AGENT-BASED MODELING AND EXPERIMENTATION FOR REAL-TIME COLLABORATIVE DECISION-MAKING IN AIR TRAFFIC MANAGEMENT

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Abstract

Collaborative Decision Making (CDM) is about improving the way different actors in the Air Traffic Management (ATM) system e.g., airline operators, traffic flow managers and air traffic controllers (controllers), work together at an operational level. In this paper we consider a special category of CDM which has to be carried out in real-time. We propose an agent-based approach to modeling and experimenting this class of problem: software agents are either able to assist or to replace human participants in human-in-the-loop experimentations. Some generic "teamwork" models can be also applied through the agents.

1 Introduction

The current airspace-based ATM system, in which the controllers are assigned all responsibility and control authority to individual sectors, does not really support inter-sector cooperations. Only the procedure of control transfer *i.e.*, "handling over" aircraft from one sector to the other, is well specified in the controller manuals. Several investigations [1, 3, 6] attempted to establish new operational concepts that allow the controllers in different sectors to work more together. Their objective has been not only to rationalize the controllers' collective behaviors, but also to steadily distribute their responsibility and workload through sectors. For instance, the controllers of a congested sector can be ensured that traffic flows arriving at this sector are smoothened by controllers of the previous neighboring sectors.

At a higher management level, there is actually an operational gap between Air Traffic Flow Management (ATFM) and Air Traffic Control (ATC): no cooperation in real-time. ATFM produces or modifies the flight plans at least two hours before they are really executed by ATC. The feedback from ATC about the current traffic is still more delayed. The FAM (Future ATFM Measures) project [6, 9] at EUROCONTROL defines the concept of Real-time Traffic Synchronization aiming at filling this gap by providing some possibilities to traffic flow managers to cooperate in real-time with air traffic controllers (in several sectors).

The above operational concepts constitute a particular category of CDM, *i.e.* Real-time CDM that deals with collaborative work to be carried out during a short period of time. This category needs not only information sharing and common awareness between actors, but also coherent and flexible collaborative procedures. We consider the following requirements for the framework for Real-time CDM's human-in-the-loop experimentation:

- A generic model that ensures the coherence of collaborative procedures; and that enables the anticipation of collective failures,
- A distributed experimental environment,
- A significant number of human operators,
- Many operator training courses.

The two last requirements evoke a difficulty often occurs in many human-in-the-loop experimentations in the ATM domain: the insufficiency of available professional operators, *e.g.* controllers or traffic managers, participating to the experimentations.

To fulfill the requirements mentioned above, we propose the use of software agents to partially replace human operators. This approach is based upon a generic "teamwork" model, *i.e.* STEAM (Shell for TEAMwork) [2, 4, 7]. We integrate the STEAM's programming tools [5, 8] with eDEP [10], an ATM rapid prototyping platform (the two platforms were all written in Java) to implement an agent-based experimental environment. Software agents can play themselves the participant roles or can assist human operators. We expect that this hybrid system could help reducing the needed human participants, including both operators and trainers. The cooperation between all software agents and human participants is based on STEAM.

In collaboration with the FAM project, we have implemented an agent-based simulator supporting the validation of Real-time Traffic Synchronization. The simulator does not only aim at demonstrating the new operational concept but also provides another kind of evaluation based on criteria for "teamwork" (*e.g.,* the number of message transmissions, the rate of collective failures or of successful responses to environmental changes) and introduces artificial actors (software agents) participating together with human operators in collaborative procedures during the experimentation. Each agent is furthermore able to assist a human operator in making decision, through an user interface. In this case, the assistant agent and the human operator constitute, with respect to other artificial/human participants in the experimentation, one unique but binomial operator.

2 Real-time Traffic Synchronization

In this section, we present Real-time Traffic Synchronization as an example of Real-time CDM.

2.1 Traffic bunching phenomenon

A major concern in leaving some loose end to ATM rules is the occurrence of uncontrolled traffic peaks at the entry of a congested area. This phenomenon, often caused by some aircraft "in bunch", is known in the operational world as "traffic bunching" effect [6].

2.2 Collaborative solution

A way to solve the problem is to structure and organize the arrival flows in real-time. A possible technique is the readjustment of the arrival time of some aircraft at a congested point, thus enabling to "de-bunch" problematical delivery. This technique should enable several controllers and flow managers to collaborate on the traffic for "smoothing" the bunching peaks before they affect the congested area.

This is in fact a collaborative work of the actors:

- Air Traffic Controller (controller) controls the aircraft flying through her/his sector.
- Local Flow Manager (LFM) manages the aircraft flow passing through her/his airspace zone. In each control centre, there is a LFM and several controllers managing together an airspace zone composed of several sectors.
- Central Flow Manager (CFM) supervises inter-centre operations.

3 Modeling & experimentation platform

3.1 Agent-based platform

A hybrid agent-human experimentation platform is developed to response to human-in-the-loop simulation needs. In this platform, each actor (flow manager or controller) is modeled by an agent, which itself is replaceable by a human actor in the experiments. We model the interaction between the artificial agents by using STEAM (Shell for TEAMwork), a generic teamwork model described in [2, 4, 7]. An ATM simulation platform, eDep [10], is used to provide real air traffic data.

Our agents actively perform contextual analysis of the environment; maintain beliefs about the world, communicate beliefs to each other, and launch activities according to their current beliefs. This agent-based model is also usable for other Real-time CDM applications.

3.2 Agent-based analysis

Our model of agents enables us to perform some special kinds of analysis based on agent beliefs. For example, we can evaluate the communication redundancy of a new collaborative procedure. In the operational work, the professional collaborators (air traffic controllers or managers) always have the potential to transfer messages to each other in order to ensure collaboration coherency, or sometimes only to confirm their awareness of some probable events. This causes useless message transmissions difficult to determine. Through agent-based model, we have the possibility to access to beliefs of a "modeled" actor in order to discover whether or not at a given moment she/he is aware of the current *team* state; if this is the case, it is not necessary for her/his teammates to inform her/him about this state. In other words, redundant messages are uncovered.

Another example is collaboration error analysis. Misunderstanding of team missions or individual roles can be also tracked by exploring the register of agent believes.

However, one can note that our model is not a tool to tackle complex human factors. Its use is limited in Real-time CDM applications, *i.e.* all analyses based upon our model are dealing with collaborative procedures, *e.g.* by beliefs about *team* state or mission.

3.3. Reducing needed staff

Human operators and software agents can work together as teammates in the simulation. This fact certainly allows reducing the required number of human participants for a human-in-the-loop experimentation. For example a Real-time Traffic Synchronization procedure can be tested with 3 real air traffic managers and 3 artificial ones (agents). In addition, the number of human operators can be changed dynamically, because a human participant is totally replaceable by a software agent.

An agent is not only able to replace a human operator but also to assist him. We will later describe this ability in detail, which is indeed an efficient way to train participants without trainer. Of course, the agent assistance cannot replace the participant training, but it helps to reduce the number of training scenarios as well as of trainers.

4 Agent as assistant

4.1. User Interface with Assistant

Each user interface for a human operator is attached to an assistant agent, which can play alone the role of this operator or assist him. One can somehow imagine an assistant analogically to an assistant in MSWord™ environment. Although our agents are much different from those developed by Microsoft™ but this idea gives a first view of assistant agent. This class of intelligent entity is able to assist the human operator by giving her/him some suggestions according to what she/he tries to do. A major distinction between our assistant agents and traditional assistants is that the first ones can totally replace human operators in the simulation. That means, each assistant agent can make decision on the behalf of the human operator it assists.

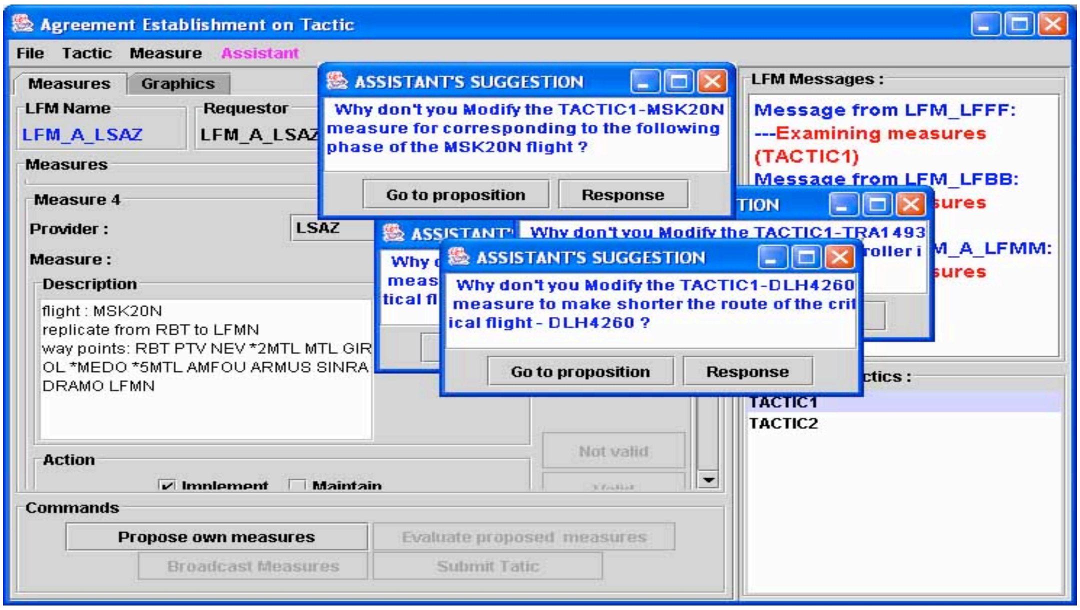

Fig. 1. User Interface with Assistant

4.2. Expert/Assistant and Agent Operators

In the experimentation, a human operator and his assistant constitute, with respect to the other operators, one and only one human/assistant operator (unique but binomial). In this case, either the human operator or his assistant can perform their common operator role. In other words, the human operator could be totally replaced by his assistant and vise-versa to establish a class of software agent operators, which are not assistant and autonomously perform its role in the simulation. All classes of operators are equal, *i.e.* there is no distinction between the roles played by the agent operators and those played by the human/assistant operators.

5 An example

5.1. CDM scenario

Based on the concept of Real-time Traffic Synchronization defined by the FAM project, particularly in [6], we simulate the collaborative procedure described below between air traffic managers.

We suppose an initial situation like the following one: a flow manager called “requestor” detects a risk of “traffic bunching” about an hour before its effect on an congested sector; this risk is caused by aircraft flying “in bunch” which will cross successively the airspace zones managed by other managers called “suppliers”; the “requestor” informs these “suppliers” of the risk and starts a session of common tactic establishment. The two roles defined here are not exclusive, *i.e.* a flow manager can be at the same time “requestor” and “supplier”.

After having received information about the risk of “traffic bunching”, the concerned air traffic managers collaborate to each other during 15mn in order to remove the risk. The collaborative procedure is as the following:

- The “requestor” builds a pre-tactic to cancel this “traffic bunching” risk. This pre-tactic is divided into several measures, each of which is dedicated to handling of one of the aircraft flying “in bunch” and managed by a “supplier”. Then it diffuses this pre-tactic to all the “suppliers”.
- Each “supplier” accepts, refuses or modifies associated measures, then

diffuses his ideas to the "requestor" and to all the other "suppliers".

- After having received all the ideas, the "requestor" sees whether there is refusal. If yes, this coordination failed; if no, it updates and then validates the final common tactics.

5.2. Categories of assistance

In this session, we run the CDM scenario presented above on our experimentation platform in order to illustrate multiple assistance of agents. This is the human operator who chooses her/his preferred category of assistance.

5.2.1 Assistance upon request

In this category, an assistant only gives instructions to its human "master" when this last one asks it for assistance. This category is not dedicated to beginner operators. Fig. 2. presents an example of assistance upon request corresponding to the second activity of the collaborative procedure presented in 5.1.

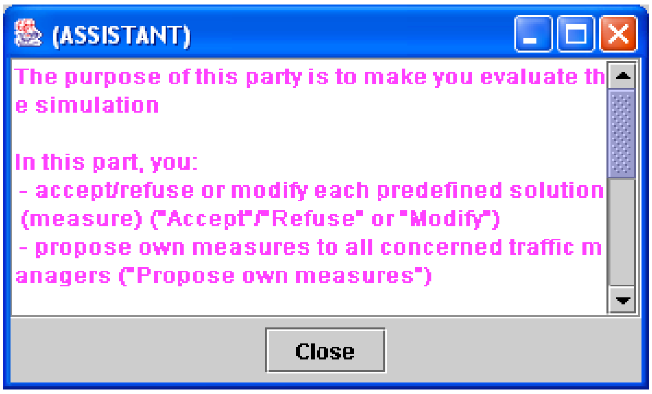

Fig. 2. Assistance Upon Request

5.2.2 Active assistance

This is the default category in which an agent recognizes what she/he is trying to do, makes itself the corresponding decision, and then gives this decision to its human "master" as suggestion. Fig. 3. illustrates an assistant's suggestion corresponding to the second activity of the collaborative procedure presented in 5.1.

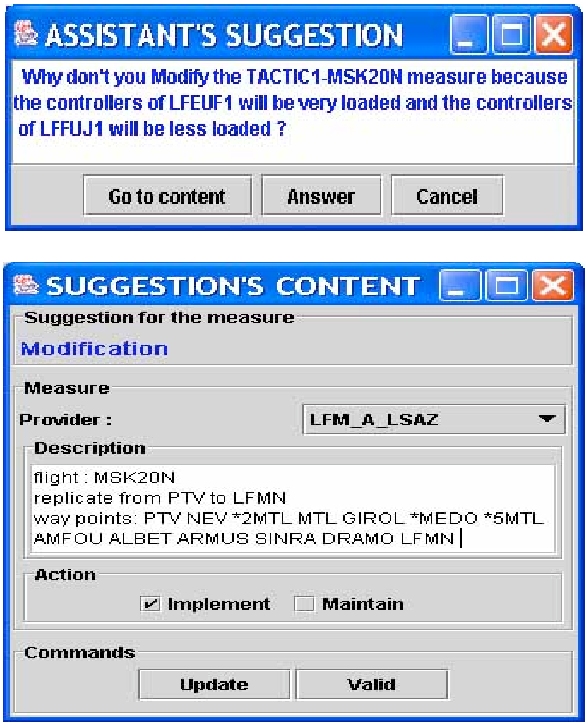

Fig. 3. Active Assistance

6 Conclusions

The work presented consists in an agent-human hybrid experimental platform, used as an efficient tool for analyzing new Real-time CDM procedures. We believe that agent-based model could offer possibilities to discover human redundant tasks or errors related by collaborative procedures. We argue however that agent-based models are far from being a typical tool to tackle complex human factors; only those concerned by collaboration can be taken into account. At this stage of investigation, some collaboration scenarios in the frame of Real-time Traffic Synchronization have been investigated in order to evaluate the benefit of using this new kind of platform. The first research results were promising. The upcoming step will therefore be to perform more experimentations with different groups of air traffic managers; the objective is to find out appropriate categories of assistance. The application of our agent-based platform to other Real-time CDM problems should be also envisaged for the near future.

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