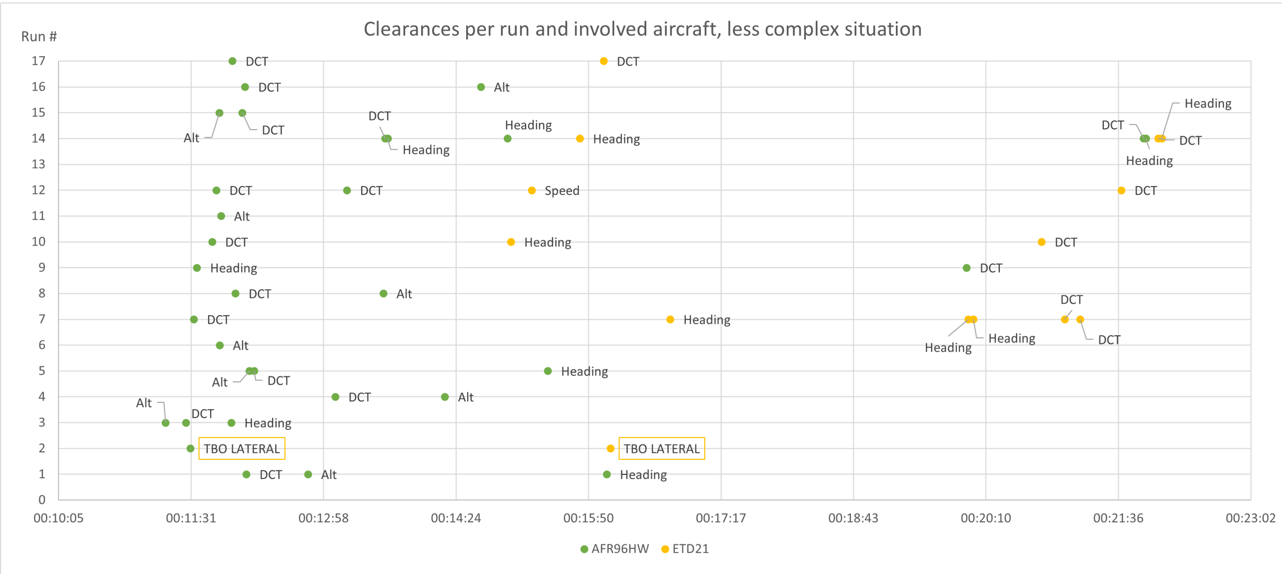

Figure 5 – Clearances for the less complex conflict, scenario 6. Clearances given around minutes 11 to 12 shows initial clearances to solve the conflict. Most clearances from minute 13 to 17 are adjustments to ensure separation, while clearances after minute 19 are given to resume own navigation to original route when the conflict is over.

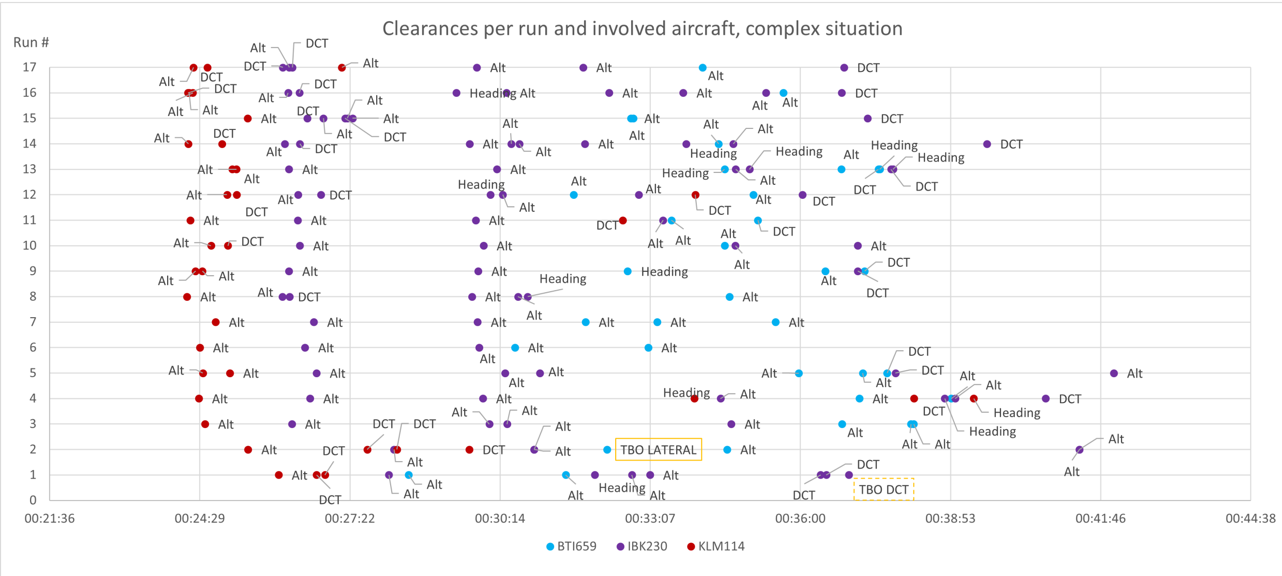

Figure 6 – Clearances for the complex conflict, scenario 7. Altitude clearances the first 30 minutes were given to maintain vertical separation between the involved aircraft. The first clearances to KLM114 and IBK230 were given directly when they called up on the frequency, hence why they were issued at approximately the same time. After minute 30, clearances are also given to BTI659 to facilitate its descend towards destination, entangled with clearances to ensure separation between IBK230 and KLM114. As can be seen, clearances after minute 30 are very diverse and depended on the choice and timing of previous clearances.