MAMMI Phase 3 - Exploring collaborative workspaces for air traffic controllers in the scope of SESAR

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The MAMMI consortium is composed of IntuiLab (1), leading the project and in charge of the HMI design and prototyping, Intactile Design (2), in charge of the graphic design and information presentation, l'Ecole Nationale de l'Aviation Civile (ENAC) (3), in charge of the ATC expertise and end-users' involvement, and THALES Research and Technologies (4), in charge of the collaboration modeling and evaluation.

I. Introduction

THE MAMMI (Multi Actors Man Machine Interfaces) project explores new ways for the Air Traffic Controllers (ATCOs) to take advantage of collaborative environments to support their activity. It relies on the following principles:

1. Several ATCOs interacting collaboratively to control wide airspaces
2. Real-time tasks sharing and workload repartition
3. Lesser specialization of the ATCOs

The current phase of the MAMMI project focuses on the exploration of the possible collaborative activities in the scope of SESAR. As the operational practices and ATC concepts in SESAR are still evolving a lot, this work is based on assumptions presented below and does not provide experimental validation yet.

This paper presents the core issues regarding collaboration that have been identified in SESAR, based on previous work in MAMMI. It then exposes a series of concrete ATC scenarios in the SESAR context showing the stakes and possible directions in defining collaborative practices for future ATCOs. Finally, this paper presents possible solutions to provide collaborative workspaces supporting the different activities of the ATCOs, as exposed in the ATC scenarios.

II. Collaboration between ATCOs in the context of SESAR

The collaboration between ATCOs in SESAR will evolve compared to the one on existing systems. However, the stakes and issues around collaboration will remain, regarding:

- The control of airspaces involving more than one person,
- The communication with aircraft
- And the requirements on the dynamic organization capabilities.

This first section presents the fundamental collaboration issues known in En Route ATC and links them with the SESAR concepts.

A. Fundamental collaboration issues

The non-verbal communication has been shown to represent up to 50% of the whole communication acts in a highly cooperative activity such as En Route ATC [1]. Usually, non-verbal communication is done while seeing the co-worker and/or the shared environment. For example, physical co-presence enables co-workers to use multiple sorts of gestures (deictic, passing, utterance-like) that improve common understanding of the situation. Physical distance between co-workers may not weaken performances in a collaborative activity, but it leads them to engage in more demanding communication acts [2], thus requiring additional efforts in their activity. The additional work is done at the expense of the main activity, which may be problematic in a situation where work is complex and cognitive load is high. Furthermore, knowing that the other user knows as much as oneself makes the interpretation of the other's intentions easier, which in turns makes collaboration better [3,4]. Multimodal communication involving speech and co-located gestures is better at building mutual knowledge of sharing than speech alone [5].

Modern ATC systems are designed to propose features for specific roles such as *tactic* and *planner*. Each role uses specific individualized tools. And as these tools are massively digitalized and designed for one user at a time, they produce a *glass cockpit effect* [6], which does not support the natural need of the ATCOs to exchange information. On the other side, technologies used on modern Control Working Positions (CWPs) rely on the same approach as traditional desktop workstations with one main screen, one keyboard and one mouse per user. This choice has enabled the introduction of more sophisticated tools but few of them are able to support a collaborative use, especially when it is the most necessary, i.e. in high workload or unusual situations [6, 7] where controllers can be two or more on a given position. As teamwork was considered as a major asset of previous systems for both safety and efficiency, several questions are raised about these newer systems, which rely mainly on digitalized and individualized tools.

On the other hand, operational practices in the different control centres worldwide, and even in the same country are known to be heterogeneous, as stated for instance in [6]. This "centre culture", augmented by individualized practices of ATCOs, makes more complex the design of new systems and puts important requirements on Human Factor issues. Designing collaborative systems still increases these requirements because of the new "collaborative dimension" that has to be integrated globally and in the different features and tools. Even if several studies [8,9] extensively explored the cognitive mechanisms used by the ATCOs individually - thus showing how the ATCOs manage information, use their memory, and how their cognitive workload evolves individually- only few studies focused on the real-time collaboration between en route ATCOs.

The state of the art achieved previously in the MAMMI project reveals a large lack in the understanding of the operational practices on modern ATC systems. Only very few publications have addressed this issue since year 2000. However, this understanding is a mandatory step for the design and the deployment [10] of adapted CWPs, including collaborative aspects.

In the same way, modern tools for En Route ATCOs that focus on strategic ATC rather than tactic ATC, require more cooperation and organization between ATCOs. These strategic tools, like ERATO or URET, have an impact on the way the controllers work individually but also as team-mates, mainly because the strategic tools rely on different time scales and different information as tactic ones [6]. Flexibility seems to be the keyword to design and deploy such systems; both in the way they are designed and in the way they are used. The users can purely and simply reject too rigid systems.

The MAMMI project proposes to study the activity of the ATCOs under a new "collaborative" scope that is missing in most of the modern systems. It aims at answering the problems illustrated above and provide:

- More flexibility, suitable to the heterogeneity of the operational practices and the adoption of complex decision support tools.
- Better communication capabilities to reduce the part of the workload dedicated to collaborative activities by the ATCOs.
- New patterns to integrate existing and future tools around the tactic and strategic ways of controlling aircraft.
- A framework to progressively explore new organizations between ATCOs and thus provide new solutions to share tasks and workload, including more advanced tools and techniques.

B. *Previous results in MAMMI regarding collaboration*

Previous MAMMI results rely on an analysis presented in [7] of the collaboration between En Route ATCOs, on systems such as the French ODS, ERATO, URET and an early prototype of CPDLC.

This analysis raised key elements for the collaboration, showing the importance of the **flexibility of the organization** for the management of workflows between ATCOs, the access to tools and tasks sharing. The **shared and common use of ATC information** between ATCOS is also a key factor for the anticipation, the mutual and synchronized situation awareness [16], and the continuity for the monitoring of actions. [7] and [11] exposed the difficulties encountered on existing systems to **support unusual and high workload situations**. They concluded on the necessity to manage the quality of the information and the complexity and adaptability of the tools used by the ATCOs, in order to provide better collaboration capacities for all the activities of the ATCOs.

The task modeling achieved and presented in [12], contributes also to the understanding of the activities of the ATCOs and, more importantly, to link these activities with the collaborative capabilities of the existing and future systems. The collaboration models provide an adapted, system-independent, grid to observe separately the different activities of the ATCOs and thus to improve the collaborative capacities for each of them without adding complexity (through irrelevant synchronization issues, additional procedures, etc.). The fact that these activities are system independent is also important when introducing new concepts like it is the case with SESAR.

The high-level control activities identified in our analysis are the following:

- **Act1** - Organization of the ATC information and management of flights' lifecycle
- **Act2** - Analysis and resolution of problems
- **Act3** - Achievement and monitoring of actions
- **Act4** - Anticipation, preparation, sequencing and sharing of tasks

These four high-level activities are common to all the observed systems, including the French ODS, URET-based CWPs and older paper strip-based CWPs. They are still relevant in the scope of SESAR even if their nature will significantly evolve for the ATCOs, mainly due to the deep revision of the concept of *sector* and *tactic/planner teams*.

C. *Collaboration in SESAR*

The SESAR program is *the European Air Traffic Management modernization program* [17]. It plans a complete ATM reorganization for 2020 and further, at any levels (technical, human, regulations, etc.) in order to manage more safely an increase of 1.7 times the traffic of 2007.

The SESAR concepts include:

- A new collaborative decision making (CDM) process to define planning and aircraft trajectories (named in SESAR, Business Trajectory) between all actors (airlines, ATCOs, airport…),
- A new approach for trajectory management with "4D Business Trajectory" that should be more precise,
- New non verbal communication means (DataLink),
- More flexibility in airspace management,
- And new separation modes (sustained by more automation), including self-separation ensured by aircraft.

Based mainly on the SWIM (System Wide Information Management) network, the SESAR concept introduces real-time information sharing concept and a "user-centered" approach for future ATM.

In the SESAR work plan, the SWIM network shall contain all the information needed by all ATM partners. This information is necessarily shared, and requires being more precise and more dynamic than today: all ATM actors can update it at any time. This environment wants to shift from a *message exchange* paradigm to *information publishing/using/contributing* one [17]. Even the position of the aircraft on his planned 4D trajectory is updated in real-time by the flight itself in the network. This allows the ground actors and system to have a **common understanding of trajectory evolution** with the aircraft and to have more precise information for trajectory prediction thanks to the time's inclusion as a core element in trajectories.

On the other hand, the SESAR concept has a *service oriented* approach [17]. It aims at improving service quality for airspace users by minimizing the change on Business Trajectories and by reducing delays. The Reference Business Trajectories (RBT) of an aircraft is the Business Trajectory instantiated before the first ATC clearance is requested or issued [17]. RBT will be more restrictive for controllers than the actual flight plan and will become their principal object of work [17]. **Any modification of the RBT requires a collaborative work** between pilots and ATCOs to redefine it without creating new problems or delays, any time it is possible without compromising air traffic safety. Moreover, the **flexible use of airspace** recommended by SESAR will also imply a **flexible organization between ATCOs**: they should be able to change rapidly their airspace of responsibility and to potentially manage or monitor actions of or with other ATCOs, beyond a classic airspace segmentation.

ATCOs will have to work in collaboration with other human actors and they will also have to share some of their tasks with the system automates. To address the workload issues, SESAR in [18] introduces automation of routine and frequent tasks (such as co-ordination in and out, usual communications, etc.) combined with automated support to conflict detection, resolution and situation monitoring. If ATCOs must minimize RBT changes, aircraft have also to follow strictly their own trajectory. And with more traffic even if routine tasks have been reduced by automation, controllers will need help to detect non-RBT compliance of an aircraft or a conflict in their airspace. Thus **controllers will have to work in accordance with the system and act as *automation managers*** [17]. To do so, they will need to access information on what the system does, and how and why it acts like that in order to be able to tackle potential problems in case of system limitation or failure. They will also have to input data in the system to update SWIM information and to inform the system of unpredictable problems (such as incidents during a flight). The cross understanding and trust with the system becomes an important part of their work, as it is the case with pilots and other ATCOs.

With automation, CDM process during definition of trajectories and RBT minimum changes, traffic will be less complex because most of the problem will have been managed before take-offs. Thus **ATCOs remain in charge of mainly non-nominal, degraded or unexpected situations. Those situations have to be resolved in collaboration with other ATCOs, pilots, airlines, and the system itself.**

D. *Assumptions for MAMMI*

In order to define relevant scenarios based on SESAR in a 2020 environment, one need important details about the operational practices for the ATCOs, the different configurations of airspace, the available tools and technologies, etc. As all this information is not completely defined yet, some assumptions are necessary regarding these subjects.

First, the candidate ATC functions or tools for SESAR are defined in [17] and [19]. The focus of the tools is to provide assistance in areas in which the human mind is less cognizant, leaving the ATCO the time to concentrate on those areas in which the human excels. These tools include: Enhanced Medium Term Conflict Detection (MTCD), Conflict Resolution Advice (CORA), Trajectory Editor, Data Link and compliance monitoring tools [19]. Based on this, the following features have been held to be available for the ATCOs in the scope of MAMMI:

- Conflict detection (20 minutes ahead or more);
- Conflict analysis including 3D/4D and extrapolation;
- Suggestions and "what if" tools for conflict resolution;
- Clearances follow-up and RBT compliance check;
- Assistance/automation for frequencies allocation;
- Information sharing (common views) with aircraft;
- Support for non-vocal communication and **real-time** information sharing;

These tools are the ones that support the activity of the Air Traffic controllers in the scenarios presented below. Even if it is not in the scope of MAMMI to invent these tools, some figurations about the form they might take are illustrated in the MAMMI environment.

In parallel, some assumptions regarding the SESAR concepts and technologies have been done. The use of the Reference Business Trajectories (RBTs) leads to a less complex traffic. However, ATCOs should still have to manage mainly :

- Unresolved conflicts,
- Non-adherence to RBT,
- Meteorological issues,
- Incidents during flight.

Finally, in a 2020 perspective, all aircraft should be completely equipped with ADS/B in/out and 4D capabilities. The exit of an airspace area should be 4D-constrained and thus automatically coordinated with other airspaces. The system should propose ways to catch the RBT back or to renegotiate it with the aircraft and/or the company. And the system should be able to show all the conflicts, RBT deviations and meteorological data.

III. Principles, Roles and Scenarios for MAMMI in SESAR

A. *The MAMMI ATCOs in SESAR*

[20] defines for SESAR concept two roles in the En Route ATC: the Multi or Meta Sector Planner (MSP) and the Tactical Controller (TC). The **MSP** works strategically on the traffic, nearly 20 minutes ahead of schedule. He/she tries to solve problems at early stage and to make the traffic as smooth as possible. The primary goal [of MSP] is not to attain specific spacing but to simplify the streams of traffic within a sector or multi-sector [20]. He/she prepares the work for a team of Tactical Controllers on the same airspace and by this way,

manages their workloads. The **TC** is in contact with the aircraft in his subpart of the considered airspace and is the ultimate ATC actor in charge of the safety. He/she manages all the problems that could not be solved by the MSP.

The MAMMI project brings some propositions of evolution to the definition of these roles, in order to introduce new collaboration concepts and innovative organization patterns. The main evolution focuses on the dynamic repartition of the activities between the ATCOs, and in the communication capabilities between these ATCOs and pilots of aircraft. The MAMMI roles rely on the following definitions:

- The **Dispatcher** monitors the traffic in a given airspace. When a problem occurs, he is notified by the system and can try to solve it directly or to delegate it to an Expert. The Dispatcher distributes/delegates and follows the work between all the Experts. He/she is also able to delegate problems to the aircraft themselves. The Dispatcher is in charge of managing the workload for himself and the Experts. The Dispatcher has a global awareness of the problems and their resolution in his/her airspace.
- The **Expert** is in charge of a series of problems from their assignation by the Dispatcher to their actual resolution (including the follow-up). Depending on the workload and situations, Experts can share a working position with the Dispatcher or have their own environment (mobile or not).

B. Scenarios and concepts

Based on these roles and on the SESAR concepts mentioned earlier, the MAMMI project has defined four scenarios involving collaborative activities between En Route ATCOs in a 2020 perspective.

1) Non-RBT compliance

This scenario is focused on the activity of a Dispatcher, monitoring an airspace and the pilot of aircraft BAW1234. The activity takes place in an En Route airspace in which the route of BAW1234 shows a discrepancy compared to its planned RBT. The problem faced by the dispatcher is the identification of the cause of this discrepancy and then, the setup of the appropriate corrective measures.

The dispatcher monitors the situation in front of a number of screens. The system detects a deviation from the RBT for BAW1234 and notifies the dispatcher. The dispatcher quickly visualizes the deviation, analyses the situation and decides to clarify it by himself and not delegate it to an expert. He contacts BAW1234 through a dedicated communication channel and asks the pilots for information.

The pilot answers that the aircraft had to go away from an unexpected bad weather situation, creating heavy turbulences. The pilot and the dispatcher quickly devise a revision of the RBT to optimize the created delay and go back to a nominal situation.

2) En-Route conflict resolution

This scenario is focused on the activity of a Dispatcher, monitoring an airspace, several experts and the pilots of two aircraft BAW1234 and AZA5678.

The activity takes place in a En Route airspace in which two RBT “intersect”. The two aircraft, BAW1234 and AZA5678, are flying along their RBT as shown in Figure 1. As indicated in the figure, both aircraft are flying at (and have been cleared to) FL290. The problem faced by the dispatcher is the conflict between these two aircraft at the intersection of the two RBT. The conflict has been caused by a delay of BAW1234 due to bad weather conditions earlier on its route.

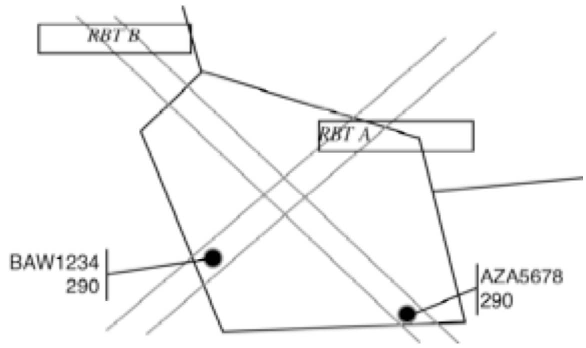

Figure 1: Intersecting RBT in an en-route airspace

The system detects a conflict that will occur in 20 minutes, and notifies it with an alarm. In order to filter out false problems, the dispatcher evaluates whether the conflict is a real problem. It seems to be a real one so he decides to handle it. He then chooses an expert to whom he will delegate the conflict resolution, based on current experts’ workload, previous delegations, and other context information (e.g. airways, airline, geographical zone, hazardous area involved etc.). All these information are displayed on the set of visualization he uses. The chosen expert acknowledges the delegation and notifies it to the dispatcher.

The expert interacts with the SESAR tools to explore the set of computed solutions optimized with respect to the RBTs. The expert chooses a particular one, and proposes it to the pilots. They use a multichannel link (audio, shared schematic view) to discuss the solution, and reach an agreement. Once agreed, SESAR automatically translates the strategy into RBT constraints, sent by data-link to automatic on-board and ground systems for execution. The expert monitors processing steps and specially the execution of the agreed solution. When execution of the new RBT is started, the dispatcher is notified that the problem is solved.

3) Pressure incident

This scenario is focused on the activity of a Dispatcher, monitoring the airspace, several experts and the pilots of two aircraft BAW1234 and AZA5678. This scenario illustrates a non-nominal situation, where an unexpected incident breaks the current RBTs. It describes the typical procedures to apply in order to maintain safety, and recover a nominal situation.

Two particular aircraft, BAW1234 and AZA5678, are flying along their RBTs. The two RBTs differ by their level:

BAW1234 is at FL290 and AZA5678 at FL 250. BAW1234 is experiencing a drop in cabin pressure and has to fly down to FL80. The problems faced by Air Traffic Management are the conflict between the two aircraft when BAW1234 crosses FL250 and the management of BAW1234 until its emergency landing.

The pilot of BAW1234 signals a drop of cabin pressure and warns the dispatcher. The pilot immediately proceeds to descend to FL80. The dispatcher first gives a heading clearance to AZA5678, so as to avoid a trajectory conflict. He then chooses an expert (then referred as emergency expert) to handle the situation. During this time, the airline is automatically warned about the incident.

Thus the dispatcher's tasks are to detect the incident, and delegate its resolution to an expert. The expert should handle the problem with highest priority, which means that she/he could be in charge of this problem only. The dispatcher role is to quantify the level of emergency of an incident, and delegate the resolution to the most appropriate expert. As all experts may be already in charge of other problems, a required task is to free the chosen expert from his current tasks, and deploy a strategy to distribute these tasks to other experts.

At first, both the dispatcher and the emergency expert monitor the hazardous aircraft progress in the same room, on the same working position. They devise the first steps of a possible strategy, and they choose together an emergency airport. Then, the expert handles alone the communication with the hazardous aircraft and the application of the strategy, while the dispatcher contacts an approach expert in charge of the airport procedures (alert of the firemen, handling of the passengers, etc.), and invites him to a real-time collaboration with the emergency expert. The two experts are then able to devise the complete strategy, and find out other impacted surrounding aircraft. The emergency expert then finds out new RBTs for the impacted aircraft, with possible discussions involving other impacted experts.

An alternative is that the experts or dispatchers monitoring other aircraft impacted by the incident see that the created conflicts are due to a pressure incident, which is a specific procedure. In this case, they leave the priority and responsibility to the emergency expert to solve the problems. This procedures can be supported by the system and also communicate the name of the airport to the airline, which is then able to run an action plan for the passengers.

When the hazardous aircraft has landed, the emergency expert notifies the dispatcher, who proceeds to reach a nominal situation.

4) *Storm problem resolution*

This scenario is focused on the activity of a Dispatcher, monitoring the airspace, several Experts, and pilots of aircraft in the airspace. It illustrates different kinds of collaboration between different agents in a situation of storm in the airspace. Multiple RBT deviations must be managed to make aircraft avoid the storm in a safe and efficient way.

The activity takes place in an En Route airspace, in which a storm is detected. Several aircraft can be impacted. The three aircraft, BAW1234, AZA5678 and AFR345, are flying along their RBT at FL 290 as shown in Figure 2. The problem faced by the dispatcher is to rapidly find the best way to make the three aircraft avoid the storm in a safe manner, without creating aircraft proximity.

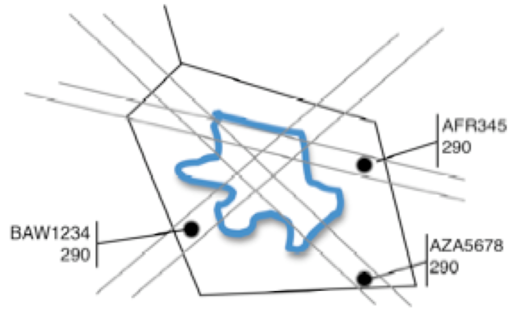

Figure 2: A storm in en-route airspace

The dispatcher monitors the situation in front of a number of screens. The system notifies a storm in the airspace, and detects three aircraft potentially impacted within 5 minutes: BAW1234, AZA5678 and AFR345, flying at the same flight level. The details of the alarm indicate the degree of emergency, i.e. actions that must be undertaken rapidly in the next five minutes.

First, the dispatcher sends a vocal and system message to the three aircraft, in order to prevent uncoordinated aircraft deviations and make them aware of the storm risk and collision risk if no coordination is done.
In the same time, the problem picture is automatically displayed on a dedicated screen, and the dispatcher designates two experts to deal with the problem with him around the screen, according to experts' workload information.
The two experts use what-if tools to "draw" 4D- trajectories on the problem picture. Once they agree on the solution, they open a video conference call with the three aircraft pilots to communicate the solution. In this scenario, the solution is non-negotiable by the pilots, because of time pressure.
Then, one expert is enough to monitor the execution of the solutions, directly on his/her usual working position. The second expert can go back to his/her original activities.

The storm can be detected in many different ways in SESAR: aircraft will be able to communicate this information, and meteorological data will be shared. This scenario could also apply for a protected area that is suddenly activated.

IV. DEFINITION OF A COLLABORATIVE WORKSPACE

The scenarios and activities described above require a collaborative environment in order to sustain all the requirements for communication, collaborative analysis, delegation and monitoring for the ATCOs. This collaborative environment cannot be provided only through isolated collaborative tools. It involves the structure of the CWPs and their interoperability in a given room, in order to adapt to various number of actors and situations.

A. Different collaborative situations

Beyond the individual tools used by each ATCO, MAMMI proposes to explore an actual collaborative workspace for the dispatcher and the experts to work together. This workspace could gather a set of interactive surfaces with different sizes and purposes:

- A **very large vertical screen** dedicated to the display of common or shared information. This screen can be interactive or not depending on the targeted collaboration opportunities
- A **large horizontal surface**, which is the main entry point for the Dispatcher
- A **set of small mobile interactive surfaces**, combined with static vertical screens (and possibly mouse and keyboard) for the experts

This workspace supports many possible configurations described by the scenarios.

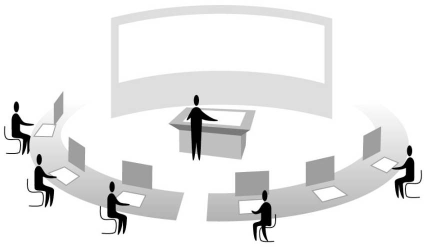

Figure 3: Dispatcher and experts in their workspace

In usual situations, the dispatcher is in front of his/her surface and the experts use their complete set of desk-like displays (Figure 3). The different workflows are then supported by the system and the communication is remote. Direct voice communication remains easy and the geographical proximity of the actors authorizes informal collaborations. The large vertical screen is seen by all the ATCOs and can be used to display information useful to all of them, such as weather in the airspace, saturated areas, traffic previsions for the next period, important notifications and information, etc.

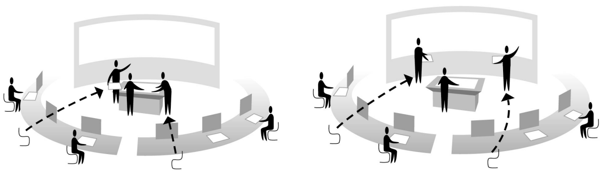

Figure 4: Different configurations for the workspace

In the case of the storm management, one or several experts can join the dispatcher for a common analysis (Figure 4.a) and be more reactive to solve short-term problems according to a shared strategy. The horizontal surface is then used as a global view of the situation, where all can make decisions, and where the dispatcher can delegate specific actions to the experts. And as the experts have their mobile surface, it enables them to achieve their actions without losing their direct communication capabilities and the global situation awareness.

In the case of a procedure management (e.g. pressure incident), the assigned expert has to communicate with a large number of actors (main aircraft, emergency airport, impacted aircraft and ATCOs) and has to monitor a large amount of information. In this case he/she may want to use a part of the very large vertical display to manage some information that can be shared also with the dispatcher (Figure 4.b), or with another expert coming in support. This large vertical display, if interactive, may enable to provide assistance to manage the procedure by presenting checklists, relevant information (about the emergency airport for instance) or communication support.

It is also possible for to experts to work in front of the same desk as teammates, reproducing the situations studied in previous phases of MAMMI.

B. Key activities in this collaborative context

Key activities have been extracted from the scenarios above. They provide a structured approach for the different activities of the **dispatcher** and **expert** ATCOs. The HMI solutions for these activities are also presented below.

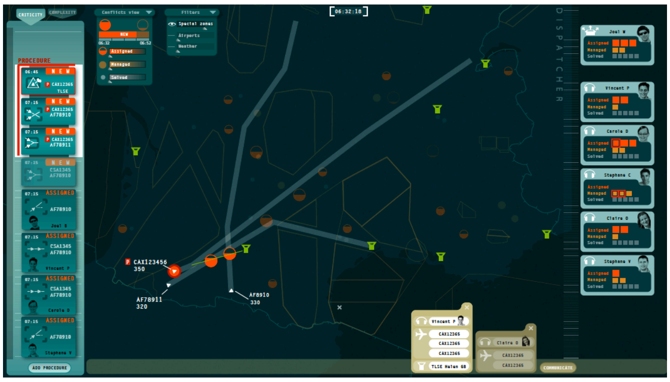

Figure 5: Global view of the dispatcher surface

1) Evaluate

The evaluation consists in a quick analysis of one or several problems (mainly by the dispatcher). It is relevant every time a new problem is brought to the dispatcher when he/she is in a monitoring activity. This evaluation shall enable the dispatcher to decide who will solve a given problem (him/herself or a given expert). The objective is to give the smartest possible overview of the problem to the Dispatcher so that he/she can make a quick decision on how to solve the problem. This task also enables the Dispatcher to keep a global awareness about what is happening on his area.

To help the dispatcher in this activity, MAMMI proposes the following elements around a problem evaluation:

- **Criticity**: time pressure and impact of a given problem regarding the whole airspace
- **Complexity**: estimation of the workload to solve the conflict, number of aircraft involved, etc.
- **Location**: area where the problem is happening and geographical context (meteo, proximity to airport or specific areas, etc.)

- **Type**: categorization of a problem (conflict, emergency procedure, regulation, etc.)

Two tools support the evaluation: the problems list (Figure 6) and the problems overview (Figure 7).

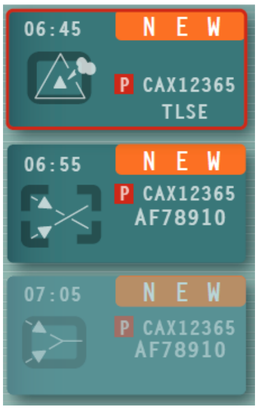

Figure 6: Representation of problems

The problem list is a vertical list presenting to the dispatcher all the problems of the airspace. For each problem, the happening time, the type, the involved aircraft and the status are presented. The status of a problem places it in its lifecycle. Status can be:

- **New**: problem has just been notified by the system and has not been analyzed by an ATCO
- **Assigned**: problem has been evaluated by an ATCO (generally a dispatcher) and assigned to an expert for analysis and resolution
- **Managed**: problem is being handled actively by an expert and discussions for its resolution have started
- **Solved**: the expert and all necessary stakeholders have resolved problem. It is monitored until its complete resolution.

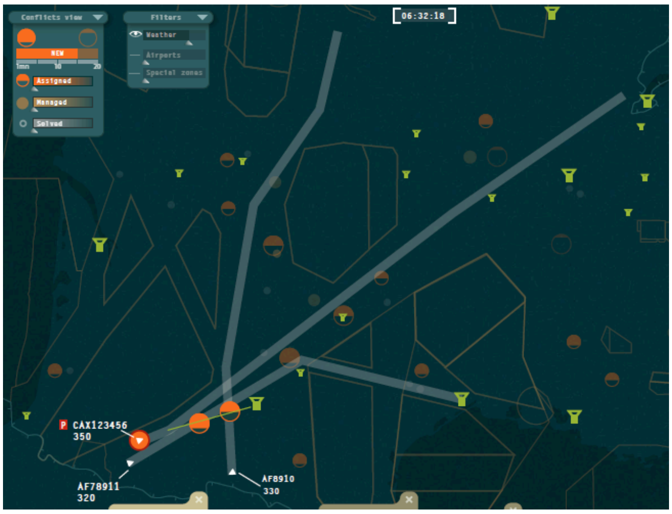

Figure 7: Geographical problems overview

The problems overview could take different forms. We propose here a geographical view presenting minimal information such as airports, special areas (approach, military, etc.) and ground boundaries. This overview does not present all the aircraft in the airspace. It is combined with some filters for time and problem status to be manipulated by the dispatcher. It is used in correlation with the problems list to highlight one or several problems at a time for evaluation. The objective remains a fast and focused evaluation of the problems with the aim of assigning their resolution to the right expert according to criticity, localization and type.

2) Manage

Once the dispatcher has evaluated a problem, he/she has to assign it to an expert or to him/herself. The dispatcher has to manage the activities of all the experts in his sector. He/she manages the workload and specialties (types of problems, dedicated areas, etc.) of the different experts according to strategies agreed between all the ATCOs. Even in real time, the dispatcher can reallocate problems (see pressure incident scenario) if necessary.

To help the assignment, the dispatcher uses a second list presenting all the experts under his/her responsibility (Figure 8). For each expert, the workload is presented, detailed according to the different status of problems, knowing that assigned and managed problems require more workload than solved ones.

Figure 8: Representation of the ATCOs list

The allocation of problems is equivalent to a transfer of responsibilities. The Dispatcher shall be able to see very quickly the whole activity of a given expert and to see links between a problem and all relevant experts (problem type, area, etc.). To do so, the dispatcher can combine highlighting of a given problem and a given expert on the problems overview to estimate the relevancy of an assignment and also the workload of an expert through the number, status and complexity of his/her problems.

When an expert or an area suffers from an overload, the dispatcher shall be able to balance this workload. This is equivalent to the sectors splits that we have today.

3) Analyze and propose

When an expert receives a new problem to solve, he/she achieves an extended analysis of this problem. This analysis shall enable to define one or several solutions to be proposed to the involved aircraft. To help the Expert in this task, we can propose:

- Various extrapolations including 3D/4D so that the expert can really estimate the nature of the problem and the best possible solutions.

- “What if” features with smart filters to define the "area of solutions", in which the resolution can be achieved.
- Easy drawing of RBTs with assistance from the system to make them realistic or to optimize them, so that the expert is not constrained by the system with potentially complex tools and is able to create propositions quickly.
- Solutions proposed by the system itself, according to relevant criteria for the problem.
- Communication support to expose the solutions to the aircraft and negotiate with them (see below).

As an example in MAMMI, we propose a 2D/3D RBT edition tool (Figure 9) with extrapolation features and simple presentation of the so-called “area of solutions”. The objective is to explore tools oriented toward simple edition rather than complex visualization.

Figure 9: The two modes of the 2D/3D editor

This tool aims at helping the expert in the definition of relevant solutions to be submitted, by bringing all the intelligence of the system for that purpose to propose and assist the construction of solutions, even if a full automation of the resolution was not possible.

4) *Negotiate and solve*

The propositions of solutions can then be addressed to aircraft and/or to other experts (including the dispatcher as last decision maker). An agreement shall be reached between the actors around these propositions. The associated negotiation is based on the following elements:

- Advanced communication with voice and share workspace to expose, validate and annotate solutions until a consensus is reached
- Tools for common situation awareness, so that the stakeholders for a problem can have the same view of the situation

MAMMI proposes to support the communications between aircraft and controllers in a more advanced way as it is today, taking advantage of all the shared information between actors and the capabilities of the SWIM network. The aim is a natural extension of the collaborative environment between a dispatcher and the experts, able to involve aircraft and remote ATCOs with a maximum continuity.

This activity was not in the original scope of MAMMI, which is focused on collaboration between En Route ATCOs. However, its inclusion in next steps of the study would be relevant due to their status in the overall ATC activity.

5) *Monitor*

The monitoring is split in two different categories. First, we have the monitoring by the Dispatcher. This monitoring is based on a sort of airspace dashboard, with different information:

- Problems in the area
- Activities of the different experts in solving these problems
- Flow management tools to anticipate the workload in time and in certain areas

This airspace dashboard can be the default view of the dispatcher when he/she is not evaluating, solving or assigning problems.

The other side of the monitoring concerns experts: when they validate a solution to a problem, they shall insure that the aircraft correctly implements this solution. Even if the system should indicate discrepancies regarding a validated solution, it is the responsibility of the expert to insure that everything is going well. In parallel, the dispatcher shall be able to see a given validated solution and to monitor it as well. To do so, MAMMI proposes to use additional displays (mainly the common vertical display) to store the solved problems on a sort of board (Figure 10) and “keep an eye” on them until their conclusion.

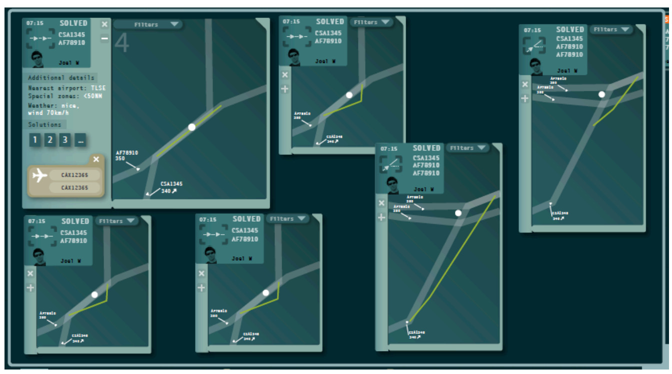

Figure 10: Problems board for monitoring

6) *Other support from the system*

Even if some tasks do not take place in the main workflow of the dispatcher and the experts, they may benefit of some support by the system.

a) *Communication*

The communication between the different actors is not only vocal. They can rely on data exchange, collaborative workspace solutions and even video if needed. MAMMI shall wisely distribute these communication capabilities in the different activities to bring them when they are really useful.

The first communication capability is based on vocal exchanges. On the dispatcher workspace, a "communicate" button is present. Combined with any actors represented in the different tools, it enables to create extensible communication channels (Figure 11). For instance, pressing "communicate" at the same time as a given entry on the experts list enables the dispatcher to communicate with the pointed expert. This communication channel can be extended the same way with a problem. In this case, all the involved aircraft of the problem will join the communication channel.

Figure 11: Standalone communication set

The second communication capability is embedded in the 2D/3D editor (Figure 12), so that an expert does not have additional actions to achieve to communicate with involved aircraft and other stakeholders.

Figure 12: Communication set embedded in 2D/3D editor

These different capabilities make the communications almost seamless and offer a deep integration with the other tools. They also offer a support for multiple communications that are relevant in the SESAR context with solutions such as watermarking that clearly identify who is speaking at a given time.

b) *Procedure management*

The system provides some support for negotiations and discussions in a flexible manner. However, some procedures are more focused on efficiency and priority (like in the pressure incident scenario). The system can bring a significant help by supporting active procedures associated to problems, and by assisting the dispatcher and experts in the fulfillment of these procedures (by achieving the different steps in the correct order and at the right time). These steps can be integrated in "Analyse and propose" but also in "Manage" and in "Negotiate and solve" activities.

For this purpose, in the problems list, problems linked to the same procedure can be grouped around a procedure (Figure 13). This is consistent with the fact that a single expert will supervise the whole procedure until its conclusion.

Figure 13: Problems linked to a procedure

In the same way, the 2D/3D editor can be "tabbed" with all the problems of a given procedure (Figure 14) to manage globally the different actions and communications. The expert in charge of a procedure becomes by the way a sort of temporary dispatcher of the procedure with all the facilities to deal with the involved aircraft and ATCOs.

Figure 14: 2D/3D editor for a procedure

V. POSSIBLE NEXT STEPS

Concrete scenarios and activities have been exhibited, closely based on the SESAR concept. They show the interest of continuing the studies about collaborative environment in SESAR, taking advantage of the new automated capabilities and new communication opportunities between actors. The SESAR concepts bring important stakes around shared and common analysis, negotiation and delegation that cannot be solved by the system only.

Principles for collaborative workspaces previously defined in MAMMI have been extended to fit with the new roles and operational background of SESAR. The MAMMI principles including interoperability of tools, flexibility of the workflows and creation of shared situation awareness are still relevant in the context of SESAR. However, current work for the application of the MAMMI principles in SESAR is still at exploration stage. Before reaching an experimental stage, the MAMMI consortium proposes to:

- Continue the positioning of the MAMMI principles in SESAR and create a more exhaustive knowledge about collaboration requirements in SESAR while the operational principles and concepts are still evolving.
- Collect feedback with ATC experts through a series of demonstrations of the current prototype, to refine our framework of solutions inside a global collaborative workspace.
- Involve ATCOs for focused tests on the solutions that are considered important during the next steps of the analysis, to start an evaluation and validation process.

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