Towards Full ATC Automation for Aircraft Ground movement: A First Step

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***Abstract*—Currently, there is already a shortage of air traffic controllers in some areas to adequately manage traffic. With rising demand in air traffic, this will likely further intensify in the next years. Increasing the level of automation of controller assistant tools could help mitigating this problem. However, higher automation harbors the risk of losing situational awareness and skills of the human operators. We present a prototypical system fully automating ground air traffic management and describe the technical details. Some features are presented that were added to the user interface to help air traffic controllers adapting to the changed workflow and reducing the loss of situational awareness. The prototype is able to run fully automatically in a predefined environment with a human supervisor. An outlook is given on human-in-the-loop trials with air traffic controllers that evaluate further steps on how to adapt the grade of automation to reduce risks of a loss of situational awareness and skills.**

***Index Terms*—Air Traffic Management, Ground Traffic Management, Automation, Genetic Algorithms, Situational Awareness**

I. Introduction

Since the end of the Covid-19 pandemic, demand for air traffic has been rising drastically. In many areas, pre-pandemic levels are already reached and forecasts predict further growth [1] [2]. Furthermore, air navigation service providers (ANSPs) are already struggling to provide enough air traffic controllers (ATCOs) to handle the traffic demand adequately [3]. This problem will become more serious as it might become harder to find enough suitable trainees to replace retiring ATCOs. One possible solution to the problem is automation; either by substitution of single ATCO roles or by task sharing of the ATCO with (automation-)systems to enable one ATCO managing traffic for which currently multiple ATCOs are necessary [4]. However, automation leads to new challenges like reduced situational awareness (SA) of the human controllers or the inability to take back control quickly when an automated system reaches a state that cannot be handled without human intervention [5]. This has to be considered when developing automated systems.

In recent years a lot of research has been conducted in trying to enable ATCOs to handle higher traffic loads by developing assistance tools like arrival managers (AMAN) [6], departure managers (DMAN) [7] or surface managers (SMAN) [8] [9]. These tools assist ATCOs for example by proposing optimized aircraft sequences, automated conflict detection, improved aircraft localization and in other ways. Some researchers go even as far as trying to completely automate certain simple ATCO tasks or developing an AI assistant or digital controller [10] [11]. A big part of this automation research is the human factor side considering SA, trust in automation or legal aspects and certification of automated tools [5] [12] [13].

We aimed to push the automation even further than most other research by enhancing the DLR surface management system TraMICS (Traffic Management Intrusion and Compliance System) [14] to a fully automated controller working position, called AutoTraMICS. Full automation is the absolute limit of automation and will not be operationally feasible for some years [15]. Nevertheless, we chose this level of automation as target for our prototype to examine this edge case. In doing so we intend to find out what the major problems to build systems that approach a full automation as far as reasonably possible are and to gather feedback during tests and validation. We chose the ground air traffic controller position, which we deem the most appropriate for this edge case, since the aircraft can stop moving in safety critical situations and therefore a problem in the system would not have as severe consequences as at other controller working positions where flights are airborne. Even though the AutoTraMICS can run fully automatically, we intent to have an ATCO to supervise the decisions of the system and intervene in case it runs into a situation that it cannot handle or for safety critical actions like runway crossings. In general, the role of the ATCO shifts from an active position to a passive observing position. To enable the observing ATCO to maintain the necessary SA some features were added to the human-machine-interface, for example a system state and notifications about future actions.

This work outlines the environment and assumptions to enable this fully automated approach and describes the important technical details of the prototype. A special focus is put on the features intending to help the ATCOs maintain SA in the new supervising role. Human-in-the-loop trials with the AutoTraMICS in a real-time simulator are prepared, for which a detailed evaluation will be published in the future.

II. Prerequisites and Scope

A. Level of Automation

To defined the term “full automation” in the context of this paper, we classify the level of automation (LOA) of typical operational ground traffic management systems, in relation to our previous SMAN prototype (TraMICS) [14] and our current proposed system (AutoTraMICS). To do such a classification, different taxonomies for the level of automation exist in the literature [16]. The Single European Sky ATM Research (SESAR) joint undertaking defined such a taxonomy specifically for ATM in their European ATM masterplan [4]. Fig. 1 shows an overview of this taxonomy. We decided to apply this one for two reasons: Firstly, the levels are defined by a differentiation between the four tasks information acquisition, information analysis, decision selection and implementation of actions. Each of these tasks plays a different role in the different systems that are compared in this paper. Secondly, it eases the contextualization of our work with other European research.

Operational ground traffic management systems usually consist of a ground traffic situation display and a flight strip display. They display flight plan information, the current position of the aircraft on the airport and sometimes currently active stop bars. More advanced systems integrate more information into the traffic situation display like the clearances given to the aircraft, weather data and similar useful information. They do not generate any proposed solutions to problems or make decisions. This means, these systems can be put in the category of “low automation”, Level 0 of the taxonomy proposed by SESAR. The human has to implement all actions manually and the system assists him only by making relevant information available.

The DLR surface manager TraMICS [14] contains more advanced assistance functions. The major advantage as opposed to current operational systems is the generation of possible solutions. These solutions include proposed trajectories that are conflict free, optimized and adapted in real time. The trajectories are presented to the ATCOs and they can decide whether they follow the trajectories or change them. According to the chosen taxonomy such a system would fit best to the “task execution support” level 2 of automation, since the human still has to give all commands via radio communication to the aircraft.

Additional to these functions, the AutoTraMICS will now select and implement the generated solution automatically and send the commands directly to the aircraft. Depending on the

Fig. 1. Levels of automation as defined in the SESAR European ATM Masterplan [4].

system's configuration this can be done for all tasks or for predefined tasks; details will be described in section II-B. The system is designed to enable supervision, so the ATCOs can monitor the system and intervene if they notice a safety risk or disagree with a system's decision. Depending on the system's configuration, the AutoTraMICS would either fall into the category "full automation" (level 5) or "high automation" (level 4) according to the applied taxonomy.

B. Simulation Environment and System Configuration

The AutoTraMICS is integrated with the real-time human-in-the loop simulation software NARSIM [17] in the DLR ATS360 simulator (cf. Fig. 2), which allows a flexible configuration of the controller working position while providing a 360° outside view [18]. We chose a slightly adapted version of Hamburg Airport as ground topology. On the one hand, it is an averagely sized airport and is therefore representative for many other airports and on the other hand, it contains some interesting challenges with its crossing runway system and a tight main apron (cf. Fig. 3). We included two controller working positions in the simulation: Tower and Ground. The Tower position handles arriving and departing aircraft until they leave or enter the runway, as well as runway crossings. The Ground position manages the remaining air traffic on the ground. As described above, we selected the Ground position to apply our automation system.

As mentioned before, there are different stages of automation configurable for the AutoTraMICS: a) full automation mode; b) high automation mode and c) manual mode. In the full automation mode, everything will be done by the system. Clearances are automatically given according to the planning and corresponding commands are sent to simulation pilots via data link. The commands can even be sent directly to the simulator, which bypasses the simulation pilots and therewith a human factor. In the second mode, high automation, the ATCO still has to perform some safety critical tasks manually. In our setup these tasks are runway crossings, which have to be coordinated with Tower, and the resolution of conflicts for which the system could not find a solution, e.g. a deadlock due to pilot mistake (cf. section III-B). Everything else will be carried out as in the full automation mode. The high automation mode is used for validation and most of the remaining paper will refer to that mode. The high automation mode includes using simulation pilots for realistic reaction times to given commands. Furthermore, the AutoTraMICS can be switched from any automation mode into manual mode by the ATCO. In the manual mode, the system will fall back to Level 2 of the SESAR automation taxonomy, which represents a switch back to TraMICS. Optimized trajectories are still generated and proposed to the ATCO, but clearances have to be entered manually and advised via radio communication. This feature is an emergency shutdown of the automated mode, in case the system runs into severe problems.

Fig. 2. The DLR Apron and Tower Simulator ATS360 [18].

C. Relevant Systems

To enable a fully automated ground air traffic management many factors and systems need to be available and work together reliably. The following list contains the important components essential to make an automated system operationally feasible. Each paragraph provides a short description of a component and how it is handled in the AutoTraMICS.

a) Algorithms: The foundation for an automated ground air traffic handling needs to be a fast and robust trajectory [optimization] algorithm. Such an algorithm calculates precise, conflict free taxi trajectories for each active aircraft. Furthermore, the trajectories have to adapt to changing conditions immediately, e.g. route deviations. Additionally, conformance monitoring algorithms and a fast and precise conflict detection triggering necessary re-calculations of trajectories are mandatory. The algorithms used in the AutoTraMICS are described briefly in section III-A and in detail in [14].

b) Data: To enable the algorithms calculating the trajectories, data is needed. Base information like the planned stand and take-off/landing runway are needed as start and end point of the taxi trajectories, as well as planning data, like reliable landing and off-block times. Off-block times depend on different factors like passenger boarding, aircraft re-fueling or baggage handling and can change on short notice. Today the uncertainties of the off-block time can already lead to an inability to follow the planned departure sequence and therefore to suboptimal traffic throughput [19]. For an automated system it is even more important to have well maintained off-block times (as well as landing times) to stabilize the planning results and reduce the number of re-plannings. Since our prototype runs in a simulation environment, this problem does not occur.

To update the trajectories while the aircraft move on the ground, position data is needed. This data needs to be precise and available in real-time. Based on this data the system can detect whether the aircraft comply with the planned trajectories. Otherwise the trajectories need to be updated and possibly re-optimized, since conflicts or other conditions have changed. In our simulation environment the position data is available reliably, precisely and is updated each second.

An optional enhancement for an automated ground handling system would be to couple other planning systems like arrival managers (AMAN) or departure managers (DMAN) with the system. This could improve the accuracy of the relevant planning times and with that increase the precision of the planned ground trajectories. There has been research how such planning systems could be coupled with surface management systems [9]. Therefore, this will not be further examined in this work. For our prototype we simulate AMAN and DMAN systems by using precise simulated arrival times and a simple departure sequencing based on departure spacing.

c) Technical Infrastructure: One major change in our system is the way how clearances are given to aircraft. Nowadays the majority of ground air traffic communication is handled via radio. In the automated mode the AutoTraMICS sends commands as digital messages. This means either there needs to be a system that can send commands fast, reliable and secure digitally to aircraft and display them in the cockpits, or the commands need to be transformed to speech and sent via radio. For the first option something like the controller pilot data link communications (CPDLC) system could be used. A problem is, that CPDLC messages still have some delay until they arrive at the aircraft and until the pilot notices and reacts to them [20]. Since the ground trajectories are planned with only small time margins, a faster communication system would be necessary. Converting the commands to speech would be possible with a text to speech tool, for which advances were made in recent years [21]. In our simulation environment, the commands are sent to the pseudo pilots, therefore this topic is not examined further in this work.

d) Ground Controller Working Position: Even though we aimed for a fully automated system initially, a supervisor is still needed, since air traffic management is a safety critical environment and the system is not yet perfectly reliable. The ATCO needs to ensure that the system makes no mistakes and intervene if necessary. To enable such an intervention and supervision it is important to have a controller working position that supports this task. This becomes especially important, since with higher automation the SA of operators might dwindle, along with other problems [5]. Features to counteract these problems include notifications about commands that will soon be given to the aircraft, warnings for non-conformances and a system state that supervises whether the automated system is still able to handle the current traffic situation. A detailed description about these features can be found in section III-C.

e) Human Component (ATCO): As mentioned above, an ATCO as supervisor will still be necessary even for our automated prototype. However, this ATCO will have a different role than today. Nowadays the ground controllers at most airports need to do everything manually, starting at planning of the optimal taxi routes and sequence up to issuing the clearances to the pilots via radio. If an automated system would ever be deployed operationally, it would be important to gain the trust and acceptance of the ATCOs. These points are detailed in section IV. To gather more information, validation trials with the AutoTraMICS are performed in a human-in-the-loop simulator.

f) Human Component (Pilot): Airports are experimenting with electrically towed taxi on the ground [22], which could be done by automated vehicles. In that case, pilots would not be relevant for the main part of the taxi phase. But as in near future, pilots will still control taxiing aircraft at most airports, the automated system needs to interact with pilots. When the interaction between the ATCO and the pilot changes from the auditory to text messages, there might be challenges regarding the communication, which need to be resolved (cf. paragraph II-C c). Another factor is the delay caused by pilots implementing the received commands. They need a few seconds to notice and react to new commands and sometimes even more for the follow up, e.g. if they are occupied with another task or are not yet ready. This delay can challenge the planning, e.g. if it exceeds a time window where after the trajectory might not be conflict free any more. This means it is necessary that the planning system considers this possible delay and adapts in case the delay exceeds the time window.

For the human-in-the-loop simulation trials using the high automation mode, pseudo pilots are briefed to follow the commands received as text messages or use radio communication as fallback solution. Similar to real pilots they will introduce delay. Additionally, they are tasked to make scripted mistakes to increase the external validity and to analyze the reaction of the system and the ATCO using it.

g) Other Ground Traffic: Aircraft are not the only traffic on the ground at airports. There are also vehicles like push back trucks, fuel trucks, baggage carts, passenger busses or maintenance vehicles. These vehicles should not, but can interfere with aircraft movements, especially when taxiway or runway checks are performed. For these reasons and for safety concerns, the positions and the plans of these vehicles would need to be available in an automated aircraft ground traffic management system at all times. Since our prototype runs in a simulator and we did not want to put the focus of the work on the additional ground traffic, we ignored it by intent in the current version of the system.

III. Technical Description of the Prototype

After the relevant systems are described and tailored to our use case and simulation environment, the following sections describe our implementation.

A. Algorithms

The main algorithm behind the AutoTraMICS is a genetic algorithm that generates and optimizes the aircraft taxi trajectories. This heuristic optimization algorithm can find globally conflict free solutions in real time. Trajectories are calculated in two steps: First the shortest route from the stand to the closest runway entry (or vice versa for arrivals) is calculated with a modified A* algorithm and enhanced to a trajectory by adding expected times at each route point. These times are calculated based on an expected speed, the route length and the earliest possible trajectory start time. For arrivals the best available landing time (base case: estimated landing time; ELDT) is used and for departures the estimated or target off-block time (EOBT/TOBT), or the target take-off time (TTOT) is used, depending on the availability. In case the aircraft is already taxiing, the trajectory is calculated based on the last known position and the current time. In the second step, these trajectories are adapted to resolve any conflicts with other aircraft. This can be done by changing the holding duration at any point, changing the route, or even changing the planned taxi speed of the aircraft. The solutions are generated and improved by the genetic algorithm in multiple calculation iterations and then evaluated and selected based on a highly configurable penalty function. This function considers many factors, for example the number of holds, the taxi duration or the route length. With the configuration of the penalty function it can be controlled what kind of solutions the system will generate by changing the weights of the various factors. The selection of these weights has an influence on the quality and properties of the generated trajectories, for example if it should be more environmentally friendly or maximize throughput. To select a fitting set of weights, regular testing and parameter tuning was necessary. To accelerate this process, the full automation mode described in section II-B was used. The system was run nightly multiple times without intervention. Trajectories that were generated in these nightly runs were analyzed and compared for different weight settings to find appropriate settings.

To supervise whether the aircraft follow the planned trajectories, the AutoTraMICS also has a conformance monitoring module. This module compares the received position and movement of all aircraft at all times with the planned trajectories. If any aircraft deviates either temporally or spatially from the planned trajectory by a configured margin, the trajectory is re-calculated. This ensures that no new conflict is developed in the global traffic situation due to the trajectory deviation. To allow these regular re-calculations, the algorithms have to be performant. Especially the conflict detection needs to be highly optimized, since it can be called thousands of times in each trajectory calculation, to check if calculated solutions are conflict free. An in-depth description of the technical details and an analysis of the performance and reliability of these algorithms can be found in [14]. Some further evaluation of the configuration capabilities of the penalty function are described in [23]. Additionally, the conformance monitoring is described in more detail in [24].

B. System Monitoring

The genetic algorithm described above, is non-deterministic and might not always be able to find a conflict free solution. This might, on the one hand, be due to limitations that do not allow a conflict free solution to exists (e.g. in case two aircraft are in a deadlock position), or because the traffic situation is too complex and the algorithm had to stop the search for a viable solution due to time constraints. In the latter case, the algorithm is often able to still find a solution in a second or third optimization run before the conflict would actually be imminent. Nevertheless, the possible existence of non-conflict-free solutions could be a major problem in the full automation mode and severely reduce the trust of the human in the high automation mode. For that reason, a new module was added that supervises the system and is able to detect any problems in the generated trajectories. These problems include not only unresolved conflicts, but also incomplete or broken routes. When such a problem is detected, the system monitoring module generates a warning to be displayed on the ATCO's HMI and a request is sent to the trajectory generator module to fix the affected trajectory. Problems that cannot be resolved automatically are collected in a global system monitoring state. This state is displayed on the ATCO's HMI as well, intending to help the human user to understand the current system health at one glance. Additionally, the current problems are classified based on their type, the current state of the flight (e.g. moving/parking) and the expected occurrence time of the problem. With these factors a severity is calculated for each problem. The weights of these factors can be configured to select which problems shall have a larger impact on the overall system state. Based on a correlation of the severities of all system monitoring alerts, the global system state is generated and displayed with a traffic light encoding. TABLE I shows the meaning of the different system monitoring states and recommended behavior of the human controller.

In case the system monitoring detects an unresolved conflict in the near future (i.e. less than one minute) the flights that are affected by the conflict will receive an immediate *hold position* command, to prevent a possible collision. The AutoTraMICS will choose which flight should stop by analyzing the situation. For example, if one of the flights is currently parked and would cause the conflict by starting to move in the way of the other flight, the parked flight will receive the *hold position* command. If both flights move towards a crossing, the flight that will reach the crossing first will be allowed to continue and the other flight will receive the *hold position* command. In case of a deadlock conflict, i.e. the flights move towards each other and there is no taxiway available to avoid the conflict, both flights are stopped and the human operator needs to resolve the situation. With these advised *hold position* commands, there should never be an actual collision between aircraft, as long as the correct position data is available and the pilots follow the commands.

TABLE I
THE GLOBAL SYSTEM MONITORING STATES, THEIR MEANING AND RECOMMENDED BEHAVIOR OF THE HUMAN ATCO.

State	Meaning	Recommended behavior
Green	No critical problem detected. No safety risk.	No intervention from the human necessary.
Yellow	Multiple small or few large system problems detected. No immediate safety risk, but danger of a developing risk.	Close monitoring of problems recommended. Intervention if deemed necessary by human.
Red	Critical system problem(s) detected. Safety can no longer be guaranteed by automated system.	Immediate intervention by human controller necessary.

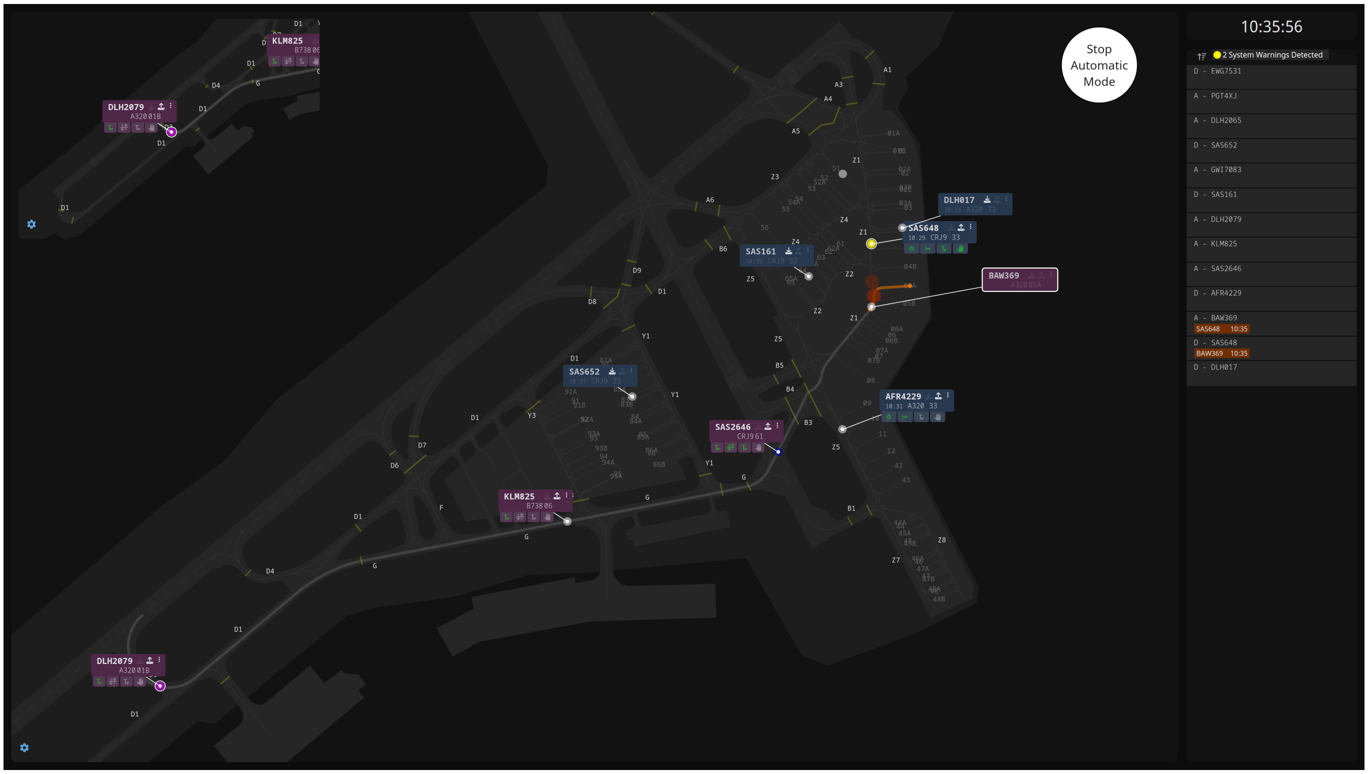


Fig. 3. A screenshot of the user interface of the AutoTraMICS. The largest part of the display is used for the traffic situation display. On the right side, the system monitoring state is displayed.

C. User Interface

A general observation in the literature is that the higher the level of automation of a system, the worse the SA of the human operator [5]. A loss of SA can lead to problems as the operator might for example miss dangerous situations or they might not be able to take back control from the system if necessary (out-of-the-loop problem). To mitigate these dangers, some adaptions to the user interface were done. The resulting user interface is displayed in Fig. 3 and TABLE II contains descriptions and examples of various features that were added to assist the ATCO in understanding the system or intervening in the automation.

D. Pilot Communication Interface

To enable the automated communication of the system with the pilots, it is necessary to convert the generated taxi trajectories into pilot commands. For this the trajectory and the current position of each aircraft is continuously analyzed. At various stages of the trajectory, the AutoTraMICS will then generate commands, that can either be sent directly to the connected simulator to enable a complete automated simulation, or to a pseudo pilot display for realistic delays. The following list of commands can be generated:

- *Start up*
- *Push back into* [taxiway] *facing* [direction]
- *Taxi to* [target taxiway, stand or runway holding point] *via* [list of taxiways]
- *Cross runway* [runway name]
- *Line up* [runway name]
- *Cleared for take-off* [runway name]
- *Contact* [position name or frequency]
- *Hold Position*
- *Disregard*

Even though the system is capable to send *cross runway*, *line up* or *take-off* commands automatically in general, this is out of scope in our validation setup. As mentioned in section III-A, the AutoTraMICS runs only for testing in full automation mode, where a simple runway occupancy and separation calculation is used, which might not follow all separation and safety rules. In any other simulations, the system only runs in high automation mode, where the use of runways still has to be managed and cleared by a human ATCO.

When a trajectory is re-calculated, the last given command might change (taxiways to be used or push back direction) or be invalidated. In that case an update of the command, or a *disregard* command is sent to the pilot.

Additional to the automatically triggered commands, the AutoTraMICS also sends commands when the ATCO manually enters flight clearances into the user interface. This way the human can intervene in the automation without using the radio.

TABLE II

Descriptions and examples of some features in the user interface to help the human controller to monitor the system or intervene in the automation.

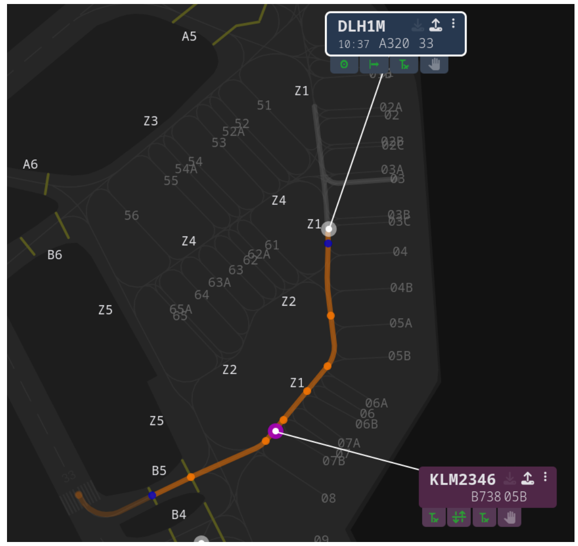
<table>
<tr><th>Feature</th><th>Description</th><th>Example</th></tr>
<tr><td>Aircraft clearances</td><td>Possible clearances of aircraft are displayed at the bottom of their track label with symbols. When a clearance was given to the flight, it is marked in green. The symbols can also be clicked to give or revoke the clearance manually. In both automation modes the corresponding commands are then directly sent to the pilots. Fig. 4 shows an example for a departure (blue label) and an arrival (purple label). For departures start up, push back, taxi and hold position clearances are available. For arrivals taxi, crossing, continue taxi after crossing and hold position. Crossing clearances are only available for arrivals, because in the example configuration, runway 23 was used for arrivals and runway 33 for departures. That means a crossing is required for arrivals to reach the main apron, but for departures no crossing is necessary.
Furthermore, given movement clearances are reflected in the route visualization, which is displayed when a flight is selected. The cleared section of the route is displayed in a vibrant orange, the not-yet-cleared part of the route is displayed in a more transparent orange. Grey parts of the route were already passed by the flight. Via the route, more precise taxi clearances can be given as well, to represent more flexible clearance limits. The taxi clearance can be limited to each circle on the route. In case a hold is planned at such a point, the circle is displayed in blue (cf. Fig. 4, Fig. 6)</td><td>

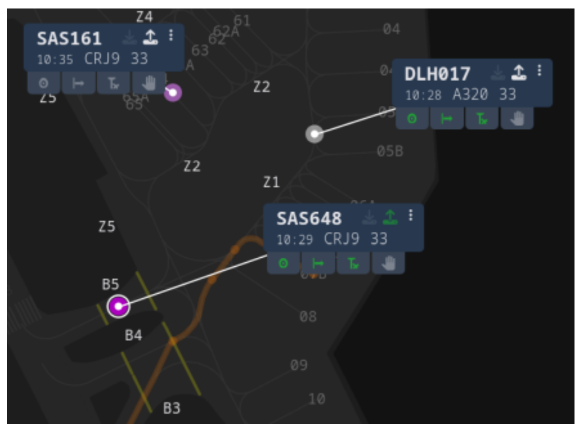
Fig. 4. Clearances displayed in the user interface for a departure (blue label) and an arrival (purple label). The cleared route is displayed in orange for the selected flight DLH1M.</td></tr>
<tr><td>Action imminent</td><td>Before the AutoTraMICS sends commands to the pilots, a colored ring is displayed around the position marker of the flight. Fig. 5 shows some examples for this. Flight SAS648 has a dark purple ring, which means the system will soon send a movement command. The flight SAS161 has a light purple ring, which means the start up command will be sent. Flight DLH017 has no color, which means no command will be sent in the near future. The rings can also have a blue color, which means the flight should stop moving in the near future. The color of the ring is given 30 seconds before the command is sent. At the beginning of that time window, the color is displayed more transparently and becomes opaquer the closer the command comes. Directly before the command is sent, a white ring is added on the outside to make it even more distinguishable (see SAS648 in Fig. 5). The rings are removed as soon as the flights start to follow the command, i.e. when they start or stop moving or when the start up command is sent.</td><td>

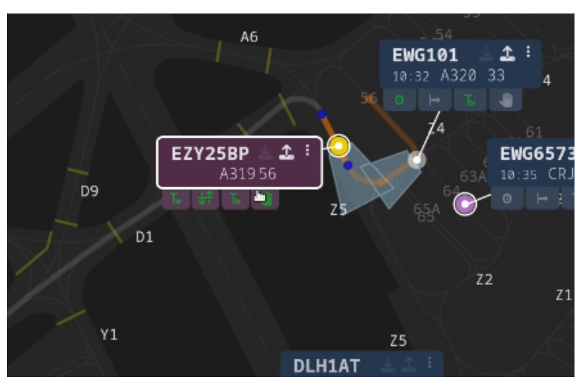
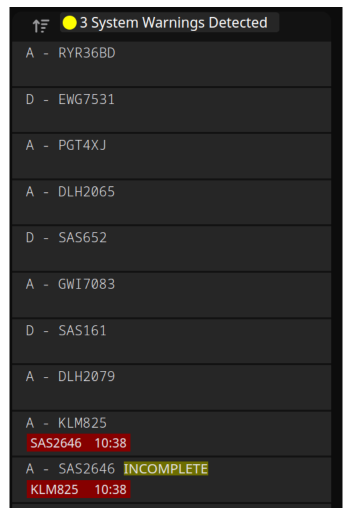
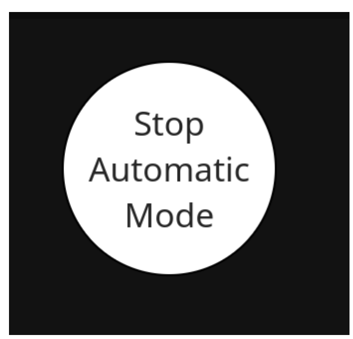
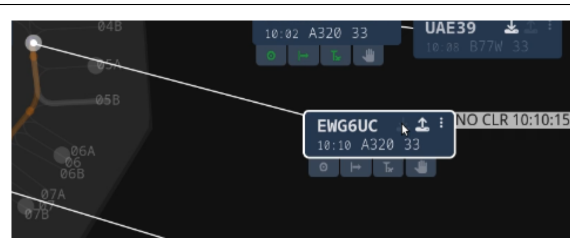
Fig. 5. Different markers for imminent actions of the system. The AutoTraMICS will soon send a movement command for flight SAS648 and a start up command for flight SAS161.</td></tr>
<tr><td>Hold enforced</td><td>In case the system monitoring detects an unresolved conflict in the near future, one or both affected flights are stopped to prevent a safety risk. To display that, hold position (hand symbol) is set to green in the label. Additionally, the ring around the position marker of the flight is colored yellow (see Fig. 6). Yellow was chosen since it is commonly used as warning color and should therefore draw the attention of the controller to the affected aircraft.
Hold position can also be issued manually by the ATCO by clicking the hold position symbol in the label. When such a hold is given automatically to prevent a conflict, it is also automatically removed when the conflict is resolved. When the hold is given manually, it can never be removed automatically by the system and needs to be removed manually instead.
Fig. 6 also shows that conflict cones are displayed when two flights move too close towards each other. The shape and size of these cones is based on the current taxi direction and speed of the flights. This should help to catch the attention of the ATCO and to better assess the severity of the situation.</td><td>

Fig. 6. A hold position command was given to flight EZY25BP, because a conflict was detected with the Flight EWG101 in the near future. Conflict cones are displayed based on the movement of the flights.</td></tr>
</table>

Route changed	The AutoTraMICS might change planned or even already cleared routes of a flight to either avoid a possible conflict, or when the conformance monitoring detects, that a flight deviates from the planned or cleared route. In either case the system informs the human about the route change by coloring the ring around the position marker orange. Additionally, two buttons appear at the top of the label to accept or reject the route change. In case the system runs automatically, the route change is accepted after ten seconds by default. When the ATCO selects the aircraft while the system is showing the route change information, the cleared section of the old route is displayed additionally to the newly proposed route. The old cleared route is displayed in a transparent yellow and the newly proposed route in orange, as usual. This can be seen in Fig. 7, where the flight was originally cleared via the southern taxiway G but took the northern taxiway D1 and the system proposed a new route via D1.	 Fig. 7. The AutoTraMICS proposed a route change due to a deviation from the cleared route. The previously cleared route is marked in yellow.
System monitoring state	The system monitoring state, described in section III-B, is displayed in a column on the right of the display. At the top of the column, the global system state is displayed with a traffic light encoding and the total number of detected problems. Below, a strip is shown for each active (i.e. in the scope of the trajectory planning) flight in the system. Whenever the planning has a problem with a specific flight, this is displayed in the related strip. In the example (Fig. 8), there is an unresolved conflict in the planning between flights KLM825 and SAS2646 that would occur at 10:38 (current time is not visible in this image section, it is 10:36) and furthermore, the route of flight SAS2646 is incomplete. The flight specific problems also have a background color, fitting to their severity. The conflict alerts in the example have a high severity and are therefore colored red. The incomplete route alert is colored green due to its low severity. The global system monitoring state is yellow in this example, since the conflicts have a high severity and a close monitoring of these alerts is encouraged. The system still expects to be able to resolve the occurred problems safely without intervention of the human and did therefore not yet enter the red state.	 Fig. 8. The system monitoring state display. The global state is yellow in this example and three flight specific problems are shown.
Automation button	When the system is running automatically, the ATCO has the ability to stop the automation at any time and change to the manual mode of the system. This way the ATCO can take back full control in case the system seems to have critical problems or the ATCO does not trust it for some reason. Since this button might especially be important in emergency situations, it was vital to make it as visible as possible and at the same time it should not be too distracting. Therefore, a large button with high contrast to the background was added to the top right that can be used to disable the automation mode (see Fig. 9). When the automation mode is disabled, the button text changes to “Start Automatic Mode” and the button can be clicked again to leave the manual mode and re-enable the automation.	 Fig. 9. The button to stop the automation mode.
Conformance alerts	The conformance monitoring module informs the ATCO about non-conformant behavior of flights by displaying warnings next to aircraft labels. The most important warning types are NO CLR (flight moved without clearance, cf. Fig. 10) and ROUTE DEV (flight is deviating from its cleared route, cf. Fig. 7). The warnings are displayed in a white box, which is in high contrast to the background and the label colors. This was done deliberately to catch the attention of the controller faster. The warnings are automatically removed when the cause is obsolete.	 Fig. 10. A conformance monitoring alert is displayed for a flight pushing back without clearance.

IV. Discussion and Next Steps

Pre-validation tests have shown, that the system, implementing the automation concept, works well in the simulation environment. Human-in-the-loop validation experiments with air traffic controllers are scheduled in June 2024, where both the AutoTraMICS and TraMICS will be used. This will deliver feedback and deeper insights into the potential and problems of the system. However, the concern, that the automation will always need human supervision to stay safe and efficient in all situations is already raised. One reason is, that the algorithms of the AutoTraMICS are heuristic and non-deterministic and can therefore not guarantee optimal and conflict free solutions under all circumstances. As mentioned before, this role shift from control to supervision harbors the risk of a loss of SA of the ATCO. To mitigate these risks, the features described in TABLE II were added into the system. Furthermore, the usage of the high automation mode instead of the full automation mode should alleviate this risk somewhat: The human still has some tasks on which they need to concentrate and is thereby most properly kept in the loop.

Whether the developed enhancements for the user interface and the system monitoring module are sufficient to support the human ATCO in performing the new role reliable without a loss of SA, will be analyzed in the validation trials. Another aspect must be kept in mind: If the ATCOs use the automation 24/7, their skills decrease or even vanish without further day-to-day training. To evaluate if this problem exists in the AutoTraMICS, longer studies would be necessary to give the participants a chance to get more accustomed to the system and analyze the long-term effects on their skills.

Studies in other research areas have shown, that systems with a human-autonomy teaming (HAT) can not only outperform manually operated systems, but also fully automated systems, while at the same time reducing the loss of SA or skills [25]. A similar concept might also be advantageous for ground air traffic management. Such a partly use of automation may be an improved solution to cope with the potential lack of ATCO personnel as well as maintaining the training level and the SA of ATCOs. The validation experiments will also provide a first impression answering the question how tasks could be shared between the human ATCO and the system for such a HAT. This will indicate the direction of further work, where the concept and the adaption of the AutoTraMICS system for an efficient human-autonomy teaming will be targeted.

References

[1] EUROCONTROL, "Eurocontrol forecast update 2023-2029." [Online]. Available: https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2023-2029

[2] DFS Deutsche Flugsicherung, "Luftverkehr in deutschland mobilitätsbericht 2022." [Online]. Available: https://www.dfs.de/homepage/de/medien/publikationen/mobilitaetsbericht2022-internet.pdf?cid=igf

[3] IFATCA, "Staff shortage survey – eur region." [Online]. Available: https://ifatca.org/staff-shortage-survey-eur-region/

[4] SESAR Joint Undertaking, *European ATM master plan: Digitalising Europe's aviation infrastructure : executive view : 2020 edition*, 2020th ed. Luxembourg: Publications Office of the European Union, 2020.

[5] M. R. Endsley, "From here to autonomy," *Human factors*, vol. 59, no. 1, pp. 5–27, 2017.

[6] N. Hasevoets and P. Conroy, "Aman implementation guidelines." EUROCONTROL. Brussels, Belgium, 2010.

[7] D. Böhme, "Tactical departure management with the eurocontrol/dlr dman." 6. FAA/Eurocontrol ATM RD Seminar. Baltimore, USA, 2005.

[8] B. Lorenz and M. Biella, "Evaluation of onboard taxi guidance support on pilot performance in airport surface navigation." Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting, 2006, pp. 111–115.

[9] I. Gerdes and M. Schaper, "Management of time based taxi trajectories coupling departure and surface management systems," in *Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015)*, 2015.

[10] I. Gerdes, M. Jameel, R. Hunger, L. Christoffels, and H. Gürlük, "The automation evolves: Concept for a highly automated controller working position," in *33nd Congress of the International Council of the Aeronautical Sciences, ICAS 2022*. ICAS, 2022.

[11] EUROCONTROL, "Argos factsheet: Muac's next-generation atc system – atc real ground-breaking operational system (argos)," 13.03.2023. [Online]. Available: https://www.eurocontrol.int/publication/argos-factsheet

[12] A. Svensson, J. Lundberg, C. Forsell, and N. Rönnberg, "Automation, teamwork, and the feared loss of safety: Air traffic controllers' experiences and expectations on current and future atm systems," in *Proceedings of the 32nd European Conference on Cognitive Ergonomics*, ser. ECCE '21. New York, NY, USA: Association for Computing Machinery, 2021.

[13] E. Batuwangala, T. Kistan, A. Gardi, and R. Sabatini, "Certification challenges for next-generation avionics and air traffic management systems," *IEEE Aerospace and Electronic Systems Magazine*, vol. 33, no. 9, pp. 44–53, 2018.

[14] L. Nöhren, M. Schaper, L. Tyburzy, and K. Muth, "Real-time calculation and adaption of conflict-free aircraft ground trajectories," in *33rd Congress of the International Council of the Aeronautical Sciences, ICAS 2022*, 2022.

[15] SESAR Joint Undertaking, *Automation in air traffic management: Long-term vision and initial research roadmap : summary report*. Luxembourg: Publications Office of the European Union, 2020.

[16] M. Vagia, A. A. Transeth, and S. A. Fjerdingen, "A literature review on the levels of automation during the years. what are the different taxonomies that have been proposed?" *Applied Ergonomics*, vol. 53, pp. 190–202, 2016.

[17] J. ten Have, "The development of the nlr atc research simulator (narsim): Design philosophy and potential for atm research," *Simulation Practice and Theory*, vol. 1, no. 1, pp. 31–39, 1993.

[18] DLR, "Apron and tower-simulator (ats)." [Online]. Available: https://www.dlr.de/de/forschung-und-transfer/forschungsinfrastruktur/grossforschungsanlagen/apron-and-tower-simulator

[19] S. Badrinath, H. Balakrishnan, E. Joback, and T. G. Reynolds, "Impact of off-block time uncertainty on the control of airport surface operations," *Transportation Science*, vol. 54, no. 4, pp. 920–943, 2020.

[20] *Global Operational Data Link (GOLD) Manual*. INTERNATIONAL CIVIL AVIATION ORGANIZATION, 2016.

[21] Y. Ning, S. He, Z. Wu, C. Xing, and L.-J. Zhang, "A review of deep learning based speech synthesis," *Applied Sciences*, vol. 9, no. 19, 2019.

[22] S. van Oosterom, M. Mitici, and J. Hoekstra, "Dispatching a fleet of electric towing vehicles for aircraft taxiing with conflict avoidance and efficient battery charging," *Transportation Research Part C: Emerging Technologies*, vol. 147, p. 103995, 2023.

[23] L. Tyburzy, M. Schaper, L. Nöhren, and K. Muth, "Greener conflict-free taxi trajectories using genetic algorithms," in *DEUTSCHER LUFT- UND RAUMFAHRTKONGRESS 2023*. Deutsche Gesellschaft für Luft- und Raumfahrt - Lilienthal-Oberth e.V., Bonn, November 2023.

[24] M. Schaper, O. Gluchshenko, K. Muth, L. Tyburzy, M. Rusko, and M. Trnka, "The traffic management intrusion and compliance system as security situation assessment system at an air traffic controller's working position," in *31st European Safety and Reliability Conference, ESREL 2021*, 2021, pp. 2825–2831.

[25] R. J. Shively, J. Lachter, S. L. Brandt, M. Matessa, V. Battiste, and W. W. Johnson, "Why human-autonomy teaming?" in *Advances in Neuroergonomics and Cognitive Engineering*, C. Baldwin, Ed. Cham: Springer International Publishing, 2018, pp. 3–11.