A ROADMAP FOR TRANSFORMING TRADITIONAL ATCO TEAMS INTO COLLABORATIVE HUMAN-MACHINE TEAMS

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Abstract

Europe's air transport sector is facing a number of challenges. Climate sustainability, rapidly growing demand combined with limited airspace capacity, a shortage of available aircraft and a lack of personnel for both ground handling service providers and air traffic control. As part of the Single European Sky Air Traffic Management Research (SESAR) programme, various concepts are being analyzed in order to solve these problems in the coming years. One of these concepts is the Flight Centric Air Traffic Control (FCA) concept. The concept offers benefits in the field of climate sustainability, due to possible fuel savings in conflict-based trajectory changes, as well as an increase in airspace capacity while maintaining the same number of air traffic controllers due to a more even, workload-based distribution of aircraft among the total number of controllers. Alternatively, a constant volume of traffic can also be safely controlled with a reduced number of air traffic controllers, however, with the current conceptual approach there is no possibility of increasing capacity with a concurrent reduction in the total number of controllers. This is precisely what collaborative human-machine teaming is supposed to enable, whereby the conventional controller team will be replaced by a team consisting of a human controller and a machine controller. This paper is intended to present a roadmap on how the Flight Centric ATC concept can be further improved with the help of a collaborative human-machine team and be adapted to the needs of the European air transport sector.

Keywords: automation, allocation center, Flight Centric ATC, human-machine teaming, sectorless

1. Introduction

The European aviation market has been in crisis for several years, which has been exacerbated by the Covid-19 pandemic and the very rapid recovery in demand afterwards. While the two pillars of sustainability in air transport and capacity demand represented the main problems facing the European aviation sector in 2019, the restart of air traffic in 2022 revealed that staff shortages, not only at ground handling service providers but also in the area of air traffic control, are fundamental issues that need to be addressed [1]. These bottlenecks resulted both from staff cutbacks to minimize costs during the pandemic and from corresponding recruitment and training bans in 2020 and 2021 **Fehler! Verweisquelle konnte nicht gefunden werden.**.

In comparison to the US air traffic market, where an acute shortage of air traffic controllers also exists, there have not yet been any serious air traffic incidents in Europe that can be attributed to an overload of air traffic controllers [3]. This may be due, among other things, to the lower rate of recovery in the European air traffic compared to the US market. (Figure 1)

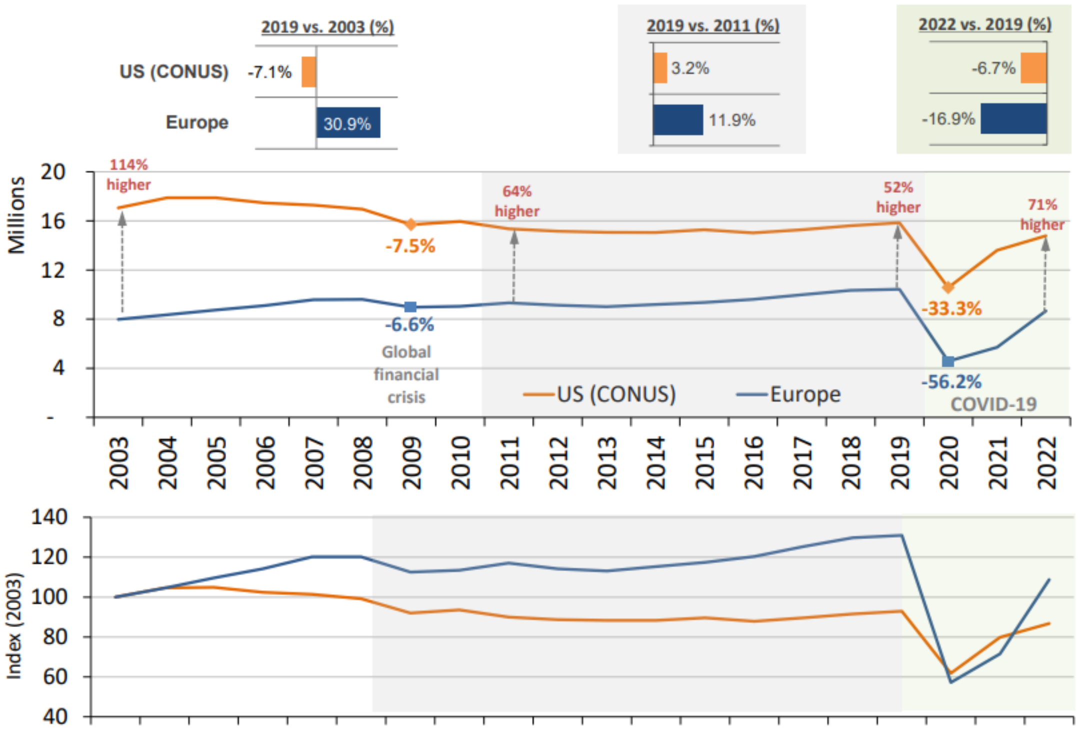

Figure 1 – Evolution of IFR traffic in the U.S. CONUS area and in Europe (yearly) [4].

While the US market has been shrinking since 2003, -7.1% compared to 2019, the European aviation market achieved a growth of 30.9% in terms of number of flights under Instrument Flight Rules (IFR) in the same time period. Nevertheless, the US market was 52% higher than the European market in 2019. The data relating to the pandemic period show that both markets suffered a major collapse at the beginning of the pandemic. Here, the European market was hit harder with -56.2 % compared to the US market with -33.3 %. The recovery phase was also much faster for the US market. A comparison of the figures show that in 2022, the US market was only -6.7 % below the traffic data from 2019, while in Europe there were still -16.9 % fewer IFR flights than in 2019.

Nevertheless, in the near future, there will be a need for new solutions in Europe to meet the air traffic demand with the number of controllers available. The Single European Sky ATM Research Programme, SESAR 3, has a decisive role to fulfil here. However, it is important not only to look for new solutions in the area of exploratory research projects, but also to integrate new methods of air traffic control directly into the existing conceptual approaches that were developed to counteract the original problems of European air traffic before 2020.

Now the question arises as to how the Flight Centric ATC concept can help to solve the acute problems in the European air transport sector by using a collaborative human-machine team. In the following, it will be analyzed which requirements the FCA concept in its current form already fulfils in order to implement a collaborative human-machine teaming. By adapting the existing controller teams (see section 2.1), combined with the new FCA concept (section 2.2 and section 2.3) an alternative concept can be developed that fulfil these requirements. The paper analyses which degree of automation according to [5], [6] is most suitable for implementation in the Flight Centric ATC concept (section 3) and which obstacles need to be overcome to enable the implementation of these sub-concepts in FCA (section 4). Finally, an outlook on the current state of research towards an FCA concept with collaborative human-machine teaming is given (section 5).

2. State of the Art

To ensure the safe management of air traffic, the global airspace is divided into designated Flight Information Regions (FIRs). In Europe, these are further subdivided into so called sectors [7]. Each of these sectors is assigned to a team of two air traffic control officers (ATCOs) responsible for controlling traffic within that sector [8].

2.1 Conventional Controller Teams

Each controller team usually consists of an Executive Controller (EC) and a Planner Controller (PC). The EC is tasked with collision avoidance and preventing separation infringements. In contrast, the PC handles coordination with adjacent sectors, monitors the entry and exit of aircraft (AC), plans traffic within the sector, and serves as a backup for the EC [9]. As air traffic increases, sectors are further divided into smaller ones to maintain an acceptable workload for Air Traffic Control Officers (ATCOs) [10]. However, this approach introduces additional coordination efforts. Smaller sectors also limit the potential for tactical and strategic maneuvers [8].

Table 1: Task description Executive vs. Planning Controller [11]

Executive Controller	**Planning Controller**
Provide separation between aircraft.	Identify safety risks.
Follow the plan of the Planning Controller.	Create a plan to resolve the situations.
Perform communication with aircraft.	Coordinate the entry and exit conditions to ensure smooth and orderly traffic flow.
Issue Air Traffic Control clearances and instructions.	Coordinate any deviations from the standard procedures and letters of agreement with adjacent sectors.
Monitor all aircraft and make sure the clearances and instructions are complied with.	Inform the supervisor of any significant situation.
Provide useful information to pilots.	Inform the adjacent sectors of any significant event.
Inform the Planning Controller of any significant situation that the Planning Controller may not be aware of.	Coordinate with the appropriate authorities about operational air traffic.
	Coordinate the passage through a special use area with its user.

Nowadays, the controller team is already supported by a variety of tools. Three different tools assist in conflict detection (Medium-Term Conflict Detection (MTCD), Tactical Controller Tool (TCT), and Short-Term Conflict Alert (STCA)). The MTCD, used as a planning tool to inform the controller of potential conflicts, has a look-ahead time of up to 20-30 minutes (depending on local implementation) and utilizes both flight plan data and ATCO clearances to calculate potential conflicts.

The TCT tool is used for conflict resolution and clearance verification. It informs controllers whether a given clearance leads to conflict resolution. Depending on local implementation, surveillance and/or FPL data are used as the calculation basis. The look-ahead time of the tool ranges between 5-8 minutes.

The third tool (STCA) serves as a safety net, warning controllers in the event of an imminent separation breach. Based on surveillance data, this tool calculates potential separation infringements with a look-ahead time of 1-2 minutes [12].

2.2 Flight Centric ATC concept

Flight Centric ATC is a concept that was first published in 2001 by [13] as sectorless ATM. Here, the conventional sectors, in which a team of controllers is usually responsible for controlling all aircraft are dissolved. Instead, the entire airspace is considered as a uniform area without further subdivisions. This airspace can, for example, cover the entire area of an Area Control Centre (ACC) or an entire Air Navigation Service Provider (ANSP). It is also possible to establish Flight Centric ATC airspace across national boundaries. While the research for an FCA area within a single country has already been extensively researched [9],[14],[15], there is still a need for further research in the area of cross-border implementation. A corresponding roadmap has been developed by [16].

The elimination of sector boundaries leads to a completely new kind of situational awareness for the controllers. Depending on the size of the airspace, it is necessary to use appropriate filter algorithms to hide those aircraft on the controller's radar human-machine interface (HMI) that are of no relevance to the aircraft under the controllers' own control. As a result, the controller's workload can be reduced. If an air traffic controller has an average of 10-15 aircraft under his control in a conventional sector, 60 - 90 aircraft would be displayed on the HMI when merging six sectors without an appropriate filter algorithm, resulting in a visual overload for the controller.

In addition, further support tools, algorithms and functionalities are required to assist controllers in their work in Flight Centric ATC airspace [17], [18], [19]:

Conflict detection and resolution tool (CD&R)

The CD&R tool is a combination of the Conflict Detection (CD) tool already commonly used today and a new Conflict Resolution (CR) tool. The CD tool detects all occurring mid-term conflicts (MTC) with a look-ahead time of 15 to 6 minutes. These detected conflicts are highlighted in a specific color (red or orange) on the radar HMI for the controllers concerned. The CR tool calculates possible avoidance trajectories based on the flight trajectories of all aircraft in the airspace and visualizes these on the radar HMI of the controller with conflict resolution responsibility. These are solely Conflict Resolution Advisories. The controller is always able to analyze and implement his own solutions.

Less Impacted Flight Algorithm

The Less Impacted Flight Algorithm (LIFA) is a support algorithm of the CD&R tool. It performs an essential calculation for conflict detection. Unlike in sectorized airspace, in Flight Centric ATC, conflicting aircraft may be managed by different controllers. The LIFA assesses the conflict based on factors such as conflict geometry, fuel consumption, distance, and time to determine which aircraft will be least impacted by solving the conflict. The controller responsible for the least affected aircraft is then assigned the task of conflict resolution and is marked accordingly on the radar human-machine interface (HMI). All other controllers who are also affected by the conflict are solely responsible for observing the conflict, but are not charged with solving it.

Probing Functionality

The probing function is a stand-alone tool that allows the controller to analyze potential vertical or lateral maneuvers on the radar HMI before implementing them. This enables the controller to validate his intentions for the next 20 minutes. In the event of a conflict arising as a result of the trajectory change, a color code is used to indicate the approximate number of minutes in which the conflict would occur. An important limitation of this function is that no combined maneuvers can be validated, such as those calculated and displayed by the CR tool.

Allocation Center

The Allocation Centre is a completely new tool that is required in Flight Centric ATC to determine the allocation of aircraft to controllers. Unlike in sectorized airspace, in FCA it is not automatically clear which controller is responsible for an aircraft when it enters the airspace. While in the sector all aircraft are allocated to the controller team that is responsible for the corresponding sector, different controller teams operate in an FCA airspace, meaning that clear allocation strategies must be defined. These can be workload-based, flow-based or conflict-based allocations, for example. The possibility of reallocating aircraft that are already in the FCA airspace is also part of the allocation center.

2.3 Controller teams in Flight Centric ATC

The Flight Centric ATC concept offers the possibility of using different types of controller teams. A distinction must be made between the role and the actual controller performing this role. As in sectorized air traffic, there are also two different roles, the Executive Controller, in this case the Flight Centric ATC Executive Controller Role, and the Planner Controller, in this case the Flight Centric ATC Planning Controller Role. These roles change slightly compared to sectorized airspace. Furthermore, the frequency of tasks to be performed decreases, especially for the Planner role (Table 2).

Table 2: Task description Flight Centric ATC Executive Role vs. Planning Controller Role [17]

Flight Centric ATC Executive Controller Role	**Flight Centric ATC Planning Controller Role**
Provide separation between controlled flights	Co-ordinate entry
Provide separation through coordination	Monitor flights
Provide sequencing between controlled flights	Change Exit conditions on request by Flight Centric EC
Identify conflict risks between aircraft and solve the conflict (if responsible)	Provide early conflict detection and resolution for conflicts before entering the FCA area
Monitor flights regarding adherence to flight plan/RBT/RMT	Monitor assignment of conflict responsibility
Monitor traffic not under control responsibility	Provide conflict detection and resolution proposal for conflicts inside Flight Centric Area in a medium and short-term horizon
Monitor weather conditions	Input tactical trajectory changes into the FDP
May coordinate exit conditions directly	Assist in Executive Controller tasks on request
If necessary, transfer the flight to another Flight Centric EC	Re-assign responsibility for specific aircraft on request
	Apply level capping and rerouting of individual flights internally in the FCA area to offload certain areas depending on the time horizon due to DCB needs

Based on the two roles presented in Table 2, four team compositions have been analyzed in previous research, which are as follows:

Conventional controller team (Executive & Planner Controller)

In the case of the conventional controller team, both controllers of the team (executive and planner) perform their usual roles, as in a sectorized airspace. This is suitable, for example, in a relatively small FCA airspace in which the workload of both controllers in a team is more or less evenly shared. The larger an FCA airspace is, the more the workload of the Planner controller decreases, as the frequency of tasks relating to coordination and communication at the FCA area boundary is steadily reduced.

One planner controller – multiple executive controller

A new type of controller team composition is the so-called multi-team, in which one Flight Centric ATC planner controller is responsible for several executive controllers. This can be a fixed assignment between the executive controllers and the planner controller, but also a flexible assignment between several planner controllers and executive controllers. The flexible assignment has the advantage that the workload of the planner controllers can be kept permanently within a normal range, whereas a fixed assignment in very large Flight Centric ATC airspaces can lead to the planner controllers being underloaded if none of the assigned executive controllers require corresponding coordination and communication at the airspace boundary.

Extended ATC planner controller

In the case of an extended ATC planner controller, the controller takes over the regular tasks of the Flight Centric ATC planner, which are supplemented by additional tasks that go beyond the usual activities of a planner controller [17]:

- Monitoring, both internal and external constraints, complexity and workload in a time frame of 15 to 40 minutes look-ahead.
- Balancing of workload, optimisation of individual flight volume on the planned tracks and within specified dynamic boundary conditions.
- Coordination of rerouting options with adjacent airspaces.
- Mitigation of the complexity of traffic and workload balancing by applying restrictions

- Close cooperation with the Local Traffic Manager via the INAP function

Depending on the size of the Flight Centric ATC airspace, one or more extended ATC planner controllers may be responsible for all or a portion of aircraft entering the Flight Centric Area.

Single Person Operator

The use of a Single Person Operator is a suitable solution, especially in very large Flight Centric ATC airspaces, where coordination and communication with neighboring airspaces is minimized. In this case, the controller responsible performs the role of both the Flight Centric ATC Executive and the Flight Centric ATC Planner Controller. A similar procedure is currently in use for the KFOR sector above Kosovo, which is controlled by the Hungarian air traffic control organization HungaroControl, with one controller taking over the traditional roles of Executive and Planner, although in this case the reason for that is the very limited number of flights in this region [20]**Fehler! Verweisquelle konnte nicht gefunden werden.**.

3. New human-machine collaboration

With the introduction of increasingly sophisticated controller support tools, the question arises as to whether the traditional controller team in its current form should continue to exist in the future. Even with the transition from traditional paper strips to electronic flight strips, or directly to a strip less system where all information are entered directly by the controller into the aircraft label and are thus available to the machine at all times, a more extensive involvement of the machine in aircraft control is made possible. Another example of providing data for corresponding controller support tools are so-called speech recognition applications, which have already been extensively validated for the en-route area [21].

In the future, the controller team could consist, for example, of a human controller and the machine. In this scenario, the machine initially takes on the task of monitoring flights that are moving conflict-free in level flight through the airspace, while complex flight trajectories (e.g., climb and descend in high complexity airspace) and aircraft with conflicts are controlled by humans. Continuous control tool support is maintained in this process. With the appropriate equipment of aircraft with Controller-pilot datalink communications (CPDLC) [22] or L-band digital aeronautical communication system (LDACS) [23], the machine can also autonomously resolve simple conflicts, which can be implemented and sent directly to the aircraft with or without human control.

[5] describes three stages leading from the current conventional controller team to a collaborative team consisting of a human controller and a digital controller (Figure 2).

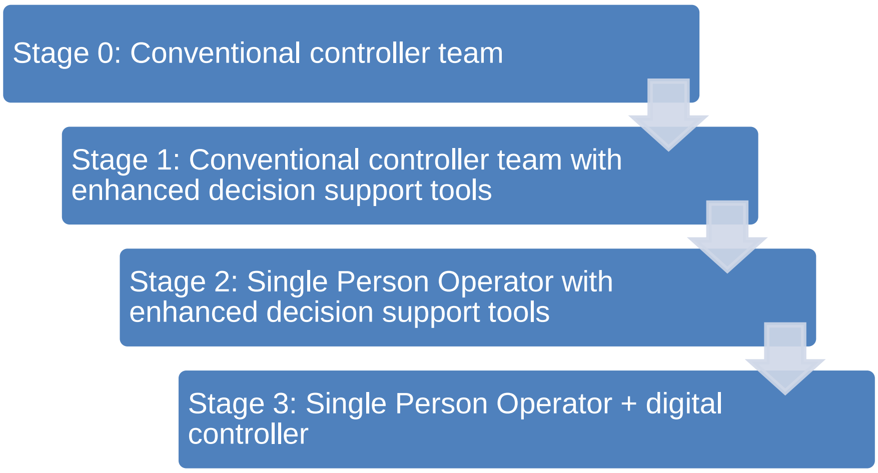

Figure 2 – Three stages of collaborative human-machine teams (Based on [5]).

The stages are described as follows according to [5], [6]:

- Stage 0: This stage describes the current status, a conventional controller team that performs its tasks using conventional support tools without high automation
- Stage 1: In the first stage, no adaptation of the controller structures takes place. Two controllers are still working as a team (executive and planner). However, they are supported by enhanced decision support tools (ENDS). The aim of this stage is to reduce the workload

of the controller team to such an extent that the controller structure can be adapted in stage 2.

- Stage 2: In the second stage, the controller structure is adapted from conventional controller teams to single person operations. Here, the controller is still supported by appropriate enhanced decision support tools in order to keep the controller's workload within an acceptable range, even if he now has to take over the roles of the executive and planner controller.
- Stage 3: In the final step, the Single Person Operator is no longer supported by enhanced decision support tools. Instead, a digital controller is introduced who can take over simpler controller tasks independently without the controller having to intervene/act. Nevertheless, every decision made by the digital controller is displayed on the radar HMI of the human controller so that he always has an excellent overview of the entire situation.

An analysis of the Flight Centric ATC concept described in section 2.2 and the different team compositions used (section 2.3) demonstrates that the concept in its current state already fulfils some of the requirements on the path from the conventional controller team (stage 0) to the digital controller (stage 3).

- Stage 1: The Flight Centric ATC concept has already been analysed with regard to its operational feasibility using conventional controller teams and enhanced decision support tools. The corresponding validation results show that the concept is operationally feasible with this controller composition and the corresponding tool support. At the same time, benefits in the areas of fuel efficiency and cost efficiency could be achieved with this composition compared to a conventional, sector-based air traffic control system. With the assistance provided by higher automated support tools, the workload of the controller team could be reduced to such an extent that stage 2 became feasible. The results of the validaitons carried out can be found in [15] and [24].
- Stage 2: Several validation campaigns were carried out to analyse the Flight Centric ATC concept in combination with Single Person Operations using advanced, higher automated support tools for the Hungarian airspace and the airspace of the European Civil Aviation Conference (ECAC). These showed that the concept is also operationally feasible in this constellation. Analyses of the Hungarian airspace also revealed that under single person operations with appropriate tool support such as the Conflict Detection and Resolution tool, the workload of the controllers can be reduced compared to the sectorised scenario. This enabled more aircraft to be handled with the same number of controllers under otherwise unchanged conditions than when the airspace was divided into sectors. [9], [14]

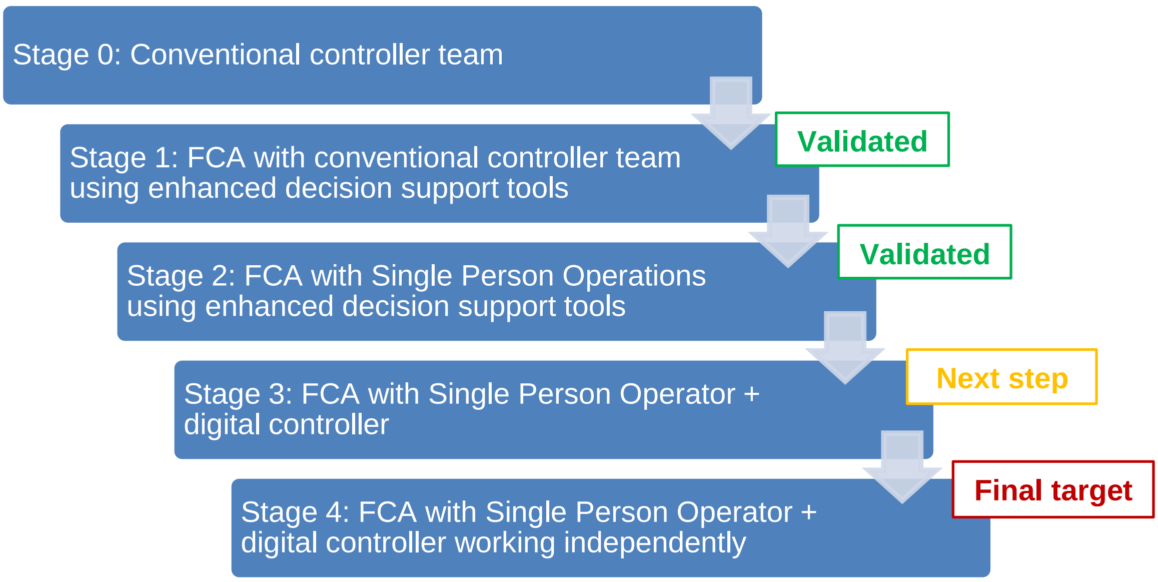

Figure 3 – Three stages of collaborative human-machine teams for Flight Centric ATC.

As in Figure 3 represents, this state of research shows that the FCA concept merely has to take the final step towards a collaborative human-machine team. While the implementation of stages 1 and 2 were relatively straightforward thanks to the use of highly automated support tools, the obstacle for implementing stage 3 is considerably higher, as this requires appropriate prerequisites to be taken into account. In addition, a fourth stage for FCA has been defined in which the human-machine team works independently of each other. This means that the controller only sees those aircraft on his radar HMI that require his attention. Aircraft that only need to be monitored, or where tasks (simple or complex, but not time-critical) are pending which the digital controller can take over, are not allocated to the human controller. This further reduces the controller's workload, but also has implications on liability aspects. These obstacles that occur at stage 3 and stage 4 are considered further in the following section 4.

4. Implementation obstacles in FCA

The integration of stage 3 and 4 into the existing Flight Centric ATC concept comes with a number of obstacles that need to be overcome first. In addition to system-orientated barriers, such as the clear allocation of responsibilities via the allocation center and the visual display on the radar HMI, these also include the availability of appropriate communication channels and the controllers' trust in the digital controller, as well as issues related to liability when introducing such an autonomously acting digital controller. These various obstacles are analyzed in more detail below.

4.1 Allocation Center

The Allocation Center plays a crucial role in the implementation of a collaborative human-machine team. It takes on the task of allocating aircraft based on the complexity level of their respective flight trajectories. The Allocation Center can operate either entirely automatically, manually, or semi-manually [25].

- **Automated Allocation:** This form of allocation is conducted entirely autonomously by a designated allocation center. It offers the advantage of not requiring additional personnel, as all rules governing the allocation are predefined, and there is no human verification for individual or overall allocations needed. However, it may be considered a disadvantage in situations where, for instance, the controller on duty's individual work experience needs consideration, information that the allocation system lacks.
- **Manual Allocation:** In manual allocation, the assignment between aircraft and controller is performed by a human, facilitated through the new role of the allocator, who bases all allocations on personal work experience. This method allows for better addressing of individual situations in the allocation process compared to automatic allocation. However, manual allocation is not suitable for complex traffic situations, limiting its application to regions with a restricted geographical extent and low traffic complexity.
- **Semi-Manual Allocation:** A blend of the aforementioned allocation types is represented by semi-manual allocation. Three distinct forms of interaction between human and machine can be identified:
    - The allocator utilizes the allocation system as a support tool for manually allocated aircraft.
    - The allocator has the ability to override allocations made automatically by the system.
    - The allocator can adjust parameters of the automatic allocation.

  This form of allocation combines the advantages of both manual and automatic allocation, making it feasible for airspaces of any size and complexity.

In the current research on Flight Centric ATC, the topic of allocation centers has been largely excluded. In the previous validation campaigns, a specific allocation strategy of aircraft to controllers was always used without considering the overall concept of allocation centers. Although there are already a few initial publications on this topic, these have so far only been of a purely theoretical nature and describe the basic structure and/or potential allocation strategies. However, a comprehensive allocation center is currently still in the conceptual development phase and needs to be validated accordingly. Furthermore, only allocation concepts from aircraft to human controllers currently exist. For the implementation of a collaborative human-machine team, however, further allocation parameters may need to be defined and corresponding allocation approaches established.

In the case of stage 3, where the collaborative team is considered like a conventional controller team, the only adjustment that needs to be considered is the fact that when calculating the workload, which is used for a workload-based allocation, only those tasks are taken into account that are effectively performed by the human controller. This can be seen as a relatively simple adjustment that can be easily overcome.

For Stage 4, on the other hand, new rules must be established to determine when an aircraft should be allocated to a human controller or a digital controller. For this purpose, clear parameters must be defined, on the basis of which a decision can be made as to whether the solution of a task may be taken over by a digital controller based on its complexity and type, or whether a human controller is required for solving it. As the complexity and also the type of tasks change at regular intervals during a flight, the issue of re-allocation is also crucial. This refers to the reallocation of aircraft that were initially allocated to a specific human or digital controller when entering the airspace. The type of handover must also be specified in detail, so that the controller should not receive new aircraft without prior warning or hand them over to the digital controller without notice. It must be ensured at any time that the human controller is aware of the situation and understands the system's decision.

4.2 Communication

Communication poses a challenge as a human-machine team can only partially work when relying on traditional voice communication. In such cases, the machine can only handle the monitoring aspect but is incapable of sending instructions to an aircraft or receiving requests from them. For this purpose, data link connections between the controller and the aircraft are necessary. A straightforward form of data link is the so-called CPDLC, which is already used today to send simple instructions (e.g., level or heading changes) to the aircraft [22]. However, one disadvantage of this form of data link is the fact that only single maneuvers can be transmitted. As the latency and error density are also very high, this method is only suitable for non-time-critical, simple instructions to the aircraft. Accordingly, CPDLC is suitable for the human-machine team according to stage 3, but not for stage 4, in which more complex, non-time-critical maneuvers shall be performed by the digital controller. It should also be noted that the aircraft has to be equipped with CPDLC, otherwise it must be monitored by the human controller regardless of the task to be performed.

LDACS is a completely new type of data link that is currently under research [26]. In contrast to CPDLC, entire trajectories can be transmitted to the aircraft so that this type of transmission is particularly suitable for conflict resolution processes and can be combined with the Conflict Detection and Resolution Tool. At the same time, LDACS is also expected to have lower latency and higher reliability than CPDLC. Accordingly, more complex tasks, such as time-uncritical conflict resolution (stage 4), could be taken over by the digital controller with this type of data transmission. The disadvantage of this concept is the fact that the system is still under development and therefore cannot be used at present, nor are aircraft equipped with the LDACS functionality.

4.3 Radar HMI

The radar HMI, as used in conventional air traffic control, is in general only partially suitable for the Flight Centric ATC concept. Apart from the new display modes based on the introduction of new tools, the conventional display of the entire controlled airspace is only applicable for smaller FCA areas. The larger an FCA airspace is, the more likely it is that new types of visualization, such as a tile display, will be necessary [27]. In some cases, such a modified display is already a prerequisite for Stage 1 and 2.

For the implementation of Stage 3, several visual indicators must be added to the radar HMI of the human controller. The controller always has an overview of all aircraft under the control of the controller team on his HMI. However, as he is only responsible for a limited number of the controller tasks himself, he must be able to identify at any time which tasks are currently or will soon be taken over by the digital controller and which are to be taken over by himself. The same applies to tasks already executed by the digital controller. As these tasks no longer need to be confirmed by the controller before implementation, as in Stage 2, it must be made clear on the radar HMI which changes the digital controller has made independently and what consequences this may have. All changes must be displayed in such a way that the human controller can access the information easily and quickly without being distracted from the primary information by additional colors or other visual presentation methods.

With Stage 4, on the other hand, the controller will only be able to see those aircraft that he has under his own control, but not those that the digital controller is responsible for. Accordingly, the changes required for Stage 3 are not relevant for this implementation. Instead, changes to the HMI are necessary insofar as the controller must be informed at any time when an aircraft needs to be reassigned to him or when he should hand over an aircraft to the digital controller. This type of reallocation of individual aircraft can already take place in Stages 1 and 2 between several human controllers, but is not part of the research question in the current research, which means, however, that this type of change on the radar HMI is not an exclusive Stage 4 requirement, and can already be used in previous Stages depending on the conceptual approach.

4.4 Liability

Liability is one of the most important factors when introducing new concepts in the field of air traffic control. The first question that arises here is: ‘Does the new operational concept/the introduction of new tools change the liability compared to liability in conventional air traffic control? In conventional air traffic control, the allocation of aircraft to controllers is clearly regulated so that responsibility is unambiguous. In addition, all controller tools used serve solely to support the controllers. This means that the controller has the final decision-making authority and is therefore also liable for faults committed by them, for example in the event of an incident or accident.

With the introduction of the new Flight Centric ATC concept at Stages 1 and Stage 2, this will not change for the time being. The allocation system, or the allocation strategy used, ensures that aircraft are clearly allocated to controllers so that liability changes due to ambiguous allocations can be ruled out. The same applies to the responsibility and therefore liability in the event of a conflict. The Less Impacted Flight Algorithm allocates a clear role to all controllers involved in the conflict, either controller with resolution responsibility or controller with monitoring responsibility. Furthermore, the tools used do not result in a shift in liability responsibility. All the tools available merely serve as support tools without any decision-making authority. The controller still has sole responsibility for this.

The introduction of Stage 3 and Stage 4, on the other hand, also leads to a shift in liability regulations. At Stage 3, initial basic tasks are taken over by the digital controller. Here, all decisions are made by the system without further confirmation by the controller, but the changes made by digital controller are displayed on the human controller's radar HMI. The first conceptual question to be clarified here is whether the controller is obliged to check the system's decisions and correct them if necessary. However, this would be a slight step backwards towards Stage 2 and would also increase the controller's workload. As this is not the objective of Stage 3, the same questions arise as in Stage 4.

Here, the transition to full automation for some tasks, such as simple conflict resolutions, in the area of air traffic control, where the corresponding decisions of the system are no longer displayed to the controller on the radar HMI and are therefore made autonomously, the liability responsibility shifts. In fact, the controller cannot be held liable for the consequences of decisions made solely by the system where he has no possibility of intervening. But who is liable for the system's wrong decisions instead? The engineer who developed the system, the programmer who was responsible for implementing the system or the CEO of the air navigation service provider as the most senior person in the company, who bears the final liability for all decisions in the company? However, no clear regulations have yet been laid down at a legal level for air transport, meaning that there is still no legal certainty for all parties involved in such a case.

4.5 Trust in tool/machine

The trust of air traffic controllers in relevant tools is one of the major hurdles in the introduction of increased automation in air traffic control [28]. This was also demonstrated in real-time experiments conducted as part of the SESAR2020 Flight Centric ATC Project, where new controller tools were introduced. The lower the level of training that controllers receive on these specific tools, including both theoretical understanding and practical usage, the less likely the tools will be accepted and utilized by the controllers. [14], [24] Therefore, it is extremely important for controllers to be involved from the early stages of the development of such new tools and processes. Additionally, providing corresponding tool training that offers an in-depth understanding of the system's calculations is essential for building the trust of controllers.

For stage 3, initial trust in the digital controller is required, but this can be established very easily as the human controller can still follow all of the digital controller's decisions on their radar HMI, even if they are not involved in the actual implementation. However, building trust in Stage 4 is a more difficult task, as in this case the human controller is not informed about the corresponding implementations by the digital controller. This means that a thorough understanding of the digital controller's calculations must already be built up during the training of the human controllers.

5. Roadmap

Based on the findings from chapter IV, a roadmap is presented below, which visualizes the key obstacles of implementation for the individual stages (Figure 4).

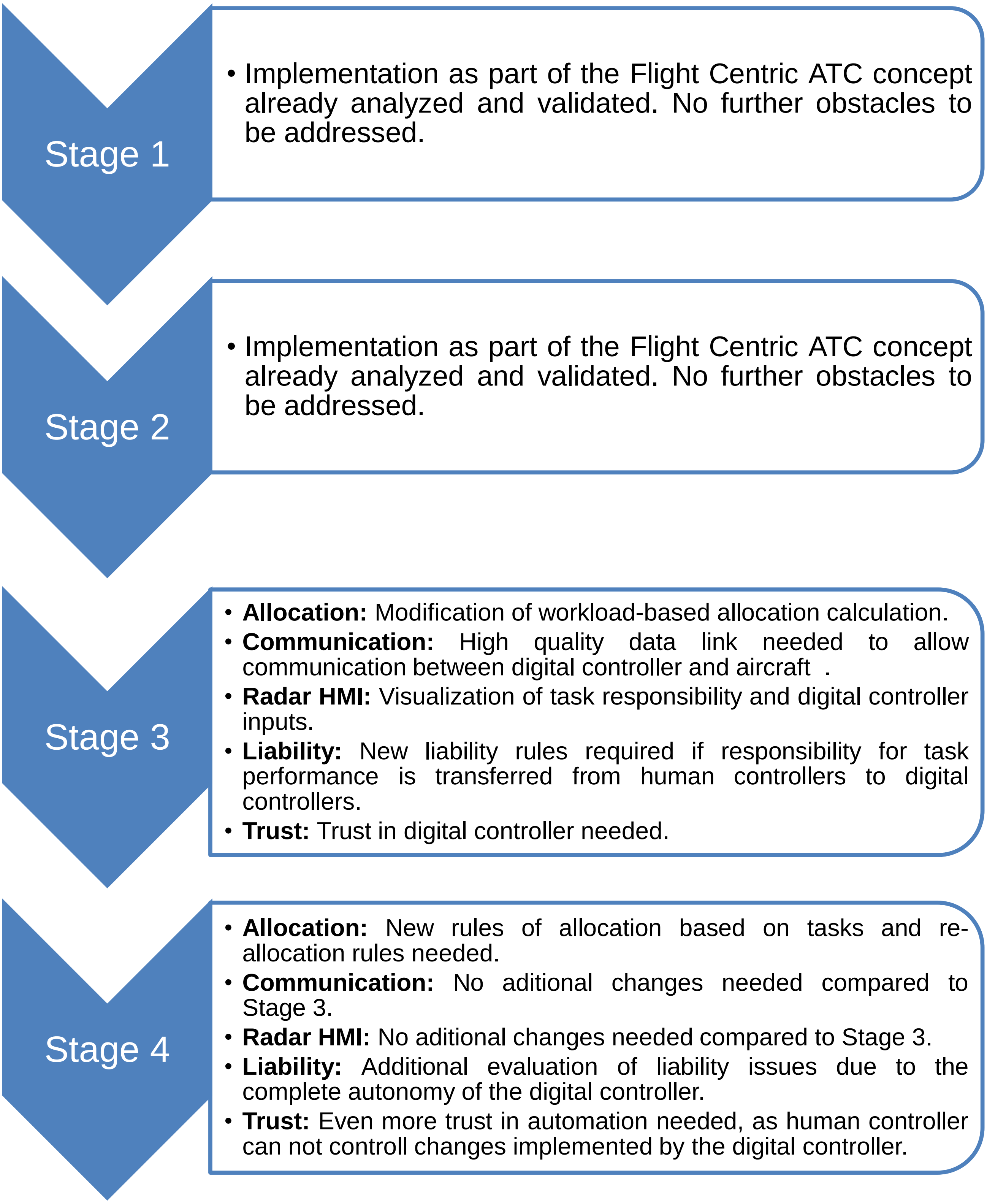

Figure 4 – Roadmap towards a collaborative human-machine team in Flight Centric ATC.

6. Conclusion

The Flight Centric ATC concept with its current state of research is already on its way to achieving a collaborative human-machine team and already fulfils stages 1 and 2. Nevertheless, a quick introduction of the more advanced Stages 3 and 4 is not foreseeable. Various implementation obstacles must first be resolved before implementation is possible. Nevertheless, the analysis of the Flight Centric ATC concept shows that it is very well suited for the introduction of a digital controller, as the current conceptual approach has already created fundamental conditions. While issues related to the allocation center and the design of the radar HMI can be addressed within the concept team, the introduction is influenced by external factors, particularly in the areas of the available communication infrastructure and the issues related to liability, which can be driven forward by the FCA concept team but cannot be resolved on their own.

It is recommended that further research in the field of Flight Centric ATC is carried out in collaboration with communication experts and legal professionals in order to lay the initial foundations for further implementation in this area.

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8. Copyright Statement

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