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Towards Human-Automation Teamwork in Shared En-Route Air Traffic Control: Task Analysis

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***Abstract*—In the quest for more efficient air traffic management, a common approach is to allocate an increasing amount of functionality to higher levels of automation, with a supervisory role for humans. This potentially leads to forthcoming issues such as skill degradation and out-of-the-loop phenomenon. If the traffic in an airspace is instead shared between a human operator and an automated system, with specific flights fully delegated to automation, operators can maintain their skills and stay actively involved in controlling the rest of the traffic. This does, however, lead to new forms of mixed conflicts, where two flights are controlled by different agents. A smart flight allocation strategy, starting with the delegation of basic flights requiring little monitoring or cognitive effort, is expected to improve combined human-automation performance. In this paper, we present flowcharts to model en-route air traffic controller cognitive think and action processes in two core tasks: conflict detection and resolution. We qualitatively describe the impact of delegating flights to automation and the associated introduction of mixed conflicts. Once empirically validated and quantified in follow-up research, these models can be used to design flight allocation strategies for future human-automation teams.**

***Index Terms*—air traffic control, human-automation teamwork, task analysis**

I. Introduction

The air traffic management (ATM) community is increasingly advocating higher levels of automation (LOA) to improve efficiency and capacity, with a more strategic supervisory role for humans [1]. The Single European Sky ATM Research (SESAR) program envisions a future in which air traffic control (ATC) tasks are increasingly automated, starting with information analysis, followed by decision and action selection, and finally action implementation [2]. At the same time, the system's autonomy should increase with more actions being initiated without human intervention. Nevertheless, air traffic control officers (ATCOs) are expected to play an important role in supervising these systems and to intervene when automation falls short [3].

Decades of human-automation research have taught us that bluntly shifting tasks previously carried out by humans to automated systems is not the way forward [4]. The manual execution of certain tasks can actually be beneficial in other tasks. Delegating only the conflict detection task to automation, for example, while leaving the resolution task for the ATCO, leads to a situation awareness (SA) reduction and increases the use of less optimized resolutions [5]. Keeping ATCOs or any other operator actively engaged is key in preventing many of the issues encountered when introducing higher LOA, such as skill degradation and reduced SA [6]. In the past decade this insight has led to a growing interest for, and belief in human-automation *team*work, with human operators dynamically sharing tasks back and forth with automation [7].

Where considerable research is devoted to (dynamically) allocating certain *functions* to automated ATC systems, Eurocontrol's Maastricht Upper Area Control Centre (MUAC) takes interest in a slightly different approach [8]. As a first step towards higher LOA, *part of the traffic* may be completely directed by an automated system to alleviate the workload of ATCOs and increase capacity or sector size. A prime candidate for such delegation are flights that can be considered 'basic' (i.e., requiring little monitoring or cognitive effort). When basic flights are delegated, the ATCOs can focus on 'non-basic' flights that require more attention and skills which humans are known to be good at [4]. Putting problem-free flights that do not require any action at all in a separate group was already proposed in the 1990s [9]. Its associated workload-relief was limited though, as ATCOs already pay relatively little attention to these flights. Therefore, we conclude that it is also desirable to delegate flights that *do* require active control. An example from more recent research focused on US-based operations and mixed self-separating flights with human-directed flights [10], requiring considerable airborne equipment and wide adoption of Time Based Operations.

The delegation of some flights in a sector introduces a couple of challenges. Firstly, the question of who should be responsible for solving a conflict when the involved flights are directed by different agents. Research on flight-centric operations (also known as sectorless operation), where ATCOs are responsible for flights from start to finish rather than based on geographical sectors, seems to focus on allocating such mixed conflicts to either ATCO, based on pre-determined (conflict) criteria [11] or ATCO workload [12]. When one of the flights is instead directed by a computer under the supervision of the ATCO controlling the other flight, a different approach may be more beneficial. The ATCO may, for example, prefer to manually solve the conflict and prevent automation from working against their sector plan. Secondly, ATCOs not actively involved with a considerable share of traffic in their sector may experience a detrimental effect on their SA.

In a previous work [13], we experimentally tested a preliminary setup where ATCOs could delegate individual flights to an automated system. While it showed the feasibility of such a shared airspace and its acceptance among ATCOs, it also revealed that ATCOs adopted different allocation strategies than we had anticipated. Their seemingly reduced attention for delegated flights suggests these are erased from their mental models, complicating CD&R of mixed flight pairs.

To shape the implementation of a shared human-automation airspace, it is paramount to better understand the implication of delegating (part of) the traffic to automated systems. This requires a thorough understanding of the tasks executed by ATCOs. In 1999, Eurocontrol published an integrated task analysis (ITA), based on interviews, observations and flight progress data obtained at five en-route control centers in Europe [14], [15]. While it provides an extensive insight into the generic tasks of an en-route ATCO, it lacks on several aspects that would be useful for shaping future human-automation teaming. For example, how the task flows change in the presence of automation and consequential mixed conflicts, as introduced in our concept of operations. In a similar way, the ITA lacks how current-day support tools are increasingly utilized and where they fit in the processes. Finally, it also lacks temporal quantification, making it difficult to objectively assess the performance and workload impact of different allocation strategies.

After presenting our concept of operations (CONOPS, Section II), this paper uses the Eurocontrol ITA as an inspiration to introduce flow charts in Section III that describe the cognitive think and action processes of en-route ATCOs in the conflict detection and resolution (CD&R) tasks. The charts have been shaped based on extensive literature research and observing professional ATCOs at work. By focusing on MUAC, the tasks are linked to their currently operational (interface) tools. Expanding upon our work in [13], we discuss the expected impact of delegating flights and potential mitigation measures inspired by current procedures and tools. The next step will be to validate and objectively quantify the models in a follow-up experiment, briefly described in Section IV. Ultimately, the models are expected to be of use in designing human-automation flight allocation strategies for future shared airspaces.

II. Concept of Operations

Our analysis takes the operations at MUAC as a baseline. MUAC is a cross-border air navigation service provider (ANSP), directing flights between 24,500 ft and 66,000 ft over Belgium, Luxembourg, the Netherlands and part of Germany. ATCOs work in pairs consisting of an Executive Controller (EC) and a Coordinating Controller (CC). The EC is responsible for tactical control and in direct contact with pilots, while the CC communicates with adjacent sectors and prepares the traffic for the EC. Our study focuses on the work of the EC.

Unlike in flight-centric operations, we (initially) assume ATCOs maintain responsibility over a geographic area, in which some flights are delegated, to ease implementation in the current ATM system. The ATCOs are ultimately responsible for all flights in this area, including those delegated to the computer, and are therefore capable of regaining control at any moment over any flight.

The ground-based automation envisioned here can autonomously ensure separation between flights and issue clearances towards their planned exit point and flight level, corresponding to Level 5 from SESAR's LOA taxonomy [2, p. 24]. The use of simple rule-based algorithms that mimic the way ATCOs work increases acceptance and reduces the need for (complex) automation decision transparency [16].

Despite future implementations of 4D time-based operations potentially leading to less conflicting traffic, flights may still need to deviate from negotiated 4D trajectories due to unforeseen events such as weather or emergencies [17]. In a similar manner, automation will not actively direct flights into conflict with human-directed flights, but mixed conflicts cannot be excluded. There are various possibilities regarding solving such conflicts, sorted here by increasing LOA:

1) The ATCO has to manually resolve the conflict, or delegate the flight to make it a fully computer-directed conflict [13].
2) Automation proposes a solution to the ATCO. This can be either implemented as managed-by-exception (i.e., the proposal is automatically executed unless the ATCO rejects it within a specified time), or managed-by-consent (i.e., the proposal is only executed after the ATCO explicitly accepts it). However, research indicates that ATCOs are reluctant to accept decision-making aids [18]. The proposals can be limited to the delegated flights only or also involve manual-directed flights if that solution appears to be more efficient. The latter should be implemented as managed-by-consent, to give the ATCO full control over manual-directed flights.
3) Automation solves the conflict by directing flights under its control around the human-directed flights [10], [19]. While ATCO workload can be lowered by automatically solving conflicts, limiting the resolution to only one of the involved flights can lead to suboptimal resolutions.

It is important to stress that manual-directed flights are not necessarily excluded from all forms of automation. The current-day practice of automating most of the information acquisition and analysis stages as well as various conflict alerts is followed. Manual- and computer-directed flights differ mainly in the decision selection and implementation authority.

Finally, Controller-Pilot Data Link Communications (CPDLC) are increasingly supplementing or replacing traditional voice-based radio transmissions (R/T). While the combined use of CPDLC and R/T has some advantages, such as sending clearances over either channel in parallel, we consider a more distant future, in which both the ATCO and the system communicate with flights through CPDLC only. The complete termination of R/T provides both automation and the human with equal communication capabilities, until text-to-speech and speech-to-text technology has sufficiently evolved to close the gap.

III. Task Analysis of Common Processes

This section introduces flow charts for the CD&R processes, in which the various steps are identified and linked through letter-coding to the accompanying interface elements and tools that MUAC currently provides to its ATCOs (Table I). At other ANSPs, many of these tools or variations thereof will also be available. The analysis by the authors, including a systems matter expert, is primarily based on observing two ATCOs on duty at MUAC for two hours each and simultaneously discussing their think and action processes with them (when their workload allowed). While the exact order, inclusion of steps, and usage of tools can differ per person and situation, we have tried to capture the most common general flow of steps as executed at MUAC. It is further supported by in-text references to existing literature.

TABLE I
MUAC Support Tools and Interface Elements

Tool or element	Information or action
Ⓐ Plan view display	Lateral flight positions and directions
Ⓑ STCA	Characteristics of short term conflicts
Ⓒ Flight label	Actual and cleared level, vertical trend, next point/heading and speed (optional)
Ⓓ FIM	Digital flight strip: aircraft type, destination, cruise level etc.
Ⓔ VERA	Conflict verification and geometry
Ⓕ Velocity leader length	Position extrapolation
Ⓖ Clearance menu	Input/uplink clearances
Ⓗ NTCA	Near-term conflict alert and probe

Furthermore, color codes (Table II) indicate at what level of the skill-rule-knowledge (SRK) taxonomy [20] each block in the flow chart is executed. Skill-based behavior is mostly associated with repetitive tasks or information processing that is readily available and pertains to tasks that can be instantly executed. Rule-based behavior entitles a decision and action processes based on fixed rules or past experience. When a new situation is encountered, knowledge-based behavior comes in sight requiring the most cognitive effort (and time). In practice, en-route ATCOs report that only few situations require this highest level, even in non-routine traffic situations [15]. Multiple colors in a block indicate a situation dependent level.

TABLE II
Skill-Rule-Knowledge Taxonomy

SRK	Example
Skill-based	Comparing flight levels
Rule-based	Applying routine solutions
Knowledge-based	Generating new solutions

Finally, the potential impact of delegating part of the traffic to an automated agent is discussed qualitatively for each of the processes based on the CONOPS from Section II. It was preliminary tested in our simulation experiment from [13] where six ATCOs could dynamically delegate individual flights to and from an automated system. When available, examples from similar situations in current-day operations are given as a first hint towards potential solutions to reduce the impact.

A. Monitoring

At the start of a shift, an ATCO takes over from a colleague and receives a short briefing about any specialties (such as weather or active military areas) and flights that might require extra attention or that have been re-directed to solve a conflict. The take-over lasts not longer than one or two minutes in which the ATCO creates an initial mental picture and sector plan. Once the new ATCO has assumed responsibility, they enter a monitoring process that continues for the remainder of the shift. Monitoring involves updating the mental picture and sector plan, and in turn triggers all of the other processes as visualized in Figure 1. While the use of flow charts may suggest purely linear processes, constant attention switching means that the processes can be interrupted or resumed due to shifting priorities.

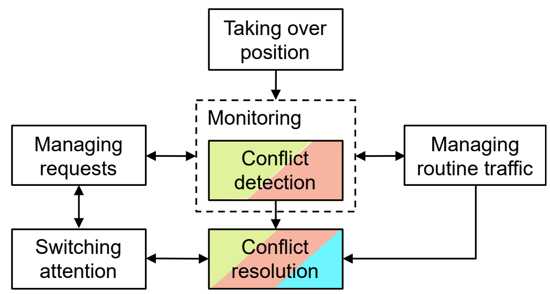

Fig. 1. Connections between processes, adapted from [15]. For color coding, see Table II.

B. Conflict Detection

ATCOs start looking for conflicts while flights are approaching their sector, still under control of the previous sector. When a pilot calls in on the radio of the receiving sector, the ATCO first has to locate the flight, which is made easier by a radio direction finder that shows a circle around the transmitting flight on the plan view display (PVD, Ⓐ). Most conflicts get identified and solved at this initial contact [21]. While we do recognize that conflict detection is mostly pattern-driven when assuming flights, for this paper we focus on the detection of intra-sector conflicts. Throughout their shifts, ATCOs frequently check for these conflicts that may have developed well after assuming a flight. Even when multiple flights are involved, ATCOs tend to solve conflicts pairwise [22] and thus perform conflict detection on flight pairs, as visualized in Figure 2.

Given a pair of flights, ATCOs first look at conflicting flight levels, as shown in the flight labels Ⓒ, before considering the directions of these flights on the PVD [23], [24]. The use of odd/even flight levels for traffic in 180° heading bands simplifies this task considerably, as level flights can then only be in conflict with flights from a subset of directions or with flights changing altitude [25]. In sectors with clear traffic streams, such flight level allocation enables further filtering of flights to be considered. Flights changing altitude often require more effort and attention than level flights for two main reasons. First, their trajectories are harder to extrapolate due to the potential ground speed variations with vertical changes as

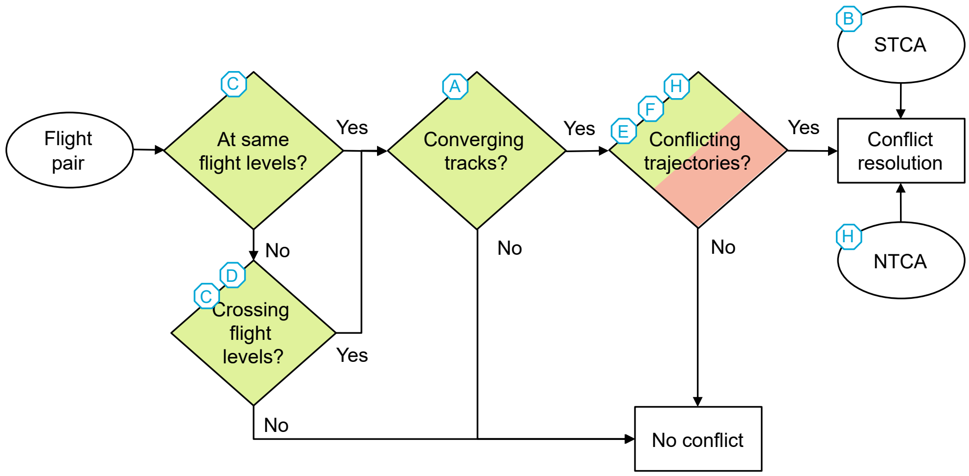

Fig. 2. Flow chart of the conflict detection process. For letter and color coding, see Tables I and II.

well as possible wind conditions at different altitudes. Second, their flight levels cross with more flights that consequently have to be considered. This is especially true for flights that need to climb to their cruise level as indicated in the Flight Information Management window (FIM, D) and subsequently descent before leaving the sector.

Fortunately, ATCOs can often rely on their so-called 'conflict possibility library', containing hot spots within the sector where conflicts frequently occur. With the introduction of free route airspace (FRA), where flights are no longer required to follow fixed routes, the usability of such a library has diminished [26], although the majority of traffic will still follow predictable routes. For efficiency reasons, airlines prefer direct routes, increasingly made possible by FRA. Direct routes also have an advantage for the ATCOs, as it simplifies the (horizontal) detection task to a mere checking of the crossing angle between two tracks: diverging tracks will never lead to a conflict (unless involving a turning outbound flight), while parallel tracks can only be a conflict when they are already spaced less than 5 NM apart. Detection complexity is largely dependent on the convergence angle between the tracks of two conflicting flights, with shallow angles being harder to detect than perpendicular tracks [27].

Only when both vertical and horizontal separation are questionable, relative speeds are taken into account to assess whether the trajectories will actually conflict in time [28]. Processing speed information requires more effort than altitude and heading [23], potentially eliciting rule-based behavior. If the ATCO suspects an imminent conflict, the VERification and Advice tool (VERA, E) can be used to validate and judge the criticality of the conflict. After selecting two flights, it extrapolates their positions along their current tracks to predict the time till and the minimum distance at the closest point of approach (CPA) between two flights. VERA also shows both flights' positions on the PVD, extrapolated to the corresponding CPA time. VERA only considers horizontal separation though, the ATCO needs to take the vertical aspect into account as well as any potential speed or heading changes. Any flight pair on which VERA is applied is added to a special on-screen list showing its parameters, until the ATCO cancels it. This list can serve as a to-do list or to ease the monitoring of the evolution of a conflict over a prolonged time. Apart from VERA, the length of the velocity leaders F can also be extended (from 1 minute to 2, 4 or 8 minutes) to quickly extrapolate the future positions of flights and gauge the CPA.

A more advanced tactical prediction tool is the Near-Term Conflict Alert (NTCA, H), which extrapolates the future position along the flight's cleared route. If a flight deviates from its route, or is flying on a heading, NTCA resorts to simply extrapolating the track for that flight, alike VERA. In contrast to VERA, NTCA is triggered automatically. If a loss of separation (LOS) is predicted within 6 minutes, an orange diamond is shown in the labels of the conflicting flights to alert the ATCO. By placing the mouse over this diamond, a VERA-like conflict geometry is shown on the PVD. Additionally, the NTCA logic is also utilized in what-if tools, which allow for the probing of alternative flight levels and/or headings before executing the pertinent clearance(s).

As a last safety measure, if a conflict is overlooked, a solely radar-based Short-Term Conflict Alert (STCA, B) triggers 2 minutes before a LOS in the form of a red/yellow flashing radar position symbol and a yellow border around the callsign in the label. The STCA is accompanied with an entry in the Conflict Alert Message (CAM) window on the screen, showing whether the two involved flights are climbing, level or descending, and the current and predicted minimum distances between them. Both NTCA and STCA can trigger the ATCO to switch attention to conflict resolution, with STCA naturally requiring an immediate response.

Impact of Flight Delegation

Firstly, ATCOs have been shown to pay less attention to flights not under their (manual) control and not updating them as frequently in their mental model, potentially leading to slower CD&R [29]. While conflicts between computer-directed flights will be automatically solved, and thus require little monitoring when the ATCO has sufficient trust in the system, the associated attention reduction can have a detrimental effect on the resolution of mixed conflicts [13]. In such conflicts, the ATCO can be taken by 'surprise' and may need to revisit the delegated flight(s) to update their mental image. In current-day operations, the CC can flag potential conflicts for the EC by adding them to the VERA list. It could be beneficial if the system acted similarly for computer-directed flights that are in conflict with manual-directed flights to timely inform the ATCO and reduce the risk of surprises.

Secondly, as ATCOs are not actively involved in delegated flights, they would not be updated either about (route) changes that the computer issues to flights in their sector. Something similar happens when ATCOs 'skip' flights passing through an empty part of their sector, meaning that the next sector already takes control over the flight. This is, however, only done when the flight is clear of any other traffic. With less strict conditions for delegating flights to the computer, it is even more important for ATCOs to maintain an up-to-date mental model of these flights that may interact with theirs. In current-day operations, the CC can, under certain restrictions, use CPDLC to uplink a clearance to a flight to relieve the EC. The uplink action is shown on the EC's screen by highlighting the flight's corresponding label item in magenta for a short time. Since the EC and CC are sitting next to each other, they can easily coordinate such actions.

If the other agent is a computer system, (complex) visualizations may be introduced to pro-actively communicate its actions and intentions [30], at the trade-off of increased mental demand [31]. The use of a smart allocation strategy is hypothesized to reduce the need for these features by keeping ATCOs naturally in-the-loop, such that the aforementioned label item highlighting might be sufficient in most situations.

C. Conflict Resolution

Once a conflict has been detected, the ATCO enters the conflict resolution process, shown in Figure 3. Based on the criticality of the conflict – which can be derived from the time/distance to go and minimum separation given by VERA (E) or NTCA (H) – the ATCO needs to determine whether any action is required. With a potential conflict still far away, ATCOs may opt to 'wait and see' [14]. Especially in large sectors, uncertainties such as wind or clearances to other flights can make conflicts disappear over time with no additional effort required from the ATCO and pilots. ATCOs may therefore temporarily switch to a higher priority task and return to the conflict at a latter stage if it still exists. However, under high workload, immediate actions are generally preferred as they relieve the ATCO from monitoring the situation over an extended period of time [22]. In most cases where a conflict triggers an STCA (B), ATCOs have already recognized and commenced resolving the conflict before the alert goes off, or they find the alert to be premature (e.g., when a fast climbing flight can get into conflict with another flight (far) above its cleared flight level (CFL)). The 'wait and see' option then involves checking that the flight truly levels off at its CFL.

The conflict geometry visualizations from VERA (E) or NTCA (H) can help ATCOs in their resolution process. Most conflicts are routine conflicts that they have experienced many times during training and their career. ATCOs maintain an extensive mental 'conflict resolution library' with standard options to solve such conflicts that therefore require little mental (rule-based) processing [28]. More challenging conflicts are those that are less common and thus require a custom solution, generated in a more demanding knowledge-based process. The process is repeated until an acceptable solution is found, which is then converted into a (series of) clearance(s) and inputted through the clearance menu (G). The ATCO then returns to monitoring and may revisit the flight at a latter stage to make sure the issued clearances are properly followed up. Indications in the flight labels (C) alert the ATCO if a flight has selected the wrong flight level, is not climbing or descending as instructed, or is deviating from its cleared route.

To solve conflicts, ATCOs can pick from several options. Speed clearances are rarely used in en-route control, as aircraft are mostly flying at their optimal speeds with very small flight envelopes margins. Exceptions are inbound flights that need to slow down at some point and for which the ATCO may receive speed requests from the next units. Preferred solutions are mostly those that optimize a flight's efficiency, by sending the flight either to an intermediate flight level closer to its exit level, or on a short-cut towards a point further down its planned route. At increased workloads, ATCOs give lower priority to such optimizations and are more prone to pick the first satisfactory solution they see [32] whereas in periods of low workload ATCOs may pro-actively re-inspect non-conflicting flights to see if they can further optimize them.

Any unsafe heading or altitude clearance, that would lead to a LOS within the next 2 minutes as predicted by NTCA (H), is automatically marked in the clearance menu (G), and the corresponding conflicting flight(s) is/are highlighted when the cursor is placed on the clearance value. Such features speed-up the decision selection process by quickly eliminating unsafe solutions, thereby offering a solution space to select a safe clearance from. The acceptable safe solution varies by the ATCO's workload. Solutions should not increase the probability of follow-up conflicts [33] and should minimize the need for further monitoring. This is especially important in complex or high workload situations when buffers are often increased as well [22], [32]. Heading clearances usually do require a follow-up clearance to bring the flight back on its route [17], but can be helpful to prevent flights from turning into each other's path unnoticed. Furthermore, using parallel headings alleviates the ATCO from taking differential wind effects into account.

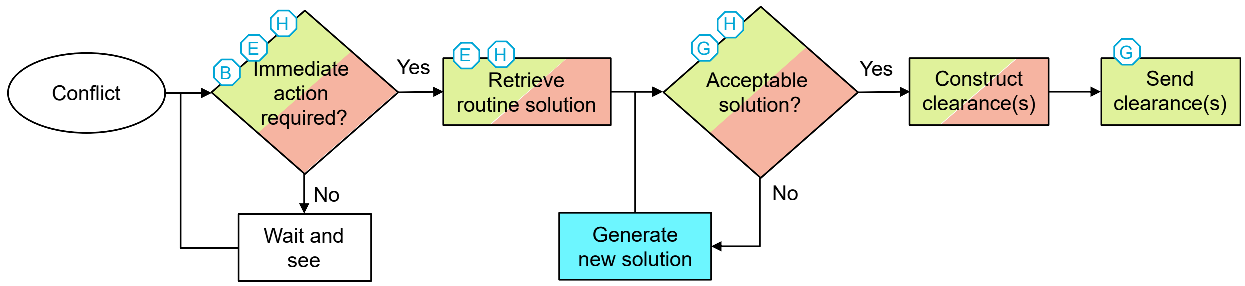

Fig. 3. Flow chart of the conflict resolution process. For letter and color coding, see Tables I and II.

In line with conflict detection, the resolution of conflicts with large convergence angles can be difficult when both flights are already flying a direct route [27]. A conflict with a 90° angle is considered easy and usually requires the slower aircraft to be directed behind the faster aircraft. Small convergence angles, on the other hand, often require larger track deviations up to a point where supplemental speed changes may be used to reduce the track deviations.

Impact of Flight Delegation

In current-day operations, flights under control by different ATCOs are less prone to get into conflict with each other due to the coordinating role of the CC and inter-sector agreements. When flights within a sector are delegated, the ATCOs need to confirm that any of their clearances have no detrimental effects on this traffic. It is expected to take more effort as, analogous to conflict detection, the flights that are not under manual control may have become dormant in or even removed from the ATCO's mental model. That would require the ATCO to actively attend them to retrieve all (updated) information before issuing a resolution clearance.

A proposal-like setup, as described in Section II, can assist in solving mixed conflicts by providing ATCOs with ready-made solutions. Instead of only highlighting the unsafe clearances in the menu (as NTCA currently does), a similar visualization could be used to indicate the suggested safe clearance. Then it would be important for the ATCO to promptly understand *why* exactly the system prefers that clearance over other (safe) solutions.

Regardless of the preceding, if flights can be dynamically delegated to the computer, a conflict may not need to be solved by the ATCO at all. Instead, they can delegate the manual-directed flight(s) involved in the conflict and have automation resolve it. Doing so is especially straightforward when one of the flights is already under automated control. Delegating both flights does mean that the automation may go beyond solving the conflict and issue additional clearances to the involved flights.

IV. Future Work: Validation and Quantification

To objectively assess the impact of reduced SA of some (computer-directed) flights on CD&R of mixed conflicts, the traversal through each of the elements in the flow charts should be linked to readily applicable measures. Since efficient and timely CD&R is key in ATC, temporal quantification seems a fitting choice (i.e., how long it takes to go from one point in the chart to another). Hereto, we will perform an experiment in which we present a large number of static traffic samples to professional ATCOs. Based on real life situations, the scenarios are cropped to reduce the number of variables and to measure individual contributions [34]. This simplification does mean that the process of assuming flights and early checking for conflicts will be left out. The focus is on intra-sector CD&R with a more medium-term time scale, in line with the presented flow charts. Each scenario will have two phases:

1) The participating ATCOs first have to indicate whether the traffic situation, with up to five flights, presents any conflict(s) or not. This allows measuring the time required to recognize conflicts. Next, the ATCOs will be asked to solve the conflict(s), if any, and/or direct flights to their exit flight levels. Once the ATCOs indicate their contentedness with the issued clearances Phase 2 starts.
2) One or more computer-directed flights will be added to the scenario. While such 'pop-up' flights are not realistic, it simulates the extreme situation where ATCOs have no (up to date) picture of these flights in their mental models. The ATCOs again indicate whether there are any conflicts in the updated scenario, taking into account any clearances given in the previous phase, followed by solving those conflicts. This time, the computer-directed flights will not be allowed to receive any clearances, so conflicts will need to be solved through the manually-directed flights only. Already-issued clearances from Phase 1 may need to be reconsidered due to the added traffic (e.g., blocking a cleared flight level), providing a measure for the ATCOs' flexibility in modifying an established plan.

By analyzing the logged usage of tools from Table I, a first estimation can be made of which path in the flow chart the ATCO follows. Additionally, eye tracking will show which other flights are considered and possibly re-visited, e.g., to reassess a no longer safe clearance. Similarly the order of elements and their associated SRK-levels (i.e., higher levels requiring more effort and time [20]) can be validated. Although the duration of individual steps might not be directly traceable, relative differences in these measures between different (mixed) conflict types are hypothesized to give an objective measure for comparing future flight allocation strategies.

V. Conclusion

The flowcharts, as presented here, based on an extensive literature review and observational data collected at MUAC, provide a structured insight into the thinking and action processes of an ATCO. Each step in the processes is accompanied by existing support tools, enabling the objective measurement of the duration and/or order of these steps. When the implications of delegating (part of) the traffic to an automated agent are taken into account, the flowcharts can be used to tune allocation strategies based on the impact of mixed human-automation conflicts. Our future work involves validating the flowcharts presented here in a human-in-the-loop experiment at MUAC. By tracking the time of each (sub)task, the influence of reduced attention to flights delegated to the computer is planned to be temporarily quantified.

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