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Towards a Multi-sector cooperation in Air-Traffic Control supported by a Meta-Common Workspace

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Abstract: For several years, the need for air traffic control has been continuously increasing. In order to maintain aircraft safety, different support tools have been built and assessed by our laboratory. The professional controllers who have tested these tools have made various criticisms. Our conviction is that it is necessary to design a more cooperative tool that would allow "true team work" to be established between air traffic controllers and their support tools, by making the support tool part of the team rather than a substitute for air traffic controllers. This paper presents a new support tool based on the delegation of tasks and a common workspace. The support tools' assessments with professional controllers have highlighted a workload decrease due to the delegation and the sharing of information. In order to improve the support system, it is necessary to extend the common workspace to the adjacent sector of control.

1. INTRODUCTION

The Air-Traffic Control system (ATC) is complex, and the role of human operators within this system is crucial. Air-traffic controllers work to maintain aircraft safety by avoiding collisions. The airspace is divided into several sectors that are managed by two controllers: a planning controller (PC) and an executive controller (EC). PCs have a strategic role: in addition to coordinating their own sector activity with that of the adjacent sectors, they also work to detect potential air-traffic conflicts and inform the EC when they do. In addition, the PC must maintain a constant traffic load for the executive controller. ECs have a more tactical role: they supervise the air-traffic and must resolve the conflicts by modifying the aircraft trajectories.

One solution for maintaining air-traffic safety, despite traffic increases, is to integrate support tools that can regulate the air-traffic controllers' workload. To this end, the LAMIH (French acronym for "Laboratory for Human Engineering, Automation Science, Mechanical Engineering and Computer Science") has studied different forms of dynamic task allocation between human operators and assistance tools in order to define the most efficient forms of human-machine cooperation. Several forms of cooperation have been evaluated using two experimental platforms: SPECTRA V2 (French acronym for "Experimental System for the Allocation of ATC Tasks Version 2) has allowed to evaluate explicit and assisted explicit task allocation between Human and support system (Lemoine et al., 1995). AMANDA V2 (Automation and MAN-machine Delegation of Action Version 2) has allowed the assessing of task delegation (Guiost et al., 2006). This paper presents now a summary of the state of the art of the Human-Machine Cooperation that was used to design and assess the AMANDA support tools.

2. HUMAN-MACHINE COOPERATION

Our study is based both on a human-human cooperation (HHC) theory and on a human-machine cooperation (HMC) theory. Section 2.1 defines HMC and the cooperation between agents. Section 2.2 presents a model of human operator, and sections 2.3 and 2.4 explain how those concepts were used to create a theory of HHC.

2.1 Definition of the Human-Machine Cooperation

Hoc defines the cooperation between two agents in this way (Hoc, 1996):

" Two agents are in a cooperative situation if they meet two minimal conditions:

Each one strives towards goals and can interfere with the others on goals, resources, procedures, etc.

Each one tries to manage the interference to facilitate the individual activities and/or the common task when it exists.

The symmetric nature of this definition can be only partly satisfied"

The goals described above are not the ones set by the supervision and control process but rather those for accomplishing a particular task. Interferences are interactions between the activities of several agents. Their nature can be positive or negative. "Positive interaction" refers to normal interaction between agents, and "negative interaction" refers to conflict between agents. The objectives of the HMC are to

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assist human operator in order to increase the system's performances while avoiding a human overload. So it is necessary to minimize negative interactions between operators and support tools. The HMC can be defined from structural or functional aspects:

Structural Human-Machine Cooperation can take two forms: vertical or horizontal (Millot, 1988, 1997). In a vertical structure, support tools can't ever act on the system. Only operators have this responsibility. However, because the support tools have the same information on the process as the human operators, they can give to the operators some advices. On the other hand, in a horizontal structure, both the human operators and the support tools can act on the system. The support tools have reasoning capacity in real time, which puts the two decision-makers (human and machine) at the same hierarchic level. Different tasks are allocated between agents in an attempt to regulate the workload of human operators.

Functional Human-Machine Cooperation can take three forms: augmentative, debative and integrative (Schmidt, 1991). In the augmentative form, all agents have the same abilities and work together to complete one task that is too extensive for a single operator alone. This task is divided into several sub-tasks that are distributed among agents. For example, this is possible in the case of the horizontal structure. In the debative form, agents again have the same abilities, but rather than share work on one task, they compare their individual results in order to obtain the best solution. In the integrative form, agent abilities vary, and the task is divided into sub-tasks that are allocated according to these abilities. The different agents supplement one another as they seek to accomplish the overall task. So, the three forms of cooperation give indications on various mechanisms of cooperation when two agents work together.

The above forms and structures are used in the conception of a support system for human operators. The following section presents the internal structure of HHC. This structure, once integrated into Hoc's definition (cited above), will provide the basis for the definition of our future system. The Rasmussen's model was used in order to describe the interactions between the agents' activities.

2.2 The Rasmussen's model for Human activities of problem resolution

Rasmussen has presented a model that describes the human cognitive activities for problem resolution (Rasmussen, 1980). Firstly, the human operator collects all the data allowing him/her to identify an abnormal situation. Then, those information allow the human operator to perform a diagnosis of the situation identifying the problem precisely. When the problem is identified, the operator can build a schematic solution answering the problem according to the inherent constraints with the system. This stage leads to the development of the solution in terms of goals and under-goals, and finally to the implementation of the solution.

The model of Rasmussen revealed three classes of human operator behaviours (Rasmussen, 1983):

The human operator applies the skill-based behaviour when it is confronted to a known situation and whose solutions are applied automatically and spontaneously. This behaviour is related to automatisms.

With the rules-based behaviour, the human operator detects a known abnormal situation and proposes a solution resulting from rules or preset procedures that she/he memorized beforehand.

Lastly, the knowledge-based behaviour is applied when the human operator is confronted with an unknown situation and that she/he uses his knowledge and its experiment to invent an adequate solution.

These various levels are not sequential. There can be short-circuits and stages of waiting.

Hoc and Amalberti (1999) expand the above model for the problem resolution in dynamic situation based on the representation instance that has the human operator of the situation. This model highlights the importance of the situation occurrence. The higher is the situation occurrence, the more its identification and its processing will be easy. As the Rasmussen's model, this model is structured according to three levels of situation understanding.

The low level corresponds to an automatic diagnosis obtained starting from the process observations. It leads to an immediate execution of the pre-established procedures. The execution of these procedures leads to micro-update of the system instance representation.

The second level corresponds to a diagnosis based on an explicit search of the procedures, which can be performed. It corresponds to the rules-based behaviour described by Rasmussen. This level implies adjustments of the instance representation.

The last level concerns an interpretation of information resulting from the process. This level implies an update of the instance representation as well as a redefinition of the objectives.

The essential contribution of this model is that it shows the various sides of the situation representation that are made by the human operators with knowing the actions and the resources available in more of the representation of the system and its goals. Within the framework of supervision and co-operative assistance, it is important to provide to the human operator the means for maintaining these three levels of situation awareness and for sharing them with the support system. This sharing must assure that their respective representations of the system and its environment are in adequacy. In addition, it must to facilitate the human-machine cooperation.

2.3 Level of automation and Situation Awareness

The situation awareness can be defined like a mental model of system state and its environment at a given instant. It includes not only the immediate perception of the data, but also the understand and the importance of these data on the future possible system states and of its environment (Endsley, 1999). The situation awareness implies cognitive, perceptuals, of diagnosis and deductive activities. Endsley presented a formal definition of the situation awareness as being the element perception of the environment in a volume of time and space, the understand of their significance and the projection of their state in an immediate future

Endsley (1996) indicates in particular the three impacts of automation on the situation awareness:

1 The changes, associated to the monitoring, in the vigilance and in the satisfaction of the human operator.

2 The acceptance of a passive role instead of an active role by controlling the system.

3 The changes in the quality or in the form of the information feedback provided to the operator

The "on line" assessment of this situation awareness would be particularly interesting to assist the human operator "in difficulty". At this time, it is very difficult. Nevertheless, the situation awareness makes it possible to direct the intrinsic evaluations which can be carried out on a human-machine system. Endsley and Kaber (1999) carried out a series of experiments in order to assess the impact of various automation degrees on the system performance, on the human operator situation awareness, and on the human operator workload. Those experiments was performed within the framework of a task of complex control, inspired of the air traffic control.

The tested automation's levels went from non automation to complete automation according to the assistance with the action, shared control, the decision-making aid, the automatic decision-making or the control of the supervision by the automatic tool (no exhaustive list). The impact of partial automation on the human operator capacities to assume manual control following an automation was also analyzed. The results suggest that the degrees of automation, which imply the sharing of tasks between the operators and the automatic tool, have an impact on the system performances. In particular, the best performances are obtained when the human operator produces the solutions while the automatic tool carries out the commands. The decision-making, shared between the human operator and the tool, has degraded the performances regarding to those obtained in the situations corresponding to a single decision-making either by the human operator or by the tool of assistance. These results also showed that the human operators most easily managed a system failure when the automation degree was relatively weak and that the command of the actions on the system would require Human-Human or Human-machine interactions. The definition of the automation level, the interactions between agents of different nature and thus in a more general way the human-machine cooperation is the framework of our research task, with an application to this complex field and little automated which is the control of air traffic. The automation of a system consists in fact to design one or more subsystem able to perform partially or completely a function which was or could partially or completely be carried out by a human operator (Parasuraman, 2000). The following section presents the means used by the human operators to maintain their situation awareness when they cooperate.

2.4 The Common Frame Of Reference (COFOR) (Leplat, 1991)

To accomplish a task, human operators build themselves a frame of reference within which they represent the process and the process state. Thanks to this construction, human operators can plan their actions and detect abnormal evolutions of the process (Pacaux-Lemoine, 1998).

Within the context of HHC (cooperation between human operators), agents exchange information verbally about their individual frames of reference in order to build a common frame of reference (COFOR). They use this COFOR to accomplish tasks whose goals or sub-goals are linked. The COFOR becomes a reference between operators.

In order to minimize the number of these exchanges, their duration and their contents, the agents often construct their own representations of what they believe a colleague's frame of reference to be; however, sometimes these interpretations are partially wrong. To improve cooperation between human operators and the future support tool, a more formal method for constructing a COFOR would seem to be necessary (Debernard et al., 2002). One suggested method is called Common Work Space (CWS).

(Debernard et al., 2002) have proposed defining the structure and function of support tool in terms of CWS notions and Schmidt's three forms of cooperation. The three forms are implemented in this way:

1 Debative form: agents add the data they judge significant to the CWS. When interferences appear, they must negotiate to eliminate them.

2 Integrative form: one agent adds data to the CWS. Other agents access the information necessary to accomplish their tasks.

3 Augmentative form: the agents themselves decide Task sharing.

Results from SPECTRA V2 have highlighted a certain number of decision-making problems and the important role played by human trust in the system. In certain situations, it appears that air-traffic controllers are hampered in their efforts to solve conflicts because their strategies are at odds with those proposed by the system (Lemoine, 1998). To solve the decision-making problems mentioned above, the AMANDA project (Automation and MAN-machine Delegation of Action) had proposed to implement a more cooperative support system than the one used by SPECTRA. The principle of this support system is to provide operators means for sharing common representations between human operator and support system in order to develop cooperative activities. The target is to build a common frame of reference (COFOR) with an assistant system called STAR (Debernard et al., 2002). STAR is able to integrate controllers' strategies in order to calculate the solution. The common frame of reference is a representation of the situation that is build by two human operators when they cooperate (Leplat, 1991).

The common frame of reference of the air-traffic controller has been identified thanks to a first experiment of which the data analysis was performed by coding the air-traffic controllers cognitive activities (Guiost et al., 2003). This encoding was based on the Rasmussen's simplified model of problem resolution (Rasmussen, 1983). This synthetic COFOR is called a common workspace and it has been evaluated thanks to the AMANDA experimental platform (Guiost et al., 2006). Next, this COFOR has been implemented on a graphical interface. This implementation provides to controllers the means to build a COFOR with assistant system and to perform the dynamic function allocation between the radar controller and the assistant system.

Figure 1 shows the function allocation between the controllers and the support system as well as the modes of cooperation. The COFOR is materialized to a graphic interface placed between the agents. The support system, called STAR, is not able to perform all the activities of problem resolution because they are strategic activities that must be reserved to the human operators to avoid any decisional conflict.

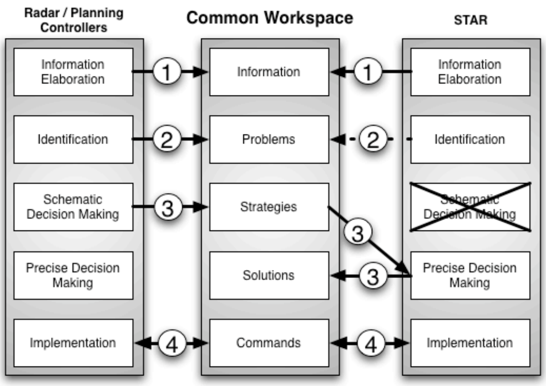

Fig 1: Function Allocation and cooperation between Planning and Radar Controllers and STAR

The human operators and the support system can add information to the common workspace. The cooperation is an augmentative form. The air controller must carry out the definition of the problem, and controls the overall representation of the traffic. However STAR is able to complete the problem representation. These activities concern activity of identification of the Rasmussen model. The cooperation is a debative form.

As STAR is not able to make strategic decision, it must be able to integrate the strategy of controllers thanks to the common workspace and to calculate the regarding solution. The cooperation is an integrative form.

Human operators or STAR can carry out the command (instructions sent to aircraft). The human operator carries out the command allocation between the agents. This command must enable her/him to control its workload. This command is called delegation because it relates to a very precise micro-task and not on the whole management of conflict.

Figure 2 shows the common workspace with several problems. Each one is composed of several aircraft in conflict and can be identified thanks to a colour. It contains information at the minimal distance between the flights, the resolution strategies of conflict, and the instructions (heading, flight level…) of trajectories deviation sent either by the human controller or by the system. The organization of this information within a window, called cluster, is described on figure 3. All problems represented on the common workspace makes it possible to provide a total representation of the situation including all the conflicts detected by the controllers as well as the problems under development (column of right-hand side). These problems will be published on the common workspace when the controllers will be certain of his/her diagnosis.

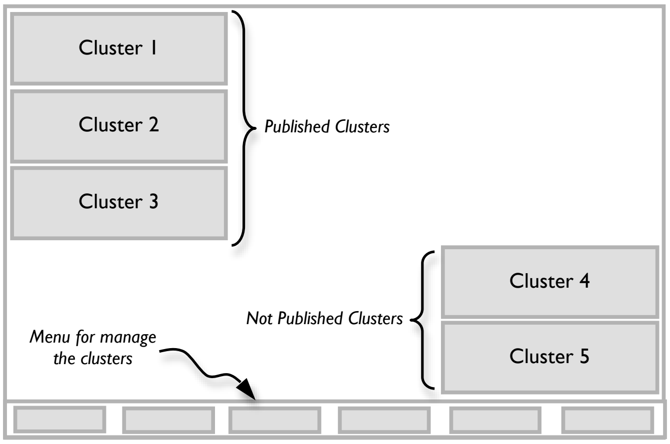

Fig 2: Screen of the Common Workspace with several problems

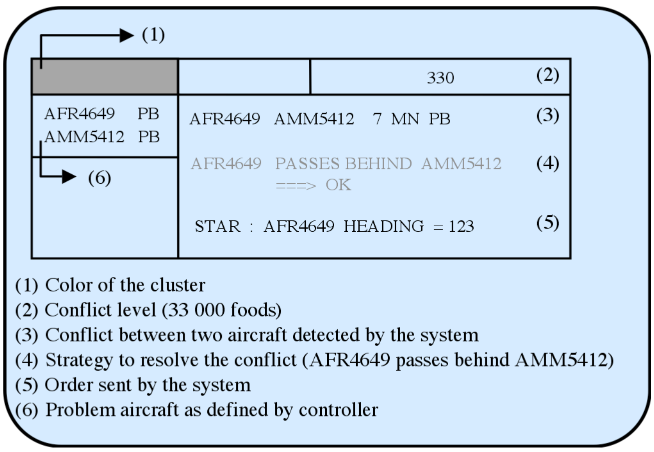

Fig 3: Graphic representation of a problem (cluster)

The evaluation of support tools was performed with objectives and subjective data. The objective data correspond to the data exchanged by the agents through the support tools. Theses data are dated and identified with their user. The subjective data correspond to questionnaires of the usability of the support tool and of the workload assessment (TLX method, Hart and Staveland, 1988).

The support tools' assessments highlight that our support system allows controllers to better anticipate air-traffic conflicts. The safety net (conflict alert) was never activated although the experiment involved a traffic-load twice that of reality. The common workspace seems to provide a good representation of air-traffic conflict as well as a necessary tool for conflict resolution. This support system requires modifying the task sharing between EC and PC, to include a PC that can create the clusters (representation of an air-traffic conflict on the common workspace) and introduce the best strategy for solving each conflict. In addition, the PC can regulate the EC's workload by dispatching the new clusters. The EC can then integrate the new cluster and evaluate the solution proposed by the support system in order to decide whether or not to delegate the resolution to the system. That is to say, instructions that solve the conflict are sent to aircraft by the support system.

The common workspace allows support system to integrate Human intentions and the sharing of solutions (trajectories). However there was uncertainty as to the aircraft trajectories that will enter to the controlled sector. Therefore we propose to use a meta-common workspace in order to publish the solutions of one sector to the following sector. In addition, this Meta-common workspace must be allowed to support the coordination activities between planning controllers. The additions of those information must allow controllers to have better situation awareness. Those new functions involve the definition of new interfaces and new tools for supporting the activities of coordination between the planning controllers. In addition, it is not possible to share all information on the common workspace between all the sectors. Indeed, all information of a sector A are not pertinent to the sector B. Moreover, it is necessary to specify a Meta-common workspace that will manage all the information between the different common workspace according to the different sector.

3. TOWARDS A META-COMMON WORKSPACE

The Common Workspace was tested thanks to the experimental platform AMANDA V2. It proposed to the controllers to share their situation representation with the support system on a given sector. One of the challenges of automation is to increase the capacity of the air traffic control and to decrease uncertainties on the information delivered with the air traffic controllers. Indeed, their activity of control is based on various information profiting from a non-null margin of error. Thus, the interpretation of the position of the aircraft via the radar systems obliges them to ensure a minimal distance from 5 MN on their radar screen. In the same way, the flight plans indicated on the strips can be altered by various trajectory deteriorations that the aircraft will have been able to undergo in the sectors upstream. The controllers intentions of the adjacent sectors not being known, there are uncertainties on the aircraft trajectories until they enter in a given sector.

To solve these uncertainties problems, we suggest extending the Common Workspace to the adjacent sector (figure 4)

Thus, it is necessary to set up two Common Workspaces. The first, called Meta Common Workspace must make it possible to support the coordination activities. This task is carried out by the planning controllers and consists in preparing the aircraft transfer from a sector to another. This coordination also consists, for a given sector X, in sending out of request on a sector upstream in order to solve, by anticipation, a potential conflict in sector X. Lastly, this Meta Common Workspace must also allow the strategies broadcast of the upstream sectors towards the downstream sectors in order to decrease significantly the trajectories uncertainties of the flights which will arrive in the considered sector. There are two expected effects to the uncertainties decreasing. The first effect is a decrease of the false detected conflicts. Thus, one can hope for a decrease of the air traffic controllers workload. The second effect is a better problem anticipation because of additional precision available in the conflicts detection. A better anticipation of the problems will have a positive incidence on the air traffic safety (Guiost et al., 2003). This Meta Common Workspace will be consequently designed on a control center scale including several sectors of control.

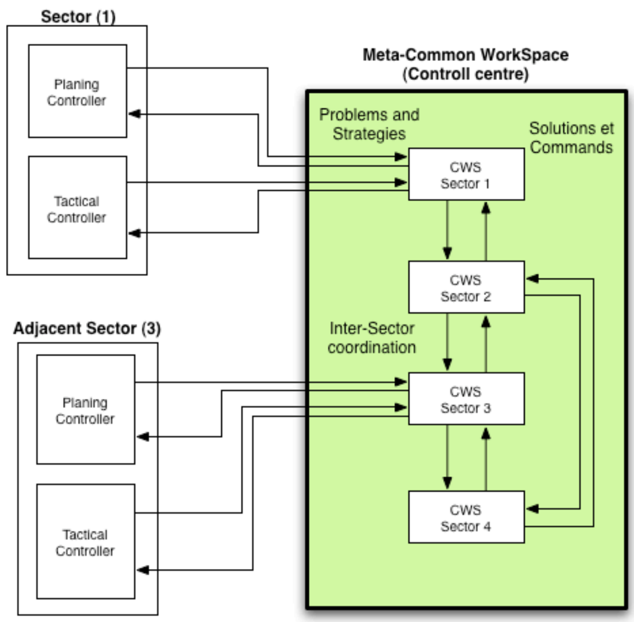

Fig 4: Architecture of the Meta-Common Workspace

The second Common Workspace will be that which was already used on the experimental platform AMANDA V2. However, it will be improved in order to be able to integrate and share the data resulting from Meta Common Workspace.

The design of these two Common Workspaces will be carried out on the basis of a new data extraction.

4. CONCLUSION

This paper presented the design steps of a Common Workspace between the air traffic controllers and a support system.

The originality of our approach is due to two particular points. The first is the knowledge extraction carried out without the controllers knowing, i.e. without explicit questionnaire, through of an identification of their cognitive activities. The second main important have consisted in identifying the points on which automation could bring an improvement of performance and to design a co-operative tool allowing to optimize working of the man-machine system. So that this cooperation is most effective possible, this tool is based on the model of the controller's cognitive activities and makes it possible to the various agents to share a common representation of the situation.

The principal results were presented. Those results made it possible to validate the contents of the Common Workspace and its capacity to support the Human Machine cooperation.

In addition, these results make it possible to define new objectives of research for the design of a Meta Common Workspace. It will have to allow the decrease of the uncertainties on the aircraft trajectories. It will have to also make it possible to improve the situation awareness and to support the Human Machine Cooperation.

This Meta Common Workspace will be assessed on the platform AMANDA V3 with professional air traffic controllers.

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