Digital Tower Assistant Functionality and Design

Planning, Analysis and Operative Interfaces based on Workshops with ATCOs

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***Abstract*—*Multi Remote Tower Operations* (MRTO), where one ATCO has the responsibility of two airports simultaneously, have become an important means to reduce the cost for air traffic control at small regional airports in Sweden without sacrificing safety or service levels. A challenge in MRTO is to keep normal movements operational on an airport while there is busy traffic on the second airport handled by the same ATCO. Earlier work has described the potential of using a *digital tower assistant* (DiTA), an automation that handles the communication and monitoring of e.g. a single, simple approach and landing on an airport with an otherwise empty sky, while the ATCO needs to focus their attention on the other airport. In this paper we let two interaction designers analyse the interview material from a recent study with five experienced ATCOs, each performing two scenarios using DiTA, and present the conclusions made from an interaction design perspective.**

***Keywords*—Remote Tower Centre; Automation; Interaction Design; Reskilling; Air Traffic Control; Multi Remote Tower Operations**

I. Introduction

A significant part of the cost of air traffic in sparsely trafficked regions covers the air traffic control at and around the small airports. This is an important factor to reverse the ongoing closing of smaller airport, something that can be devastating for a remote and sparsely populated area. In an ongoing effort to reduce this cost while maintaining both safety and service levels several steps have been taken; first the introduction of *remote tower centre*, RTC, for smaller airports and, as a continuation on this route, the *multi remote tower operations*, MRTO, two airports being handled by a single air traffic control officer, ATCO.

As long as there, at any specific time, is traffic only on either airport handled by this single ATCO, it is expected that the concept of MRTO works with little effort (see e.g. [1]). The only additional cognitive load in this situation stems from the fact that there are two of each display and control — the ATCO has to keep track on which environment that applies for each aircraft and situation. Further challenges appear, however, when there is traffic on both airports. The ATCO needs to build situation awareness, both by monitoring instruments and displays, making annotations (for future reference or to use by automation), communicate aspects of the situation to others for their situation awareness. This is thus a process that is situated both in the context of the work environment, as a medium for situation awareness aspects, and a process that is situated in a system of other agents [2]. Further, the activities must be possible to carry out in a temporal flow, where the information also needs to be aligned between perceptions, decisions, and actions, to manage cognitive load [2]. Within this, the ATCOs need to gain an operative concept that works for them [1]. Further, when the ATCO is occupied with complex traffic patterns at the one airport a minimum of traffic can be handled at the other airport, for safety reasons, e.g. incoming traffic can be instructed to hold until the traffic situation on the first airport has cleared up. This can happen during workload peaks, which can be hard to predict perfectly. A solution concept with potential for this type of situation is *DiTA*, a *Digital Tower Assistant*, an automation to handle the relatively simple landing or takeoff procedure on one airport while the ATCO is concerned with the more complex traffic situation on the other airport. The DiTA concept has earlier been described and discussed in other publications [3].

We have earlier reported on a study on DiTA and on the analysis of included interviews with ATCOs. In this paper we instead discuss the results from an interaction design perspective, and present a qualitative analysis of the results together with a DiTA human-computer interaction concept based on this analysis. Even though the resulting concept is far from validated and not even a complete and final design, we believe that it provides an important discussion point for the ongoing work on automated systems in air traffic control.

II. DiTA Concept of Operation

The underlying needs that define the prerequisites for DiTA stem from the situation for *multi remote tower operations* (MRTO). Already in an RTC the out-of-window view is replaced by an *optical sensor presentation* (OSP), also called *visual presentation area*, showing a 360° video feed from the remote location. In MRTO the OSP is split in two, each half showing the feed captured at one of the two airports, as well as two sets of digital flight strips, vehicle follow up, radar screen and airport system interaction, see figure 1. Some features, however, can potentially be shared between the two airports, to reduce the risk for confusion leading to human errors, such as using similar or identical routines at the two airports and coupling the radio channels. Because of these double interfaces, the separation of data between the sets of traffic, actively managing flights at the two sites involves

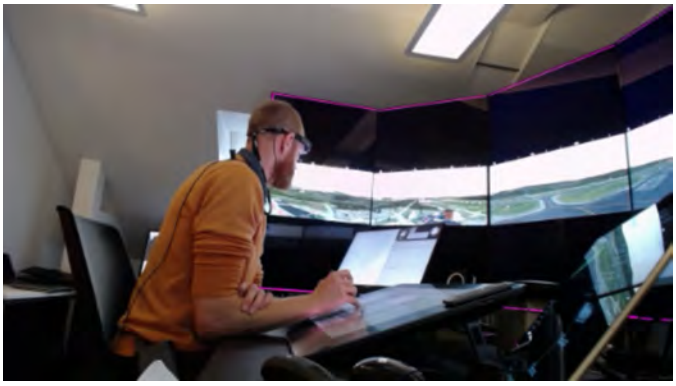

Figure 1. The MRTO simulator environment consisting of one large display, with optical sensor presentation (OSP) split to show the 360° camera feed from both airports, one radar display for each airport to the left and right of the ATCO, respectively, and a split digital flight strip display in between. Here the right radar display has been replaced by our DiTA display. Also, only one OSP presentation, indicated by a purple border, is visible in the photo due to its angle.

context switches, potentially increasing cognitive load as well as sense of stress for the ATCO. As a result, when the ATCO is occupied with non-trivial traffic patterns over the left side airport, they may for good reason be reluctant to accept even a straightforward landing procedure over the right hand airport. For an airport situated in airspace class C, as is the case with the airport used in our study described below, the ATC service is required, leaving e.g. incoming traffic on hold until the traffic situation over the first airport has cleared up.

To alleviate such cross site effects the concept of a digital tower assistant, or DiTA, was introduced [3], [4]. The ATCO will keep both control and responsibility and just use DiTA as a means to communicate routinely, expected and approved clearances to the pilot, at the correct times even if the ATCO is preoccupied with the other traffic. With that in mind, DiTA is meant to operate autonomously based on the instructions given by ATCO but with full transparency for the ATCO to monitor and verify its actions and plans. For example, if an unexpected situation arise, the system would detect this by using sensor data and subsequently make a decision for continuation until the ATCO is available again. It therefore visualizes (see below) both its plan and the actions within this plan (clearances). DiTA will off-load the ATCO by issuing expected clearances within a predefined arrival or departure plan, at the right moment even if the ATCO is busy at that time. The idea is that off-loading the ATCO from having to perform both the monitoring and execution of plan adherence and the verbal communications in turn off-loads low-level human work thereby increasing their focus on high-level human work, i.e. the tactical decisions.

The DiTA also includes predefined contingency plans for normal deviations, such as having to go into a holding pattern before arriving at the airport (e.g. due to some runway-not-clear condition) or to manage a go-around and placing the aircraft in a holding pattern. All automated monitoring of the flight process DiTA performs will be displayed on-screen to keep the ATCO up to date with DiTA's current actions and intent.

III. DiTA Experimentation Interface

To explore the concept of DiTA, we designed an experimentation software based on the *Wizard of Oz* concept, i.e. an interface for the ATCO to work against but with an back-end automation simulated by being controlled by a human test supervisor. This interface was iteratively designed together with selected ATCOs who would *not* be involved in the final user studies.

A. UTM City Platform

Our experimental DiTA interface is built on top of a simulation platform for drone traffic and drone management (see e.g. [5]), *UTM City*. This system was built as a platform for research on drone traffic planning, management and control, and on visualization and human-computer interaction. The core provides 3D map model visualization in a Cartesian coordinate system, selected based on simulated area, in this case SWEREF 99 1630 with RH2000 height definition (EPSG:5849). Its graphical interface provides 2.5D touch-based navigation and interaction, and a large menu system for fast and simple touch interaction, making it suitable prototyping platform for the MRTO environment. There is also a module for handling simulation of drone service and air space authority negotiation, and drone traffic planning and simulation, however this was deactivated for the study on DiTA. Instead, UTM City was modified to visualize the traffic simulated by an MRTO simulator, described further below.

B. DiTA Implementation and Visualization

The Wizard of Oz approach to the DiTA functionality, making decisions based on pilot communication and situation, means practically that keyboard input was used to trigger pre-set signals and events on the DiTA interface. Communication between DiTA and pilot was simulated to go via the text menu-based communication system *CPDLC*, however we do envision that voice synthesis and recognition could allow real-world DiTA systems to communicate also over voice.

The DiTA interface, see figure 2, was presented on a touch screen replacing the radar display on the right hand side of the setup, as shown in figure 1. The DiTA visualization includes information that could be useful for several purposes, firstly during operations to monitor and control DiTA, secondly for training to gain expertise in working with DiTA, and thirdly for preparing use of DiTA, in evaluating it and adjusting it before service in specific areas. This includes the vital step of building a mental model of DiTA, to understand its operational limits and abilities based on established rules and procedures. However, since it is much easier to ask what to take away than to ask people to imagine new things to add, we purposefully integrated all these in a single interface, with the purpose of dividing the information into these categories after the trials (as the results of the trials).

Figure 2. DiTA visualization and user interfaces during a live execution. The screen recording is overlayed with a camera view showing the ATCO's interaction with the interface.

The DiTA visualization consists of several areas (Figure 2). The main part of the DiTA screen consists of the main situation display, a radar image. When the flight arrives to the TMA sector of the airport the suggested approach path is presented here. At the top left a descent profile is also presented. Both these graphs present both the current position of the aircraft, as a purple dot, and the acceptable deviation entered into DiTA, as a green area, providing wiggle room without need for further action. In the yellow area, DiTA will automatically request the pilot that they return to the correct path, and if the flight fly even outside the yellow area, DiTA will attempt to place the aircraft in a holding pattern, and the ATCO will be notified. In our prototype, the horizontal path can be modified by the ATCO, including adding new route segments, e.g. to delay the aircraft by turning away from and then back to the original route. Further, the wiggle room can be edited by the ATCO, increasing or reducing margins. This interactive function was only tested for the horizontal route. The ATCO can also view the original, unmodified, standard route at any time. (This can also be done before engaging DiTA).

The interface also presents DiTA decision points on the approach path, shown as large red dots, where important decisions are made. These can be moved by the ATCO during the planning phase, to allow or force DiTA to make decisions earlier or later during the approach.

The sensor data used in the current decisions are presented in textual form to the left in the interface, see figure 2, at the same time as the associated decision and accompanying communication with the pilot are presented in the action and communication protocol at the top right corner.

IV. Concept Studies

The interface described above was installed in an MRTO simulator environment, for execution together with new ATCOs that had never seen or discussed the DiTA concept before.

A. *MRTO Simulator*

The MRTO simulator environment used in the study comprises a set of interactive displays set up in a manner reflecting the setup used in real MRTO environments. These are all connected to the SAAB MRTO simulation software running on a cluster in a separate room. The airplane pilots and other human operators involved in the simulation, such as ground vehicle drivers, are played by actors in an adjacent room, see figure 3.

The primary equipment provided in the simulator can be seen in figure 1: 1) one set of seven monitors in a half circle showing 360 camera views with possibility to zoom and slide the view, 2) two interactive radar displays, 3) one digital flight-strip display split in two sections presenting each airport, and 4) a communication module. In our setup the right radar display was replaced by the DiTA display. Also, the standard communication module was replaced with a conference systems for enable better control over the communication and audio between DiTA, pilot and ATCO.

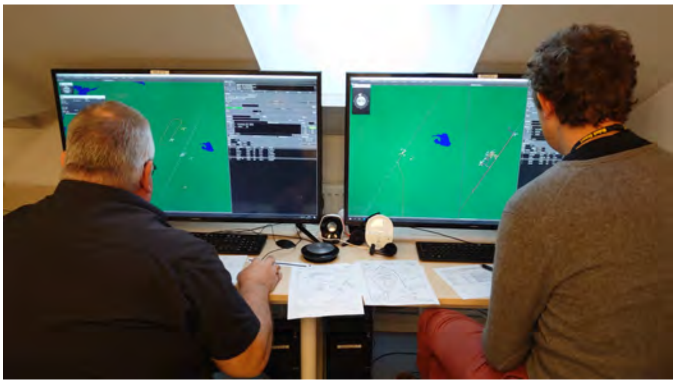

Figure 3. The actors playing airplane pilots and other human operators involved in the simulation.

B. Execution

For each subject the study followed the same procedure starting with an introduction to the project and the purpose of the study, and a session for learning the MRTO system and the DiTA interface. To facilitate for the efficient use of DiTA the introduction to DiTA interface features included a *reskilling* [6] procedure, a session during which the ATCO was presented with automation transparency information and visualization. The aim was for the ATCO to gain understanding of which data that are monitored by DiTA and which decision by DiTA that are affected by these data.

After this, the ATCO used DiTA to explore the plan for the incoming traffic, checking the pre-programmed DiTA procedure and conditions, also modifying the default route if they wanted to, setting their own margins. The ATCO was then asked to handle the first of two scenarios, which presents a normal landing handled by DiTA. This scenario contains an initial warm-up period with a slowly increasing situation at the second airport. At 9 minutes 4 seconds into the scenario the landing planned to be handled by DiTA appears, approaching the airport's TMA sector. At this point DiTA makes a signal ("plong" sound and an on-screen message) to indicate that the ATCO needs to either activate DiTA to handle the approach and landing or choose to (and hereafter) handle the pilot communication themselves. All ATCOs did choose to activate DiTA even though some of them needed several reminders (more and more frequent sound). After activation DiTA handles all pilot communication and display the related information for every communication with the pilot, both incoming messages and sent clearances and directions.

In the second scenario the same situation at the second airport was presented and initially the same approaching flight in-bound for landing. In this scenario, at the check before clearance for final approach, however, DiTA reports that sensors have detected something on the runway and that the flight is redirected to the predefined delay pattern. The ATCO was informed with both signal and message. The ATCO was free do disengage DiTA at any point during any scenario, but all ATCOs let DiTA handle the full approach up until final clearance to land.

Between the two scenarios a short debriefing took place where the ATCO could ventilate any immediate thoughts and answer a few short questions. After the final scenario a full interview with open ended questions took place. The concept discussion below is based on these interviews and observations during the experiments.

C. Subjects and Apparatus

Everything was recorded during the study, both system screens (including DiTA), camera capturing the ATCO and eye tracker data, as well as audio recording of debriefing interviews. The full experimental setting included participating controllers from both Sweden and Singapore. This study however focuses only on the qualitative evaluation, only on the Swedish side, a total of five experienced ATCOs over two and a half days. Also, eye tracking data was not analysed for this study.

V. DiTA Interaction Design Concept

Two different interaction designers have scrutinized the interview transcripts to identify important points related to the necessary design of a DiTA with respect to their functionalities and the interface to the ATCO. They worked individually and did not communicate until setting up the final concept, listed below, based on their common understanding of the stakeholders' needs.

A. Interaction Designer I

Several references to predictability and the ability to understand why a decision was taken makes it clear that ATCOs do not *want* creativity *behind the decisions taken by DiTA and they do* not *want it to solve any problem for them, just follow procedure and report back as it progresses. The two most important aspects seem to be* transparency *and* predictability. *Thus, the DiTA needs to be a preconfigured* Deterministic State Machine *or* Automata *and definitely not an AI, an* Artificial Intelligence*, as was simulated in the study.*

It was also clear that the ATCOs were uninterested in the many graphs and data points that were provided in the interface used in the study. At the same time, there were occasions when some checked a number here or there, or even in one case followed the full DiTA/pilot conversation to every point, even the pressure values reported. ATCOs are used to clean, concise displays and should thus be provided by the bare minimum as a default setting with the option for additional information about the current states.

The conclusion from this is that a graphical configuration concept is needed that lets the local authority configure approach and takeoff patterns into DiTA and let the ATCO adjust patterns, visualization details and allowed ranges of airplane velocity, altitude and other sensor values. This way a set of standard procedures can be defined, to be used when the weather and other conditions allow, at the discretion of the ATCO, see figure 5. As understood from the interviews, these conditions should lead to either of two things: continue as normal or abort the procedure, enter a holding pattern

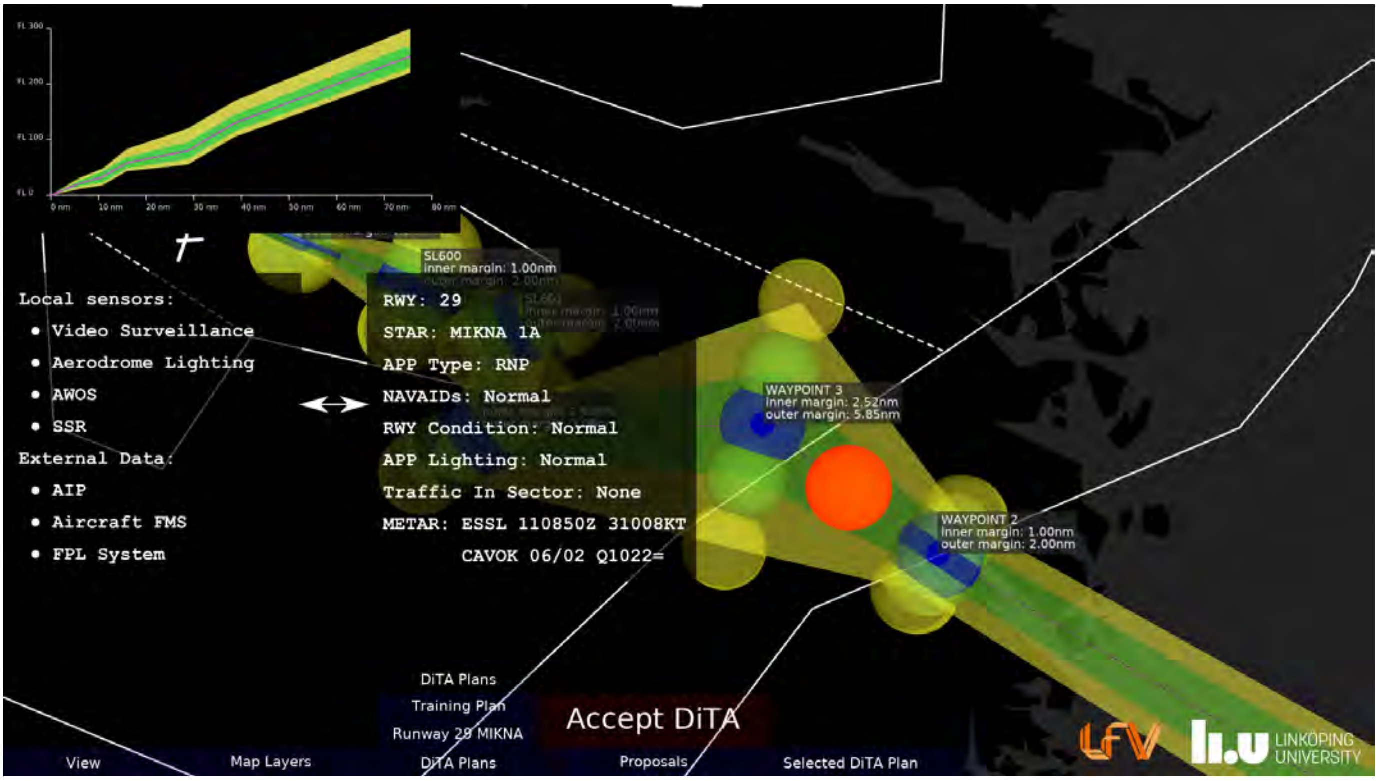

Figure 4. DiTA visualization in reskilling mode, showing more information that is needed for automation transparency. The ATCO is able to adjust the margins, move decision points and see the different data sources used.

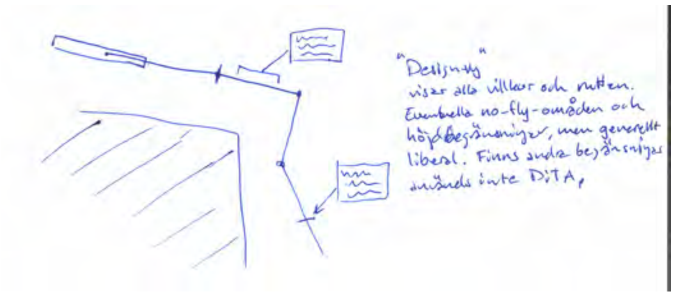

Figure 5. Designer view sketch of designer I: an interface should be provided for defining and modifying a set of standard approaches, each to consist of a set of waypoints and checkpoints with configured position, altitude, allowed sensor range, communication messages, etc. The approach definition to use is selected by the ATCO when planning for the incoming or outgoing traffic. Translation of the Swedish text on the sketch, from top to bottom: "'The Design View' shows all conditions and the route. Possible no-fly areas and height restrictions, but generally liberal. If there are other restrictions, DiTA will not be used."

and hand over control from DiTA to the ATCO. The interface should support adding waypoints and checkpoints and for each such point provide the specification of sensor value ranges to allow and sensor values to present to the ATCO, as well as defining communication messages to send to the pilot and which communication messages to expect during each leg.

During the operational use the ATCO just need to activate the previously selected procedure of choice, or an alternative predefined procedure due to changes in the weather or other conditions. The approach and the position of the waypoints and points for decisions should be presented in an integrated manner on the radar display, see figure 6. Since the ATCO already during planning has set the conditions used by DiTA to approve each step, these conditions and results can be presented during the approach, at a preconfigured level of detail. All subjects expressed a need to follow the progress, some expressed a need for larger display and one suggested to move the presentation of progress to the visual presentation. *Thus, a chat-like progress presentation should be provided in the larger OSP display, showing both the latest and historical decisions and actions, but with highlight on the latest entry. A sound for each new entry was a good thing and should be kept in future designs, however possibly complemented with a visual indication since some of the subjects expressed that it was sometimes hard to hear the sound while communicating with pilots on the other airport.*

B. Interaction Designer II

It was clear that the operative DiTA cannot contain any reskilling information at all during busy multiple remote tower operations. In such situations, it needs to be reduced to the minimal requirements for operation, thus the margins and interactive features (alterations of routes, points) all need to be hidden. Whether reskilling interfaces can be used during low-density traffic or should be reserved for training remains to be evaluated. The interactive design features must be used in a preparation phase, building all the routes and procedures

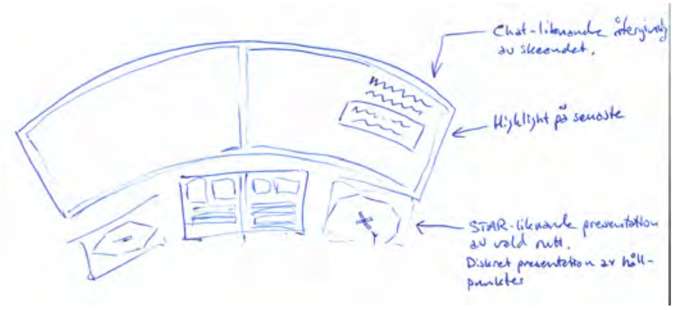

Figure 6. Run time view sketch of designer I: the process of DiTA is shown on the OSP display, highlighting the latest message, and the selected approach route is shown on the radar display, including the points of decision. Translation of the Swedish text on the sketch, from top to bottom: “Chat like presentation of the procedure”, “Highlight on the latest”, “STAR-like presentation of selected route”, and “Unobtrusive presentation of waypoints”.

for DiTA. Further, the clearance list was useful for ATCOs to stay in the loop — even more important perhaps than the actual aircraft position. However, after having built confidence in DiTA it is less clear how salient and central to the interface these clearances must be; how much they must be monitored. It also seemed, although this is a question for future research, that different ATCOs used the displays differently during the tests.

C. Final Concept

The final concept for DiTA that emerged is a procedure assistant, a deterministic state machine. DiTA should off-load the ATCO by carrying out a pre-defined plan, according to existing procedures that are known for the pilot and ATCO. It should be carrying out the plan by monitoring adherence to the plan, and by issuing pre-defined clearances (e.g. by voice or electronic communication). These clearances should be visible to the ATCO on the interface for monitoring, as well as audible. This off-loads the ATCO in two ways. Firstly, the verbal channel is a bottleneck, since when the ATCO is talking to one aircraft, they cannot talk with another one (including the read-backs). Secondly, the automatic monitoring means that the ATCO can follow that this particular aircraft is doing what it should. A critical part of the design is the automated standard contingency plans. In our example procedure, this means that DiTA can place the aircraft in holding when a pre-defined situation occurs. This gives the ATCO some temporal wiggle room — the ATCO does not have to immediately attend to the situation. Further, DiTA can also automatically resume the aircraft for another approach attempt if the standard contingency is temporary/fleeting, such as runway not clear, or a missed approach.

In a first preparation phase, a DiTA procedure designer prepares all the route segments that are to be used by DiTA in an airport, according to AIP information for that airport. This designer simulates and tests the procedures, margins, decision points, DiTA data sources, clearances, and standard contingency procedures (e.g. holding pattern procedures). In a second, familiarization or reskilling phase, the controllers may learn to use DiTA and navigate an extended set of standard visualizations, explicitly indicating the configuration such as data sources, expected levels, configured margins, and expected and enacted communication. In a third, operative phase, the sources and margins are hidden, and DiTA shows only minimal information: routes, decision points and clearances. Whether the reskilling interface should be an option during operations requires further analysis of the data and possibly also further experimentation.

In the experiment, DiTA was presented on a separate screen. In the final concept, it is to be integrated into other parts of the screens. DiTA can in a conventional tower environment be integrated in the radar presentation as a secondary display area on the main radar display area. In an digital tower environment there is an additional option and that is by using the visual presentation area as augmented information and interaction by using picture in picture technique.

VI. Discussion

The DiTA concept as desired by participants, comprising a library of standardized procedures as a selection basis, could take inspiration from the Playbook approach proposed by Miller and colleagues [7], [8] as an flexible human-automation delegation architecture originally applied to contexts where human operators achieve missions with unmanned aerial vehicles (UAVs). To accomplish a mission (e.g., land an aircraft), the human operator can choose from a library of ´plays´ (e.g. procedures) how the automated agent (e.g., aircraft) should behave in terms of goals to be achieved and task to be executed.

Future studies could extend the study of the DiTA concept to other flight phases, including standard departures, enroute and ground movements. It could also test the different ways of integrating DiTA into other screens. Finally a small but important aspect is the naming. If it includes the word ”assistant” then it might be suggestive of more human-like capabilities than it has in this concept, a concern that has been voiced recently regarding AI [9]. Future studies could explore whether such naming actually has these undesirable side-effects, and whether the reskilling interfaces (that should facilitate the building of correct mental models) can counter such misconceptions and problems with the implementation process into operations (change management).

Moreover, regarding the operative concept, further studies should address how much workload and task load the monitoring of DiTA incurs, including both the process of building situation awareness of the airport situation, DiTA progress and status, and the status of the flight that is being monitored. For instance, using approaches such as in [10] to explore the temporal decision-making and in [2] to examine work with situation awareness. Finally, this study has included only one aircraft being guided by DiTA at one airport. Further studies should include new designs that can incorporate information regarding DiTA for more airplanes at more airports.

VII. Conclusions

In this paper we have explored the DiTA concept from a design perspective, in particular the DiTA concept used in a study conducted with five experienced ATCOs, focusing on the specific details that worked well in the prototype and what should be changed in a final implementation and deployment. We can conclude that the following was made clear by the ATCOs involved in this study: 1) DiTA should be a procedure execution assistance tool, removing the need for much of the manual low-level work (clearances, monitoring of route adherence), for standard procedures, and 2) a two-stage use of DiTA seems promising, with an explore/design/planning phase separate from the execution phase. ATCOs may be experienced but still have little experience with automation and may in those cases need reskilling exercises, however it was made very clear that ATCOs want most of the rich information hidden during operation, leaving only the essentials on display. Also, in following the literature, we see no need to call the DiTA an "assistant" when in use. Indeed this might suggest human-like capabilities, and creativity is not wanted.

When it comes to the use of deep learning and pattern recognition, that might be useful in a next stage, to further increase efficiency in predicting deviations or in the preparation stage. However, for the core concept, to get started with DiTA, a simple procedure assistance tool set seems to be more promising.

Acknowledgements

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