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THE AUTOMATION EVOLVES: CONCEPT FOR A HIGHLY AUTOMATED CONTROLLER WORKING POSITION

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Abstract

Air traffic controlling demands planning, coordination, and active management of airspace for safe flight operations. Human air traffic controllers are a highly skilled and trained workforce to perform air traffic control tasks augmented by system support. However, the growing air traffic volumes push human controllers to their limit in safely managing air traffic, compounded by difficulties in increasing the controller workforce. A feasible solution to meet the growing demand is to automate controller tasks by introducing the latest technology such as artificial intelligence and machine learning. Therefore, we propose a concept for highly automated Single Controller Operations (SCO) that provides a roadmap for future air traffic management systems to address this challenge, which was conceived as part of the project "The Individual and Automated Air Traffic" (DIAL)[1].

The most important ideas in the proposed concept are the introduction of the Digital co-Controller (DC) as an integral element of the new controller working position and the reduction of the number of human controllers to a single person. This paper describes the three-stage approach to evolve from a setting with two controllers (radar and planning) to a system consisting of a team with one human and one digital co-controller. Our paper presents the grouping of controller tasks along with the distribution of roles, responsibilities, and achievable automation levels in each stage. Furthermore, it discusses the necessary automation tools, the evolution of the role of the air traffic controller, and the technical background supporting the newly defined controller working position. Finally, fallback solutions are discussed in case the DC is unable to cope with an unexpected and complex situation.

Keywords: Single Controller Operations, Automation, Controller Working Position, Digital co-Controller

1. Introduction

Human controllers perform primary operations in current Air Traffic Management (ATM) and control systems, with the Controller Working Position (CWP) as an interface providing the necessary air traffic information. However, this approach will not sustain the high demands moving into the future, resulting in controller overburden and, therefore, a restricted operating environment. Even in current air traffic operations (excluding the COVID situation), the maximum defined capacity cannot be provided at all times in particular due to ATCO-staff shortages [12,13,14]. As the skill requirements of new ATCOs are very high, compensating for staff shortages by hiring more employees is not a feasible solution. On the contrary, there is a need to reduce the number of human controllers required to manage each sector to optimize the Air Navigation Service Providers (ANSPs) workforce. Therefore, the level of automation and support in CWP needs to increase to meet future challenges. Nevertheless, moving from the current system to a highly automated system is a challenge on its own, primarily due to the safety-critical nature of the operations. With this in mind, the DLR internal project "The Individual and Automated Air Traffic" (DIAL) was defined and launched to investigate the possible design of a highly automated system combined with an integrated digital co-controller providing a roadmap for future ATM systems.

One of the main objectives within DIAL represents the definition and development of an architecture model for a highly automated Air Traffic Control (ATC) system. In this context, an automation approach analogous to the future single-pilot cockpit has been developed for air traffic control, which we termed "Single Controller Operations". It is assumed that in the SCO concept, a fusion of the tasks of the

[1] The project "Individual and Automated Air Transport" (Der Individuelle und Automatisierte Luftverkehr; DIAL), initiated by the DLR, bundles research to expand the automation of flight guidance

planner and the radar controller takes place, resulting in a significantly changed workload for the single human controller, which must be balanced in its form concerning the work remaining there. Therefore, it will enable a constellation with only one human controller for almost all situations instead of a conventional two-controller setting (radar and planning controllers). The central element to achieve SCO is a DC that performs several time-consuming tasks to support the single human controller in ATC tasks.

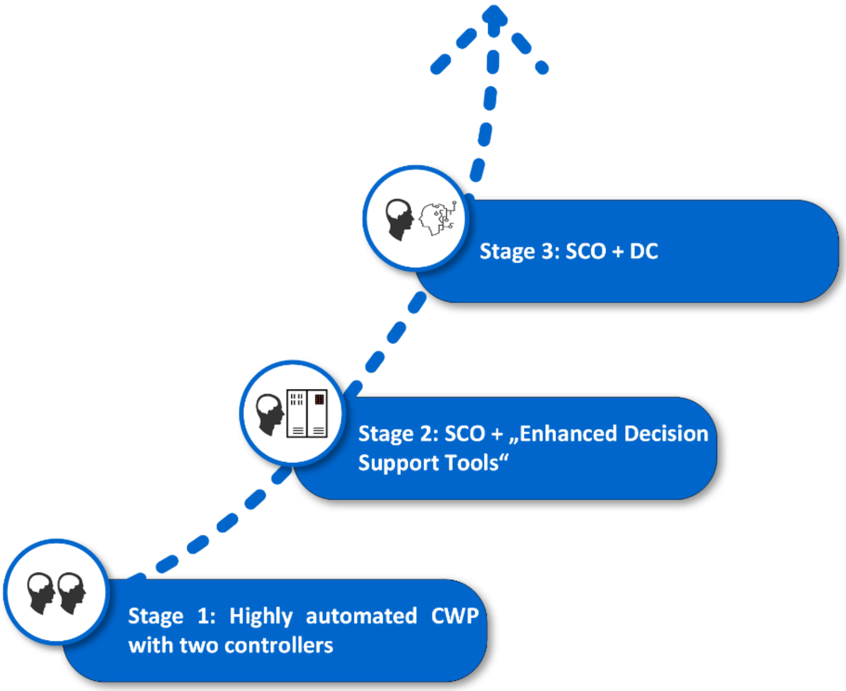

Figure 1: The three stages of Single Controller Operation (SCO) Concept with Enhanced Decision Support Tools (ENDS) and Digital co-Controller (DC)

The transition from a system with two human controllers with a clear and well-defined distribution of tasks to SCO is a fundamental step. Therefore, a concept is developed to guarantee a smooth transition to SCO using three stages. In the first migration stage of our concept, a conventional setting is used with two controllers but complemented with several support tools like context-adaptive information management [36] and attention guidance [35]. For the second migration stage, only a single human controller is in charge and supported by highly automated tools such as Trajectory Generation, Conflict Detection and Resolution, and Traffic Monitoring. The role of the human in SCO evolves further in the final stage and changes from an active to a more supervisory role. In this stage, the DC should be capable of assessing the traffic situation from different data modalities and construct an action plan to manage the traffic by employing artificial intelligence and machine learning methods and techniques. To give the controller the possibility to stay in the loop, he/she will always be informed about the work the DC is carrying out through a special interaction display and information overlays for the radar display of the CWP.

Finally, changes proposed to the current ATC system due to the increased level of automation can be a limiting factor, especially if they significantly alter the operational procedures. Therefore, the operational concept is designed to minimize the impact of changes in roles and responsibilities of ATCO and focus on incremental changes to the current system. For example, the automation of controller tasks is carried out step by step within the current ATM structures and working methods. This approach avoids technically complex and costly modifications to the ATM system, which are significant obstacles for introducing a new automation concept. Furthermore, it provides several options that facilitate the introduction of the SCO concept described and provides the opportunity of gradually putting the developed concept into operation, thus increasing the chances of success for implementation. The DIAL project also investigates the integration of climate optimized trajectories for aircraft. Most likely, these will deviate from current (capacity) optimized trajectories and thus increase the workload of the Air Traffic Control Operator (ATCO).

To recap, our contributions are:

- We performed a detailed analysis of the controller working position to develop a taxonomy for task categorization.
- We propose the concept of Single Controller Operations to reduce the number of human controllers and complement it with a digital co-controller that collaborates with a single human controller with the capabilities to takeover simple traffic control tasks.
- We developed a technical concept based on microservices architecture to implement and validate the operational concept of a highly automated controller working position.

This paper is organized as follows: Section 2 provides a comprehensive background of single controller operations in combination with a highly increased level of automation. Section 3 analyzes the working system of human controllers and provides a classification of different automation levels. Section 4 explains the operational concept of Single Controller Operations by defining three stages to incrementally increase levels of automation and insights into the technical concept. Finally, Section 5 concludes the paper with some discussion about future work.

2. Related Work

Projections have been made on automation of air traffic related workspace and processes. The Association of European Research Establishments in Aeronautics (EREA) promotes a fully or at least highly automated air traffic system for the future [7,8,9,10,12]. Another vision is provided by Higher Automation Levels in Air Traffic Management (HALA!) [11], a programme funded under Single European Sky ATM Research (SESAR) [10], which suggests a new role assignment, considering the most suitable time, decision place, and player as decision criteria. The envision is a high level of automation for unpredictable events when there is only a short time to react but to rely on humans supported by decision support tools for the remaining cases.

SCO is a relatively new concept with many relations to Single Pilot Operation (SPO) with different approaches to reduce cockpit crew from two to one pilot by replacing the second pilot with an onboard automated system [16,17], a ground operator [15,17,18,19,21,26] or a combination of both [20,22].

There are already single pilots in use for specific situations mainly military or general aviation related (one-seated aircraft (air situation)) [23]. This is comparable to some sectors, positions, or situations operated by only one ATCO (ground situation, as described e.g. in the German manual of operations air traffic management document), but not for the majority of commercial aviation and air traffic control. Furthermore, there is a clear difference between these situations and SCO as the workload in these situations is low enough to be safely handled by one ATCO without additional technical support.

Bilimoria et al. [20] and Lim et. al. [22] pointed out that one key requirement in aviation that affects automation as well is that at least the current level of safety has to be maintained.

Lim et al. view automation as useful for workload reduction to enable the deployment of single pilot instead of two [22]. On the other side Bilimoria et al explained a replacement of each copilot might require high effort for deployment of automation thus is not cost-effective [20]. Same applies for ATCOs: for some sectors/situations it is not reasonable to introduce SCO. Lim et al. [22], Bilimoria et al. [20] and Endsley et al. [25] argued furthermore that replacement of as many tasks as possible by the system can be counterproductive as this will possibly reduce situational awareness of the remaining pilot. For Cummings et al. [16] further automation might require a change of task allocation instead of replacing just one pilot.

Furthermore, capabilities and functionalities that a highly automated system requires to enable deployment of single pilot can be gathered from the various SPO research papers and projected to SCO. The automated system should be able to interrupt the pilot in case of emergencies and urgent situations [16]. It should have the ability to self-diagnose [16] and inform the pilot ahead of time about unserviceability and the reason for it [20], as well as the ability to fail-safe [16], to display (visual/audial) what it is “thinking” and doing [16,20] and to recall information for the pilot [20]. Furthermore, the highly automated system should be part of a human-machine team instead of a subordinate [20,24]. That requires the possibility to “hand tasks back and forth in a simple, quick, reliable, and well understood fashion” between pilot and system [20] and for bidirectional communication/interaction between system and pilot, where the pilot sets the priorities and modes of communication [22,24]. This assumes an appropriate, intuitive HMI [17,22] and understandability of intents and reasonings (of the system) to the pilot [17,24]. On the other hand, the system must be capable to recognize, interpret, and act upon non-verbal communications from the pilot [16]. Additionally the system should serve to remind the pilot about open tasks [20] and to monitor errors of the pilot [16]. On top of all a basic premise is to build up automation trust [22].

Two major differences related to research in SPO ease the introduction of SCO in comparison to SPO. First, unlike pilot incapacitation [16,19,20,21] a replacement of an incapacitated SCO will always be possible on the ground at least to a certain extend. Second, there is a requirement to change the mode of training for co-pilots [26] as currently a significant part is provided by the pilot. The ATCO on the job training contrary is provided by an instructor who is not the team-ATCO at the same time. Therefore, the training modality does not have to be changed. Of course, the content and tasks to learn might change or be merged from the two roles.

Other aspects stated by Bilimoria et al. [20] will require further investigation, to decide whether they can be transferred to SCO: First, the automated system shall follow best practices for human-human Crew Resource Management (CRM) with the remaining pilot [20,24], and second assigning one task entirely to human or system might be detrimental.

In Multi Remote Tower Operation (MRTO) [27,28] one single tower controller is taking over tasks originally allocated to several tower controllers. Unlike the situation for SCO the single (tower) controller taking over similar tasks from several positions with (normally) low workload. Nevertheless, both concepts aiming for fewer controllers for same task load. Therefore, the following findings can be considered for SCO as well: Li et al. [27] stated that “a well-designed interface should provide sufficient cues to rapidly direct the operator's visual scanning to desired objects with the least fixation duration”. Li et al. [27] and Kotval et al. [29] found that the number of fixations can indicate that an object is of importance while the length of fixation can indicate that an ATCO has difficulties to extract required information from an object.

3. Operational and Functional Analysis of Air Traffic Service and Controller Working Position

Within this section the analysis of the actual operational system is described including a survey of the relevant controller tasks and their distribution to task groups. Because the automation of several of these tasks can be seen as the target of the Single Controller Operation, a categorization of automation levels is presented in the second subsection.

3.1 Work System Analysis

Within this paper we use the iCAS-system (iTEC Centre Automation System) used in the German upper en-route control center in Karlsruhe as representative example for our work system analysis. The iCAS-system developed by Indra is used in slight variations by several European ANSPs, e.g., Spain and the UK, and is an example for state-of-the-art ATC systems. The German airspace under the control of Karlsruhe UAC (Upper Area Control) center is one of the busiest airspaces in Europe [32,33]. Our Work System Analysis covers the en-route traffic control scenario, which serves as a good starting point to introduce a new concept, and is based on consultations with an experienced former controller as well as legislation documents and related ATC journal articles [1,2,3,4]. It is focused on operational aspects from an ATCO point of view.

The investigation of the roles, responsibilities and tasks within the operational environment results in the classification of ATCO tasks regardless of the role into nine groups based on the purpose of task (see Table 1) and not on ATCO workload or execution like other classifications (e.g. [30,31]).

Table 1 Identified ATCO Task Groups

Task Group	Explanation
Assurance of Separation	every task describing a required defined distance to maintain
Coordination	every communication between two or more ATCOs or other associated roles or their equivalent electronic substitution to exchange information and agree on joint operation

Monitoring	every process of scanning for new/revised current information (situational awareness)
Documentation	every task to record actions for at least one of the following purposes: update system (enable e.g. CD/R tools to work properly), legal issues, update the PC/EC (enable coordination/ enable situational awareness)
(Compliance with) Control Procedures	every task referring to guidelines and regulations which are not or not directly linked to 'Assurance of Separation', e.g. follow coordinated/agreed XFL's
Preplanning	every process of preplanning and anticipation of future situations
Non-Nominal	tasks regarding situations which deviate or imply a deviation from standard procedures/handling
Additional	tasks which are up to ATCOs discretion and in general subordinated, e.g. FIS
Organisation	everything which needs to be done to enable the provision of ATS, though with an administrative or preparative character, e.g. adjust radar display, login

The in-depth analysis of the iCAS system from an ATCOs perspective is the basis for a system with current main functionalities available to ATCOs and supports the validation of the proposed highly automated CWP. In addition to iCAS system analysis, various ATC systems currently in use worldwide were investigated to collect standard functionalities of the state-of-the-art ATC systems. Furthermore, this analysis provides a better understanding of the available support for ATCOs to perform traffic control tasks and serves as a basis for the new concept and automating strategy developed (see sections 3.2 and 4.1) to enhance the level of automation in CWP. As the analysis aims to capture an ATCO perspective of the system, this part focuses on the radar display and its functionalities.

Major results of the analysis are:

- potential to reduce workload of ATCOs by resolving the disjunction of execution and documentation of tasks
- weak (technical) support (low automation) in decision-making and execution of tasks for ATCOs
- developable knowledge of aircraft performance/intention (possibly by use of AI if not delivered by airlines)
- attention guidance to direct ATCOs focus to relevant/important tasks/information
- no legal constraints for deployment of a single controller instead of a controller team, but no basis for introduction of digital co-controller (DC)

3.2 Level of Automation Taxonomy (LOAT)

For a classification of the level of automation, we refer to [8,9] and their level of automation taxonomy. This classification was designed primarily with an eye on aviation needs which makes it a good choice for classifying the tasks related to CWP's. In these papers, Save et al. propose to analyze the automation per task (not for a full system) assuming each is built up by four consecutively information processing steps (from A to D). These steps are listed below with the theoretically highest achievable level (full automation) in parenthesis

- A: Information Acquisition (5).
- B: Information Analysis (5).
- C: Decision and Action Selection (6).
- D: Action Implementation (8).

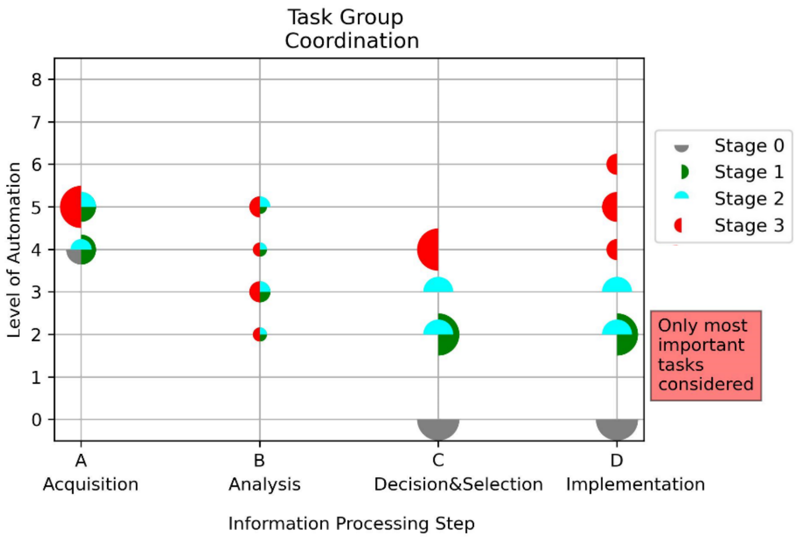

Figure 2: Assessment of current and anticipated Level of Automation of Task Group 'Assurance of Separation’

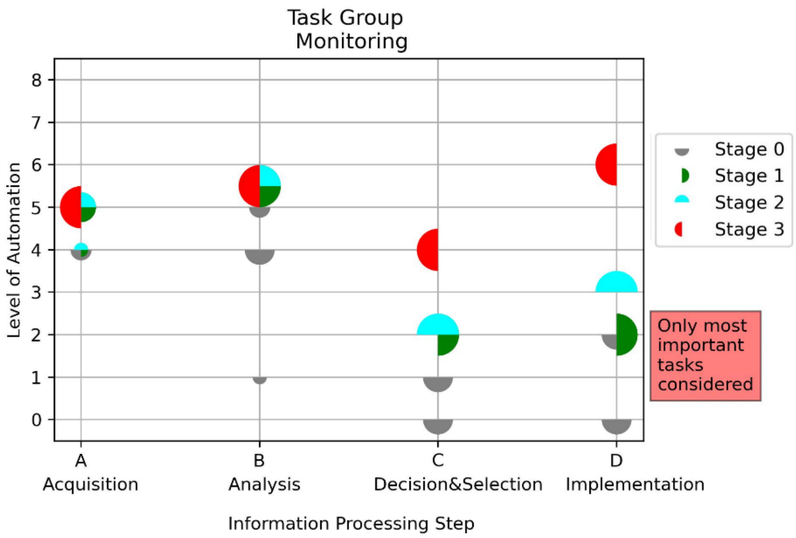

Figure 3: Assessment of current and anticipated Level of Automation of Task Group ‘Monitoring’

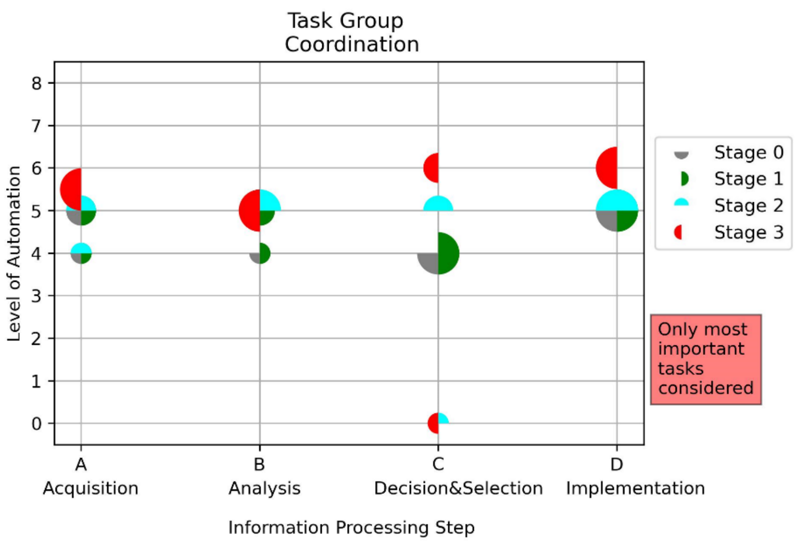

Figure 4: Assessment of current and anticipated Level of Automation of Task Group ‘Coordination’'

These Levels indicate the extent of the automation for a particular information processing step. The lowest possible level is always 0, which means a controller does a job manually without any support tool. For example, group "D" ranges from "D0: Manual Action and Control" up to "D4: High-Level Support of Action Sequence Execution" and "D5: Low-Level Automation of Action Sequence Execution" up to "D8: Full Automation".

The authors emphasize that it is always necessary to divide a system into tasks and to assign automation levels to them instead to the complete system. Furthermore, each automation level is not just a technical improvement but has an impact on how the human is supported in this task and the way this task is conducted.

Keeping in mind the described taxonomy and the ATCO task groups identified in section 3.1, we assessed the current automation level(s). Following additionally the concept stages we estimated the automation levels for each stage as well. In this study, we focus on the important, complex, and time-consuming tasks, including assurance of separation, monitoring, coordination, and documentation tasks groups. The assessment of these four selected task groups were conducted over several workshop sessions with former ATCOs. It results in four tables assigning at least one automation level (0-5/6/8) to each information processing step (A-D) within each concept step (stage 0-3, see sections 4.1 and 4.2). For some minor tasks within the task groups, no possibility or benefit is seen in higher automation, leading to cells with large ranges of automation levels. For better prehension these tables are converted into diagrams (see Figures 2 - 4, without 'Documentation' as there are only few improvements). The diameter of the half-circles in these figures indicates (non-linear) the percentage of all tasks within the respective task group that are allocated to an automation level within an information processing step. What could be seen is that the automation level for 'Acquisition' and 'Analysis' is already high, whereas there is mostly non for 'Decision' and 'Implementation'. Broken down to some specific tasks, this assessment is incorporated into the operational concept (see Table 1) and determines some required tools, functions, and services.

4. Concept for a highly automated Controller Working Position

Based on the findings presented in the previous sections, we lay out details of an operational concept for SCO that stipulates an incremental approach to increase levels of automation in the current system and an associated technical concept to serve as a validation platform.

4.1 Operational Concept

The proposed operational concept consists of three stages, each stage utilizing ENDS to further automating ATCOs manual tasks with the last stage introducing the concept of a digital co-controller that is capable of taking over the responsibilities of managing simple traffic scenarios.

Stage 1 - Current System with ENDS Support: The current ATC work system consists of two controllers. Stage 1 proposes to automate the tasks and enhance support tools to assist both controllers in their respective tasks. From the group of ENDS tools, we choose extended support tools like Attention Guidance (AG) and context adaptive information management to demonstrate an increased level of support. The AG tool tracks the current focus area of the controller with the help of an eye tracking module. This is a useful information, because if there is an event at the area of the radar screen that requires immediate attention of the controller, the AG module can trigger a visual cue like generating a glowing effect around aircraft of interests. Similarly, the context adaptive information management tool aims to optimize the information. For example, an aircraft is approaching the sector boundary and the next task for the controller is handling the handover sequence. In this context, the controller should be shown the frequency of the next sector in the label of the aircraft. Similarly, there are many contexts that require specific information particular to that instance. Tasks connected to monitoring, conflict detection and resolution, and general traffic management are carried out by the controllers in the same manner and with the same responsibilities as today. Especially, the clear distinction between tasks within the responsibility of executive and planning controller is maintained. Primary focus for this stage is lowering the workload of the controller team to prepare the system for the reduction of the number of controllers from two to one.

Stage 2 - Single Controller Operation with ENDS Support: Stage 2 introduces the concept of SCO, where a single controller will be responsible for all tasks without the distinction between execution and planning. Decreasing the number of controllers from two to one controller could mean a workload increase for a single controller. However, SCO will be accompanied by an increase in the level of automation support. To enable a single controller to perform controlling tasks, he will be heavily supported by a set of advanced ENDS services. The ENDS services will consist of advanced tools including Assistance Based Controller Command Creator (ABC[3]), Conflict Detection and Resolution, Heat Map calculation. The ABC[3] tool can forecast a set of possible commands for a traffic situation using flight information and status, the conflict detection and resolution tool detects conflicts and generates conflict-free routes and the heat map tool visualizes traffic hotspots in a sector. These tools will be built in addition to those already developed in stage 1. The controller always carries out the last decision when handling a situation. The target of stage 2 is to enable SCO by increasing controller support and automation.

Stage 3 - Single Controller Operation supported by a Digital Co-Controller: In stage 3, the primary objective is to introduce a digital co-controller capable of performing some of the simpler controlling tasks on its own (Figure 5). We named our implementation of a DC "Digital Interactive Radar Controller" (DIRC) and used both terms interchangeably. DC complements a single controller by taking over the simpler tasks and allowing the human controller to focus on more complex traffic scenarios. The system provides a unified view of airspace structure, traffic in a sector, and automated services developed in all stages of the operational concept. To enable DIRC to manage traffic effectively, it monitors traffic, performs analysis for certain problems or tasks, carry out situation evaluation, probing solutions, and generate "Take Action" plans. In the new configuration of stage 3, it is no longer necessary for the human controller to approve every task and solution from DIRC. However, he should be informed about every action of DIRC via the radar display and a special purpose interaction display that provides a communication medium between the human controller and DIRC. Because the role of the controller changes from an active traffic manager to supervising the traffic, he must be able to create additional tasks and handle special requests or exceptional situations. Therefore, it is crucial that the human controller has complete situational awareness and is always in the loop with the activities of the digital co-controller.

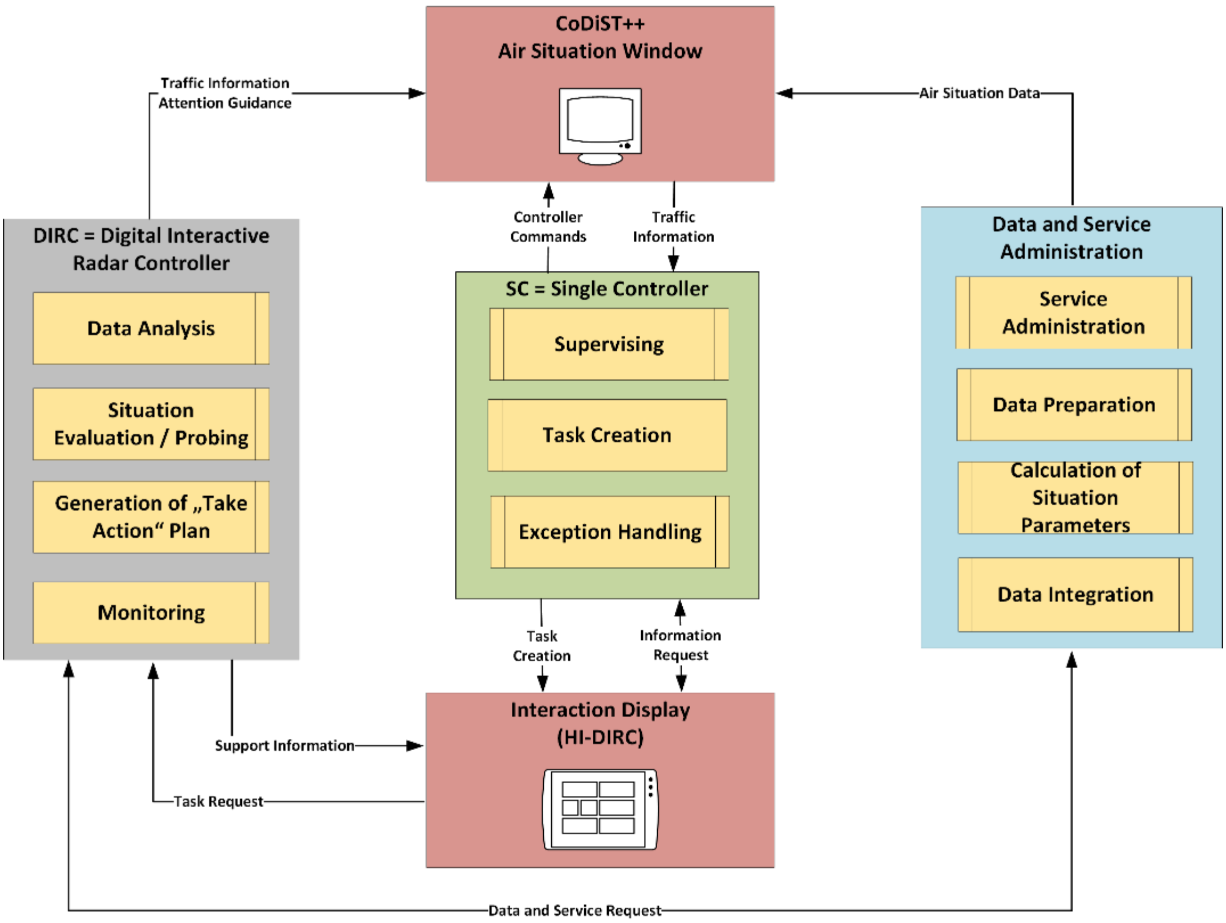

Figure 5 – Structure of a highly automated controller working position for stage 3.

Table 2 shows various tasks grouped into three stages of the operational concept with the associated LOAT classification scheme. Most of the tasks in the table evolve step by step to reach a higher level of automation. Particularly, stage 2 and stage 3 focus on achieving higher automation levels for "Decision and Action Selection (C)" and "Action Implementation (D)" groups. The task groups "Information Acquisition (A)" and Information Analysis (B)" are already at a higher level of automation at stage 1 and remain at a higher level throughout stage 2 and stage 3. Full automation based on "Controller Pilot Data Link Communication" (CPDLC) is planned only for the readback control.

Table 2 – Set of tasks for a highly automated controller working position.

Group	Task	Stage 1	Stage 2	Stage 3
Monitoring	Lead ac with radar	A5 / B3 / C1 / D2	C2 / D3	C4 / D4
	Deviation control	A5 / B5	C3 / D3	C4 / D4
	Deviation adjustment	A5 / B5 / C2	C3 / D3	C4 / D4
Clearances	Issue clearances and commands	D2	D2/3	D4/5
	Clearances for adjacent sectors	D1	D2/3	D4/5
	Readback control	D1	D1/7	D7/8
Identification	Identification (Initial Call)	A5, B5	A5, B5,	C3, A5, B5
	Identification (Initial Monitoring)	A5, B5	A5, B5	C3, A5, B5
	Identification continuously	A5, B5	A5, B5	C3, A5, B5
	Transfer Call	A5, B1, C1, D1	A5, B4, C2, D2/3	B5, C4, D5
Conflicts	Conflict detection	A5 / B5	A5, B5	A5, B5
	Conflict solution (using e.g. Conflict / Risk Display)	C2, D2	C2, D3	C4, D4
	Conflict check for special zones	A5 / B5	A5, B5	A5, B5

A closer look at the relation between human and digital co-controller, especially in stage 3, shows that the communication between them is mainly performed using a data link (CPDLC) and a text to speech tool in the cockpit. As presented in Table 2 the second group (Clearances) will be highly automated by applying a command generation service to a trajectory and sending the result to the pilot in text form. The "Readback" is received in text and can be easily compared to the original command.

Many other tasks are automated as well like e.g. aircraft monitoring and control. An example for the sequence of actions for this task in stage 3 is given in Figure 6.

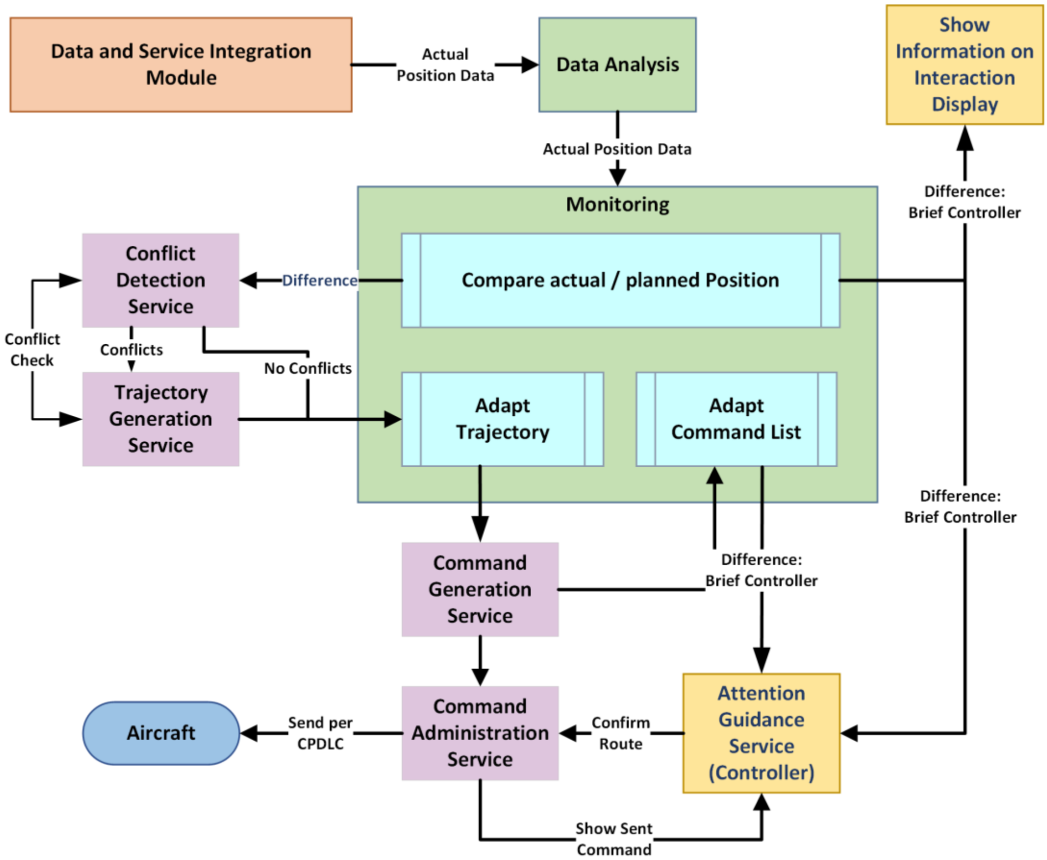

Figure 6 – Example for the task chain to monitor and control aircraft in stage 3.

The first step is the transfer of an actual data set including aircraft position data to the data analysis part of DIRC, where the data is extended at least with the planned trajectory and send to the monitoring service. This service compares the actual and the planned position and in case of a significant difference sends the received data to the conflict detection service for further analysis. Additionally, it informs the human controller using the attention guidance service and the interaction display. If a conflict is detected a new trajectory is requested from the trajectory generation service and afterwards send back to the monitoring service. If no conflicts are detected or the difference is not significant a procedure is started to adjust actual position and planned trajectory. Afterwards, the resulting trajectory is sent to the command generation service where the necessary commands and their time stamps are generated. The resulting list is then integrated into the general command list provided by DIRC. This list is operated by the command administration service which sends the predefined commands in time to the corresponding aircraft.

4.2 Technical Concept

This section lays out the technical foundation required to implement the operational concept and provide a platform to perform evaluation and validation. The first aspect the technical concept addresses the requirement for a highly flexible and extensible software architecture that supports a higher level of information fusion and system integration. The second aspect focuses on allowing the implementation of the functionalities and services as a stand-alone entity that automates individual tasks defined in the operational concept thus supporting incremental design.

4.2.1 Software Architecture Design

Keeping in view the requirements of high flexibility, information fusion, and integration, we designed our system on the principle of microservices architecture [34]. Microservices is an architecture design that breaks down complex software into smaller components. Each component is responsible for solving a well-defined sub-problem and exposing it as an independent service. As a result, it has numerous advantages over a single monolithic software, such as flexibility, maintainability, and expandability. In our view, it is the optimum choice with many benefits. Firstly, different functionalities can be developed as a standalone service, allowing for ease of development and usage in more than one context. For example, we envision building a DC with the same view of the traffic situation as a human controller and the ability to request information. A standalone service can serve a request from both the human and digital co-controller, providing the same information, each utilizing it differently. Secondly, it supports incremental development of each component without breaking down the complete system. This is particularly useful for step-wise enhancing the automation capabilities of a service. Thirdly, it provides flexibility in choosing technologies as each service can be written in a different programming language, allowing the seamless integration of existing components into the new system and saving additional re-implementation efforts. Finally, the information exchange allows a loose coupling between different components through well-defined interfaces.

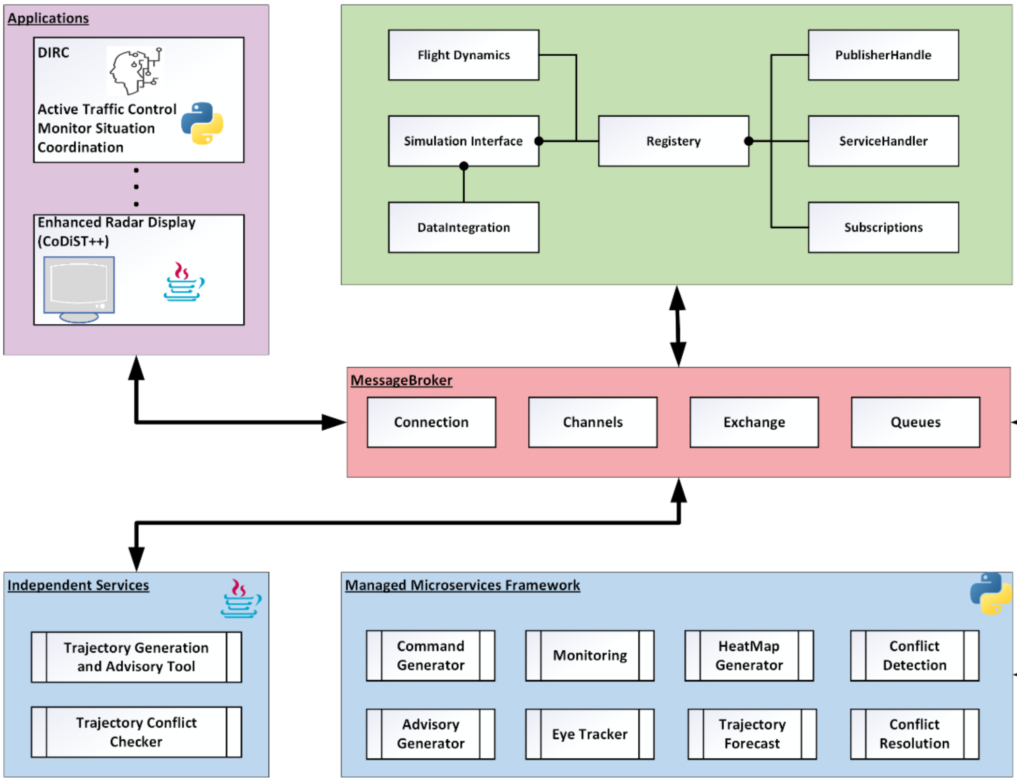

Figure 7: The high-level software architecture design to support implementation of automation of CWP.

The high-level software architecture presented in Figure 7 consists of four main components. The central component of the architecture is Data and Service Integration Module (DASIM), with the responsibilities of integrating data from different sources and providing the functionality for service management. This component acts as a middleware that holds information about the available services and allows the application a unified access mechanism for the available services. The loose coupling between application and services is realized by a communication layer based on message broker service, enabling interaction through message exchange between services, radar display, and digital co-controller interface. Each service exposes a well-defined interface and expects a request to be made in a well-defined message structure. The results are returned in a predefined format, which allows for flexible message exchange. The second component comprises services. Each service implements a particular functionality as a standalone entity capable of servicing concurrent requests. These loosely coupled services can easily be replaced with more advanced implementation without changing other parts of the system. For example, machine learning models are continuously developed and trained on newly collected data, requiring periodic updates of the module, easily achievable with a microservices framework. The services in our technical framework consist of functionalities such as conflict detection, command generation, heatmap, trajectory generation, attention guidance, context-adaptive information management, etc. The third component is an enhanced version of our Controller Display and Simulation Tool (CoDiST++), an enhanced radar display, and a primary Human-Machine-Interface (HMI) module, allowing ATCOs to control air traffic directly.

Finally, the DIRC is the fourth component, a DC capable of controlling air traffic. DIRC is empowered with AI methods and techniques for enabling autonomous decision-making. It continuously monitors the situation by analyzing the information received from various services. Then, it translates the received information into actions using its central decision-making module. The DC works as a subordinate to a human controller, necessitating to inform about its decisions and actions in a human-friendly way. DIRC will consist of an interactive display (HI-DIRC), a second HMI module that allows interaction between a human controller and a digital co-controller.

4.2.2 Automation Services

The services are the core building block of the technical concept. Each service implements a functionality that enhances the overall capabilities of the system. The services can be categorized as primitive and composite. The primitive services implement a functionality that can service a request by itself. For example, the trajectory forecast service - responsible for calculating the position - only needs the current flight location and flight plan, and it generates the flight path consisting of latitude, longitude, altitude, time, and speed. On the other hand, composite services depend on other services to complete their task. For example, a conflict checker service requires the trajectory service to generate the complete path to two aircraft and use the internal logic to detect a conflict. Below, we list a few examples of services and their descriptions to give a better idea of possibilities, including some developed in previous projects undertaken at DLR. The idea is to integrate the existing services and build new ones to complete the automation efforts.

Trajectory Conflict Checker: The conflict checker service checks for a given pair of aircraft potential conflicts arising in the future. It uses the aircraft's projected trajectories and calculates the points where the two aircraft lose and regain safe separation and the point of closest approach. Safe separation in an en-route flight constitutes a radius of 7NM in the upper airspace around each aircraft. If the safe separation is impossible to maintain in the project path, the controller is informed through a Conflict Information Window. In addition, this service could be used in the attention guidance service to trigger visual effects to inform the controller about the imminent conflict scenarios.

Attention Guidance: The Attention Guidance (AG) service's main purpose is to bring to the notice of the human controller the most critical situation that he has missed addressing. It uses an eye-tracking module to get the current viewing area of the controller and map this information to the radar screen coordinate. The mapping helps the AG module check if the human controller has looked at the most important event or situation on the radar screen. In case the controller has not looked at this situation, the AG module triggers the visual attention by generating glowing effects. In case the controller has not looked at this situation, the AG module triggers the visual attention by generating glowing effects. The concept of Attention Guidance was tested in the context of a SESAR project PJ16-CWP-HMI [35].

Context-Adaptive-Information: Context plays an important role in handling a situation in air traffic control. For example, an ATCO can tailor actions for an aircraft capable of climbing at a higher altitude if this information is available in the context of climb command. Similarly, for direct to command, ATCO will be most interested in the possible waypoints and navigation aids that are relevant for a particular flight [36].

Trajectory Generation and Advisory Tool: The Trajectory Generation and Advisory Tool (TraGAT) is a composite service incorporating the Trajectory Conflict Checker and the Command Generator Service. It develops a new trajectory for a flight with given start time, origin, destination, predefined start and end heights and start speed. For this it takes the flight data of other aircraft into account as well as restricted areas with varying positions and validity periods. The trajectories are generated with methods based on evolutionary algorithms and can take combinations of several different evaluation factors like “number of conflicts”, “time within a restricted area”, “route length”, “climb and descent rates” and / or “punctuality” into account.

4.3 Failsafe Solutions

In principle, every system should be outlaid in a redundant way with at least a second system in the backhand, as it is the standard today. This does not only mean that a second hardware system has to exist or every functionality has to be duplicated, but that another functionality should be able to take over the most important and safety relevant features of the failed system.

The software architecture described in section 4.2 can be seen as the first step to a fallback system because it consisted of a network of connected functionalities instead of one general tool. Every task like the calculation of a conflict free trajectory will be operated by DIRC and the necessary functionalities have to be requested by the central data and service integration tool DASIM. In case of a partial failure e.g. of the trajectory generation functionality the other functions should be able to work on with some smaller drawbacks for directly connected functions like conflict resolution. Only the failed functionality has to be substituted. With this failsafe approach it can be prevented that the failure of a small part of the system in stage 3 will not lead to a complete breakdown of the whole system. Instead it may be possible to step back to the stage 2 functionality with one controller and an ENDS or at least to stage 1.

Table 2 lists examples for highly automated tasks for stage 3 and the corresponding possible fallback solution.

Table 2: Examples for highly automated task and their fallback solutions.

Automatic Tasks	**Fallback Solution**
Datalink CPDLC	Radio communication (RC)
Send clearances / commands (CPDLC)	Commands are announced in time and send by the controller using RC
Attention Guidance	Standard procedures (CWP Alerts, Warnings…)
Integrated information management (Head-down information)	Information request using „HI-DIRC“
Context-adapt. Information Management	Presentation of standard Information
Sector coordination	Standard procedures carried out by controllers
Command Generation	Creation of standard trajectories with beacons instead of coordinates, execution by controllers.
Flight guidance by sending commands in time	Commands have to send by controllers. Command list can be requested from „HI-DIRC”.
Heatmap Generation	Basic traffic information from „HI-DIRC“
Deviation control (Flight information using CPDLC)	Visual presentation of actual and planned position
Deviation correction with commands (CPDLC)	Commands provided by controllers
Conflict detection	Standard procedures supported by existing CWP tools.
Conflict resolution	Stage 2 procedures supported by CWP tools for trajectory generation / probing (Elastic vector tool).

Figure 8 shows an example for a stage 2 conflict resolution as substitute for the automated stage 3 version where a conflict-free trajectory is created automatically. The trajectory of the aircraft in question is shown to the controller allowing him to create a waypoint on it and move it until a green color indicates a conflict-free trajectory. Furthermore, the controller has the possibility to select a re-entry point where the new trajectory part should meet the original one.

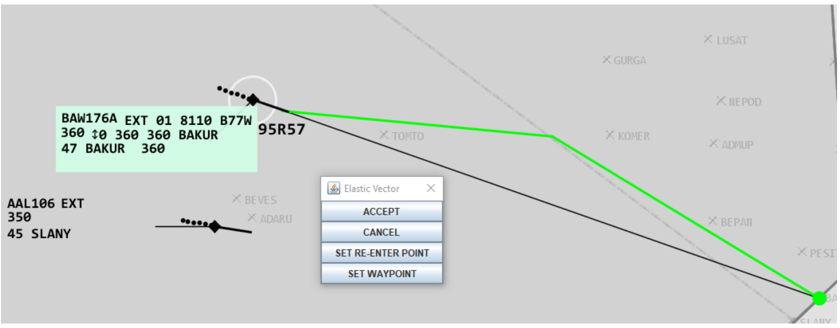

Figure 8: Example for a stage 2 failsafe solution for conflict resolution.

5. Conclusions and Future Work

This paper presents a concept to increase automation support in CWP. It is centered around the single controller operations that enable a single human controller to collaborate with a digital co-controller in managing air traffic and substitute radar and planning controllers in a conventional en-route setting. SCO tasks are assumed to differ significantly from the current two-controller setting and could represent a fusion of roles. A work system analysis was conducted on the current operational boundary conditions in en-route control for the upper airspace of the Federal Republic of Germany to examine the current controller working positions, including support systems, tasks distribution, and roles. As a result, a task grouping was defined, and automation levels for each group were assigned by conducting several workshops with ATCOs.

An operational concept was proposed to increase the level of automation in CWP incrementally in three stages. The first stage uses the conventional two-controller setting with increased automation support. The second stage introduces SCO with a single human controller supported by Enhanced Negotiation & Decision Support tools. Finally, the third stage adds additional automation support by introducing a digital co-controller that can independently perform simpler traffic control tasks. The transition from a system with two controllers (stage 1) to one with only a single human controller with primary responsibility (stage 2 and stage 3) is not easily possible, as it would lead to an overload of the single human controller or, in the case of misunderstandings regarding responsibilities, to severe incidents. Therefore, an automation strategy was developed to enable a gradual transition of automated solutions within three stages which is also reflected in the operational concept. A technical concept based on microservices architecture was proposed to implement the automation concept to evaluate and validate in real-time simulations.

In future work, the proposed operational concept with its automation level will be further developed and evaluated in real-time simulations. The evaluations aim to obtain feedback from the controllers on the proposed solutions, discuss them critically, and use them as a basis for further developing the concept. Besides the aim to refine the concept, another major goal of the evaluation is to prove the extent to which the SCO concept benefits human performance and operational performance. For this purpose, we will collect qualitative and quantitative data consisting of performance parameters such as human performance metrics, situational awareness, system usability, and automation trust. Additionally, we also plan to collect operational performance data such as flight efficiency, airspace capacity, and the number of separation violations.

Finally, regardless of the evidence of a possible increase in controller productivity or even improvement in operational performance through SCO, subsequent safety assessments must also be carried out. In addition, possible effects of SCO on personnel planning and thus the profitability of an ANSP should also be examined. However, it is already apparent that the SCO concept is aligned with the interest of ANSPs since, according to the opinion of operational experts, a significant reduction in ANSP costs could be achieved while maintaining the same level of safety.

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