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Cooperation between Humans and Machines: First Results of an Experiment with a Multi-Level Cooperative Organisation in Air Traffic Control

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Abstract. The increasing air traffic and the ensuing increasing burden on air traffic controllers suggest to attempt to provide enhanced assistance to air traffic controllers. As it is difficult to reduce the number of primary tasks, a solution is to give active assistance to controllers by means of computer tools that allow for optimal control in order to maintain the level of safety and at the same time regulate the air traffic controllers' workload.

The objective of our research is to propose and validate a new organisation of air traffic control. It aims at integrating both levels of the organisation of air traffic control: a tactical level managed by a radar controller and a strategic level managed by a organic controller. Our study at first addresses the tactical level, aiming at 'horizontal cooperation' consisting in dynamic allocation of control tasks between a human air traffic controller and an assistance tool. The results of this first approach has oriented the study toward the implementation of a scheduling module for the tactical level.

This paper reports the functionalities of air-traffic control and the results of few preceding experiments. A description of the new multi-level organisation is given, to conduce to the presentation of experimental platform, experimental protocol and the first results of experiments.

Key words: air traffic control, human-machine cooperation, dynamic task allocation, load evaluation, tasks allocation criterion

1. Introduction

Our research addresses dynamic task allocation in Air Traffic Control which is characterised by a lot of interactions between humans and machines. French air space is divided into five control centres which in turn are divided into sectors. Each sector is managed by a pair of controllers by means of a specific kind of work station, a control position or 'suite'. Each suite is staffed by two controllers, a tactical and a strategic one. Today, if a sector is saturated because of increasing air traffic, the room manager of the control centre will divide that sector into two. But the size of sectors cannot be reduced further, because both input and output coordination tasks between sectors in that case would increase and conflict resolution would be more difficult. Thus, the only way to avoid increasing the

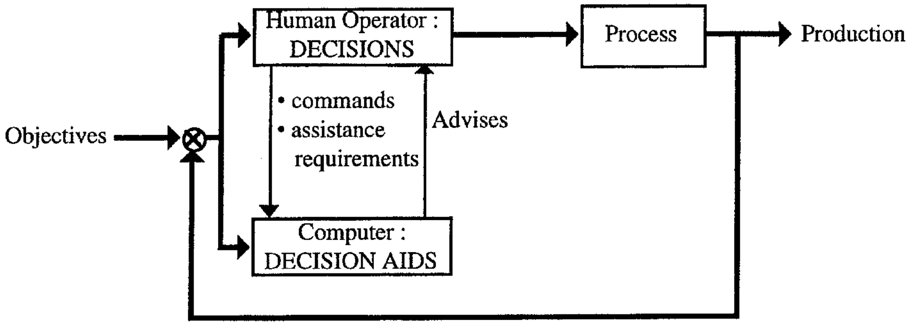

Figure 1. Vertical cooperation principles.

workload of air traffic controllers, is to provide active assistance to controllers by means of computer tools.

Two types of human-machine cooperation can be distinguished (Millot, 1988). The first type is called vertical cooperation and consists in providing the human operator with a set of tools which assists him/her in his/her decision making. In addition to such services, the second type of cooperation, called horizontal cooperation, allows to provide the operator with an aid to action. This cooperation consists in allocating tasks dynamically between two decision-makers, the human operator and an automatic system. In the case of Air Traffic Control, the tasks are shared between the radar controller and an Artificial Intelligence system for air traffic control regulation, SAINTEX (French acronym for: Experimental Automatic System for Night Traffic Control) (Mordchelles et al., 1989).

2. Human-machine cooperation principles

The concept of human-machine cooperation was born as a result of the appearance of Artificial Intelligence tools as assistants to a human decision- maker and from the necessity to predict and, moreover, to prevent the decisional conflicts liable to arise between these two types of decision- makers (human and artificial) (Millot, 1988). In its first stage, the research addressed single-operator systems and defined two cooperation modes called ‘vertical’ and ‘horizontal’, respectively.

2.1. Vertical cooperation

In vertical cooperation, the operator is responsible for all the process’ variables and if necessary he/she can call upon the decision support tool, which will supply him/her with advice (Figure 1). Within this framework, two principles can be distinguished:

- One aims at guiding the operator in his/her problem solving so as to lead him/her to find a solution himself/herself. This principle is very attractive since it lets the operators maintain and enrich his/her operative knowledge

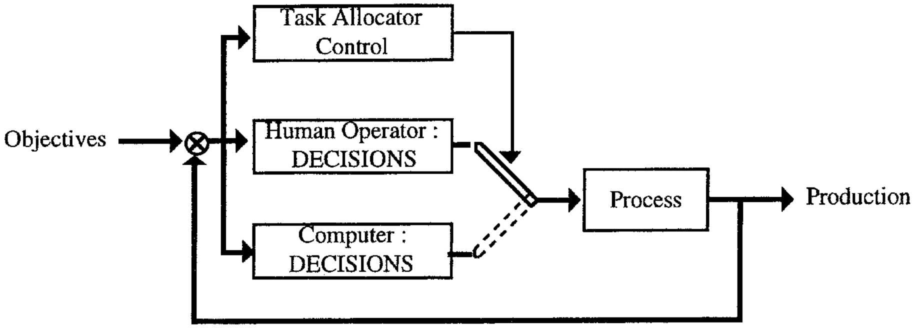

Figure 2. Horizontal cooperation principles.

of the process. However, it requires a high degree of adaptability on the part of artificial intelligence system so as to ensure consistency between its own reasoning and the operator's while reckoning with the latter's cognitive level. Moreover, decision time can be fairly long, which excludes emergency situations!

- The second principle is aimed at emergency situations in which the operator can 'lose' his/her capabilities for objective reasoning, through stress, for instance. For this reason, it is advisable to propose him/her solutions which time pressure could prevent him/her from finding. In this case, conflicts can arise when the human operator rejects the solutions proposed by the support system; the designer must therefore provide the support system with an interface for dialogue and justification of its reasoning. The human operator will then be able to check rapidly who is wrong, himself or the support system, and why. Such an graphical interface providing explanation and justification has been implemented for a real time expert system integrated in the supervisory system of a simulated power plant (Taborin and Millot, 1989; Taborin, 1989).

2.2. Horizontal cooperation principles

In horizontal cooperation, the A.I. decision tool's output is directly connected to the process' control system. This presupposes that the A.I. tool reasons in real time (Figure 2). In the following, such a decision tool will be called an agent. The two decision-makers, the operator and the agent, are then on the same hierarchical level, and the supervisory tasks, as well as the resulting actions, can be distributed dynamically between them, in order to relieve the operator in situations of overload. This cooperation can be implemented according to two principles:

- The first principle is an 'explicit' dynamic allocation, controlled by the operator through a dialogue interface. He/she evaluates his/her own workload and the performance of the process and may then allocate some tasks to the agent if he/she is overloaded. The implementation is fairly easy, but the main drawback lies in the supplementary human workload involved in managing the allocation of tasks and issuing orders to the agent. To deal with that, Greenstein and Lam (1985) propose to optimise the ergonomics of the dialogue interface in order to minimise the extra load; and in an experimental study on an air control simulator they define and evaluate the criteria to take into account for characterising this interface.

- The second principle is an 'implicit' allocation managed by the computer. The main difficulty here lies in the necessity of defining an allocation criterion and in its implementation. To deal with that, Greenstein and Revesman (1986) propose to integrate a predictive model of human actions in the allocation control system and to allocate tasks which the operator is not supposed to do to the agent, in accordance with this model's predictions. Although the idea is enticing, it is nevertheless hardly feasible at present, given the difficulties encountered in the attempts to model human decision processes. Another method consists in seeking an optimal task allocation between the operator and the agent (Millot and Kamoun, 1988). The principle consists in searching for the optimal performance of the process controlled by both decision makers, by modifying iteratively the number of variables allocated to each of them. Furthermore, two constraints of maximum and minimum admissible workload, respectively, have been introduced in the task allocation controller, in order to avoid human overload as well as underload. This principle has been validated on a experimental laboratory platform which incorporates a simulated continuous process. Additional disturbances were introduced in the process and the decision team (operator and agent) had to compensate the corresponding process errors. The results have shown a near-optimal performance of the process and a well regulated workload for the human, due to the implicit allocation (Kamoun, 1989; Kamoun et al., 1989).

These horizontal cooperation principles have been transposed to the air traffic control domain, especially for the tactical level which involves the radar controller. The experimental platform, SPECTRA, built for this purpose is described below (Debernard et al., 1990).

3. The multi-level organisation in the air traffic control and assistances

3.1. AIR TRAFFIC CONTROL FUNCTIONALITIES

The air traffic control consists in supervising all flights to ensure flight safety, regularity and also economy. French air space is divided into many sectors and each sector is supervised by two controllers. The controllers have to guide aircraft in the sector from its entry beacon or departure airport to its exit beacon or arrival airport.

Air traffic control is a hierarchical activity. Its constituting functions are separated into two levels (Figure 3).

Controllers' tasks are defined with respect to these levels. The tactical controller, called the 'radar controller', supervises the traffic and talks with aircraft pilots. The

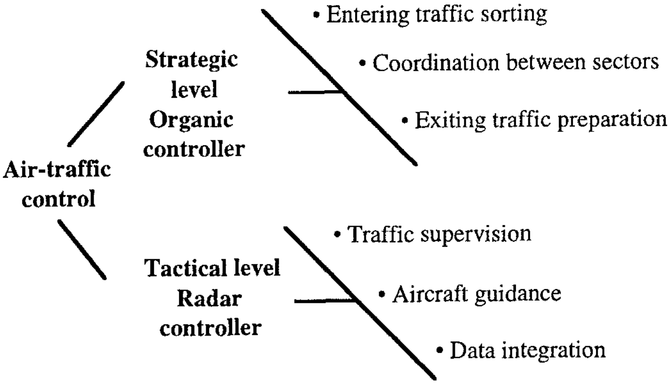

Figure 3. The roles in the air-traffic control.

CALLSIGN	EFL	last beacon of the precedent sector	entry beacon	exit beacon	first beacon of the following sector	CAPE
TYPE	TFL					RATE
DEP ARRIV		passing hour	passing hour	passing hour	passing hour	MACH SPEED
RFL LEVEL/	CFL					KNOT SPEED

Figure 4. A strip.

supervision consists in anticipating possible conflicts and resolving them. The dialogue with pilots consists in informing them about traffic and perhaps asking them to modify their initial trajectory in order to avoid a conflict. The strategic controller, called the 'organic controller', ensures the coordination between sectors in order to avoid conflicts on the borders of the sector which are not solvable. His/her second task consists in anticipating traffic density and regulate the radar controller's workload. Presently, both radar and organic controllers use paper strips and radar screens. Each strip contains the flight plan of an aircraft (Figure 4). The organic controller receives the strip before the entry of the plane into the sector. He/she analyses it and transfers it to the radar controller who sorts it according to the dynamic evolution of planes.

The proposed new organisation aims at increasing sector capacity by regulating the controllers' activity and maintaining optimal global performance and optimal global system reliability. This new organisation integrates human-human communication and proposes an assistance at each level (Figure 5). On the one hand, at the tactical level, the assistance tool is based on the dynamic task allocation principle. It consists in inserting, in the control and supervisory loop, a task allocator which shares control tasks between two agents: the radar controller and the expert system, called SAINTEX. On the other hand, at the strategic level, the assistance tool is a system cooperating with the organic controller and oriented toward a scheduling assistance tool. Its main purpose is the regulation of the radar controller's activity,

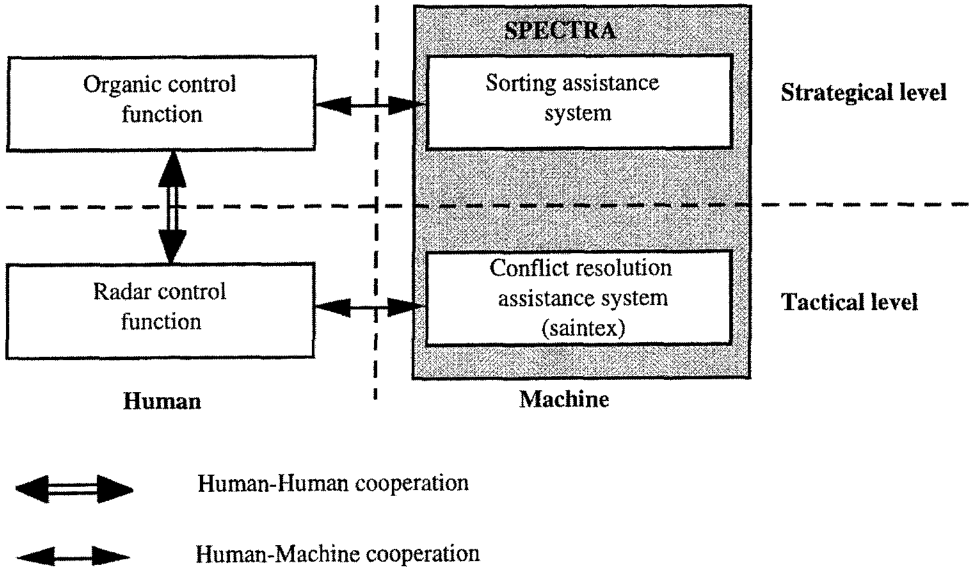

Figure 5. Generic assistance structure.

managing the tactical task allocation between the radar controller and SAINTEX. The assistants at both levels are integrated into an experimental platform called SPECTRA.

The assistants are presented in the next sections.

3.2. TACTICAL ASSISTANCE

At the tactical level, the experimental platform, SPECTRA, integrates two different cooperations (Debernard, 1992).

The first one opens opportunities for conflict resolution automation between controllers and aircraft. In SPECTRA, the controller can modify the flight parameters and obtain their exact values which are displayed in real- time. Presently, this communication is done by radio. In future, it will be done by mode S radar and data link.

The second provides assistance to the aircraft guidance by conflict detection and resolution. This is the expert system 'SAINTEX' (Angerand and Le Jeannic, 1992) (Figure 6). It can resolve conflicts under rather simple conditions. In its first version, SAINTEX can detect conflicts by extrapolating the trajectories of the planes which are inside or near the controlled sector, but it can only resolve conflicts between two stable planes (i.e. planes with a flight level which can not change) by deflecting one of them. Moreover, the context is that of night control which is easier than daytime control, because each flight crosses the sector in a straight line between two beacons: a sector entry and a sector exit point (during

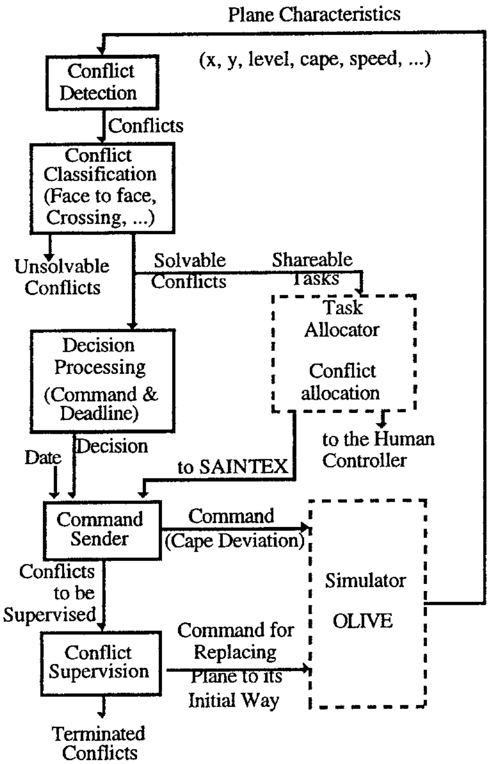

Figure 6. SAINTEX description.

daytime, because there is a lot of traffic, a flight has to follow a route defined by several beacons to avoid too many conflicts and to facilitate conflict detection).

Furthermore, SAINTEX classifies the detected conflicts and determines whether it can solve them or not. The solvable conflicts define the shareable tasks and SAINTEX calculates the trajectory deviation order to be issued to the pilot so as to solve the conflict. When a conflict is allocated to SAINTEX, the order is sent to the plane at the time calculated. When the conflict has passed, SAINTEX issues an other order to put the deviated plane back on its initial bearing.

The task allocator informs each decision maker, the radar controller and SAINTEX, about the task allocation so as to prevent decisional/command conflicts between them. The functioning of the task allocator control depends on the mode of the dynamic task allocation. In explicit mode, the task allocator is managed by the human air traffic controller. In implicit mode, the task allocator is managed by SPECTRA.

3.3. Strategic Assistance

To help the organic controller in his/her role of sorting entering traffic, ensuring coordination between sectors and preparing exiting traffic, the assistance suggests a prediction about the traffic and its interactions. The organic controller has to anticipate the influence of entering aircraft on the current traffic and estimate the influence the implementation of solutions from SAINTEX may have on the radar controller. We therefore need to construct a model of the air traffic control, and for that purpose we have used the production control as a model. Functionally, the organic controller's role of sorting entering traffic corresponds to a detailed scheduling function.

Formally, a scheduling problem is defined as (Gondran et al., 1985): given an objective to be achieved, which involves the prerequested execution of tasks under many constraints, determine the execution programme for these tasks. This formulation shows that scheduling is a way to specify concrete problems practically, with objectives, tasks, and constraints.

As far as air traffic control is concerned, the objective is to take the aircraft from their entry to their exit beacons. Constraints are radar controller capacities, sector capacities, economical flight parameters, and safety parameters. Thus, the organic control functions' role of filtering entering traffic is a scheduling problem.

In reality, this scheduling task is qualitative. He/she appreciates the control situation the radar controller has to face. When he/she estimates the situation as being intolerable, when the radar controller tends to be overloaded, he/she will modify the aircraft flight level in order to eliminate conflict or will delay the aircraft. In the case of automation, this qualitative appreciation is not sufficient, and with an significant number of planes this task becomes more and more difficult for the organic controller to manage. In the case of human-machine cooperation, an assistance will be developed. Hence, a quantitative appreciation of the radar controller situation is necessary.

The scheduling module contains three sub-modules (Figure 7): task set prediction, characterisation of the predicted set of tasks, and partitioning. All these submodules are based on an activity model of the radar controller.

Air traffic situations are decomposed into several tasks which the radar controller has to do. Each task is described by four parameters: its released date, its due date, its processing time, and a sharing indicator with the value 'true' if the task can be allocated to SAINTEX. The characterisation sub-module uses the set of tasks given by the prediction sub-module in order to determine subsets in which tasks cannot be processed without overlapping. When such subsets, called strictly intolerable, exist, the partitioning sub-modules attempt to separate each strictly intolerable subset into two subsets, one in which no overlapping occurs and one consisting of only shareable tasks, allocated to the controller and to SAINTEX respectively. This partition is transmitted to the task allocator.

The following sections detail the tactical integration and its validation.

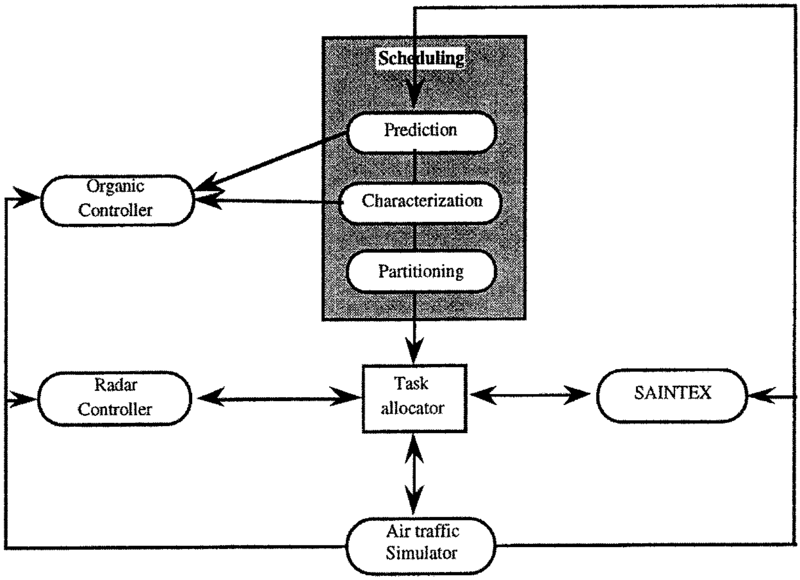

Figure 7. Composition of the assistance on the strategic level.

4. Tactical level experimentation

4.1. SPECTRA V1 GENERAL STRUCTURE

The first experiment with dynamic task allocation is implemented on an experimental platform for air traffic control, called SPECTRA V1. It simulates the radar controller's tasks. This platform is simplified, with an imaginary sector and traffic.

SAINTEX, the tactical assistance, can only solve simple conflicts, called shareable conflicts. The experimental platform presents two allocation modes: explicit and implicit (Figure 8).

The former mode concerns a pre-emptive explicit task allocation. In this mode, the human air traffic controller manages the task allocator through a dialogue interface (Radar View and Electronic Stripping Interface). He/she estimates his/her own performance and workload, and he/she allocates tasks either to himself/herself or to SAINTEX. Shareable conflicts are indicated with a specific colour on the operator dialogue screen and radar view. The deadline for the conflict to become non-solvable by SAINTEX as well as the deviation order it proposes, are displayed on the flight strip. Initially, all planes are allocated to the controller. If he/she feels overloaded, he/she can select a conflict and transfers it to SAINTEX. In pre-emptive allocation, the controller can modify the allocation of a shareable conflict. But at that time, if the order deadline given by SAINTEX is passed, this conflict cannot be solved by SAINTEX anymore.

The latter mode is non pre-emptive implicit task allocation controlled by an automatic management system implemented on the computer. This allocation depends

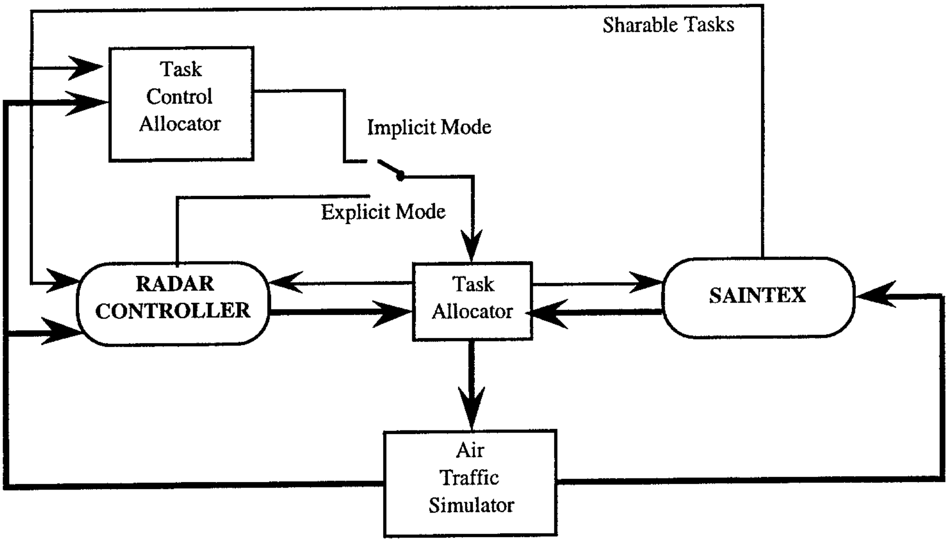

Figure 8. Explicit and implicit modes integrated into SPECTRA V1.

on the intrinsic limitations of the two decision-makers. For SAINTEX, those limitations are technical: it can only solve the most simple conflicts. For the human radar controller, these limitations are related to workload. For the moment, only the task demands are assessed in real-time. So, when those demands are too high and exceed a maximum level, the shareable tasks are allocated to SAINTEX. In this case, the conflict with the nearest order deadline is chosen and transferred to SAINTEX which displays its resolution strategy on the strips. Otherwise, the conflict is allocated to the human controller.

4.2. Main Results

The scenarios used for these experiments have been designed to overload the air traffic controller in such a way that dynamic allocation would be useful. Therefore, they involve a great number of planes (between 40 and 50 per hour), that are generating a lot of conflicts ($\approx$ 20) of different nature, within a large geographical sector (Vanderhaegen, 1991).

One training scenario permits controllers to get used to the SPECTRA interface in explicit mode in the course of two hours. Other scenarios have been created for three kinds of experiments. In the first type, the controller is not aided. In the second kind, he/she is supported by SAINTEX in an explicit dynamic allocation mode. In the last scenario, he/she is assisted in an implicit allocation mode.

These experiments have been performed with nine qualified male air traffic controllers. Each controller began with the training scenario. Subsequently, three experiments, with three different scenarios so as to avoid learning effects, were performed without assistance, in explicit mode, and in implicit mode.

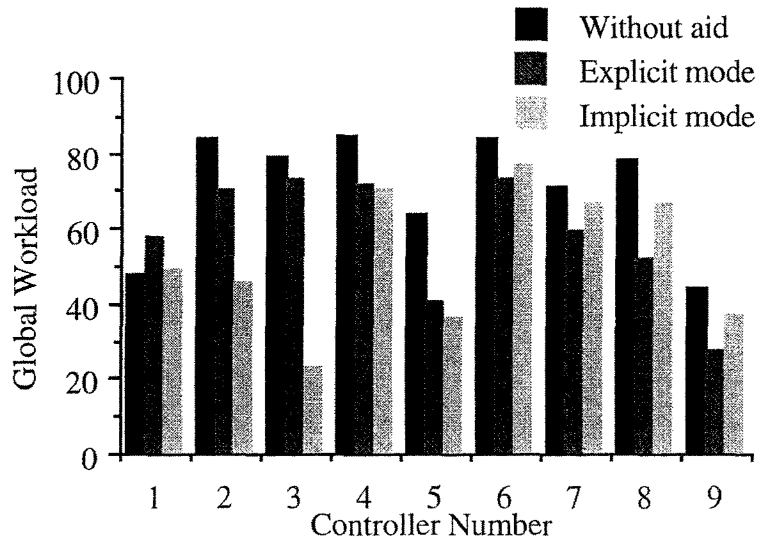

Figure 9. TLX results for each experiment.

The global workload was calculated for each controller and for each experiment on the basis of the TLX method. Figure 9 presents the global workload for each experiment.

All of the controllers, except controller number 1, have assessed that the experiment without assistance was more difficult and more overloaded than the others. For four controllers (2, 3, 4 and 5), their workload with the implicit mode was less serious than with the explicit mode. For the others (6, 7, 8 and 9), the explicit mode generates the less serious workload.

A dynamic task allocation mode (either implicit or explicit) therefore seems to improve the air traffic control task and to reduce the global workload.

Figure 10 shows the two criteria related to the performance. Economic criterion is defined as the ratio of real consumption of each plane between the entry and exit beacons by the theoretical consumption of each plane. Safety criterion is defined as the ratio of the air-miss number by the conflicts number. Here again, we can see that in a context without aid, the performance is not as good as with dynamic task allocation. Furthermore, the implicit mode seems to be the most efficient with regard to the safety criterion.

The X-axis of Figure 11, represents the cooperation level defined as the ratio between the number of conflicts allocated to SAINTEX and the total number of conflicts to handle. We can see that the more SAINTEX is used, the better the safety criterion.

Therefore, dynamic tasks allocation helps to increase the efficiency of the traffic control management in a context of high traffic density.

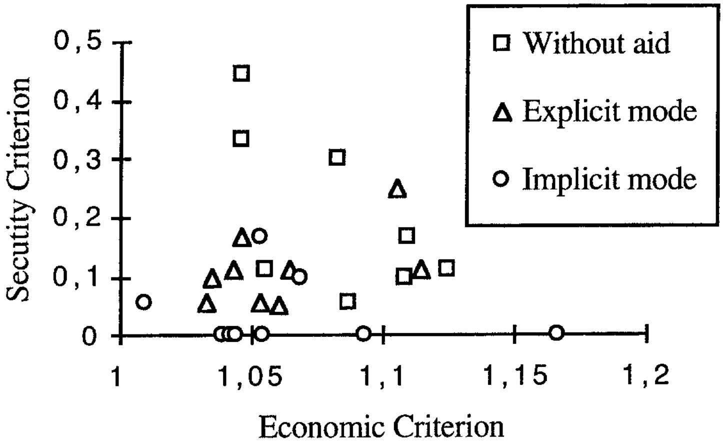

Figure 10. Global performances: economic and safety criterion.

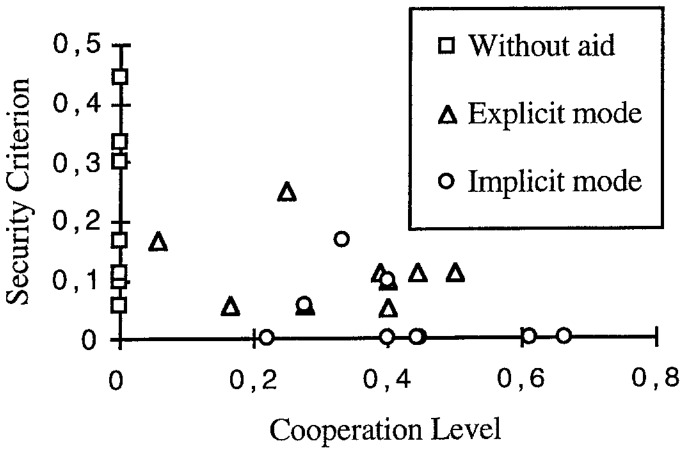

Figure 11.

4.3. Discussions and Criticisms

SPECTRA V1 indicates that assisting the controller in the role of aircraft guidance is not sufficient. The aim of the assistance is to put the controller neither in situation of weak workload in comparison with his/her capacities nor in a situation of overload. For example, consider a shareable conflict. The controller makes its resolution without overload. When a non-shareable conflict occurs, only the controller can resolve it. He/she thus takes it on and enters a overload situation. His/her workload cannot be reduced because a shareable conflict resolved by a controller cannot be reallocated to the system.

Of the two modes of dynamic task allocation (Millot, 1988), the implicit mode seems to be the most efficient according to the results, but the radar controllers

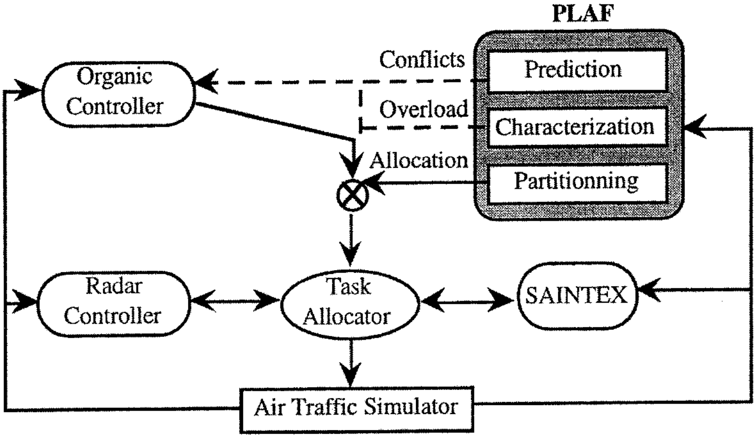

Figure 12. SPECTRA V2 general structure.

do not like this mode because they cannot modify the allocation if SAINTEX's solution is not the best one (Debernard et al., 1992). The present allocation system does not regulate the workload in an optimal manner. Moreover, from a qualitative point of view, in the explicit mode the controller must play a double role: a tactical role in terms of conflict resolution for all the tasks at the tactical level, and a strategic role in terms of conflict prediction and allocation between SAINTEX and himself. That is, he/she plays his/her own role of radar controller as well as that of organic controller.

5. Strategic assistance

The experimental platform integrating the new organisation implements the two levels of tactical and strategic assistances presented above. The following section describes the new experimental work station which integrates both controllers and the experimental conditions.

5.1. SPECTRA V2 GENERAL STRUCTURE

This new experimental platform, called SPECTRA V2, consists of two work stations, the strategic and tactical one (Crévits et al., 1993) (Figure 12).

The experimental platform is developed under VMS, in ADA, and with X-Windows tools.

Each suite presents two interfaces, a radar screen and an electronic stripping interface. A third screen is positioned between the two work stations and represents the strategic assistance interface (Figure 13).

In this experiment, we asked the controllers to assume their radar or strategic tasks and not the task of the other controller. In reality, sometimes, the organic controller helps the radar controller by giving orders to pilots. But in this case,

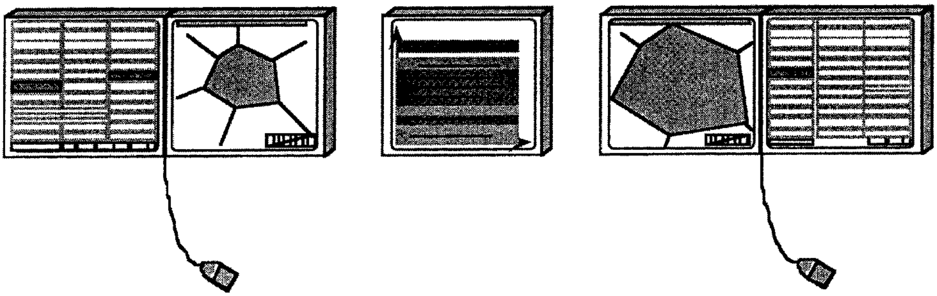

Figure 13. Experimental platform integrating strategic assistance.

we asked controllers to use the tactical assistant, instead of getting help from the organic controller. Displays were constructed according to these principles. That is, the radar controller and organic controller interfaces are different with respect to the actions the operator can perform, but the information presented is the same. The radar and strip views represent the aircraft evolution in real-time, in the controlled sector, and in the adjacent sectors. On the radar interface, a plane is displayed by a square indicating its actual position and a 'comet tail' indicating its previous positions. On the strip interface, a flight is illustrated by a strip, where all flight plan information is given. Three action types on the screens are possible:

- to give order,
- to take information,
- to point out something.

The cooperation with SAINTEX is organised as follows:

- orders proposed by SAINTEX are displayed on the concerned flights strips,
- the strip and radar representation of a flight managed by SAINTEX are designed with a specific colour.

When an aircraft crosses the controlled sector, from its entry beacon to its exit beacon, the possibilities offered by the screens would be described as follows: The organic controller receives one strip. He/she includes it on his/her strips board. A few minutes later, when the plane enters the sector, he/she transfers the strip to the radar controller.

Both radar and organic controllers have the strip on their strip board.

The experiment implements two experimental modes, the explicit mode and the assisted explicit mode. The first one allows the two controllers to allocate a conflict to SAINTEX. In the second mode, PLAF (French acronym for 'PLanification d'AFfectation') makes the allocation according to the radar controller's workload and only the organic controller can change the allocation.

In explicit mode, if a conflict appears and if it is shareable, the organic controller must decide to allocate it to SAINTEX, if the radar controller is overloaded, for example, or to leave it to the human operator. The strategic assistance interface is described in the following section.

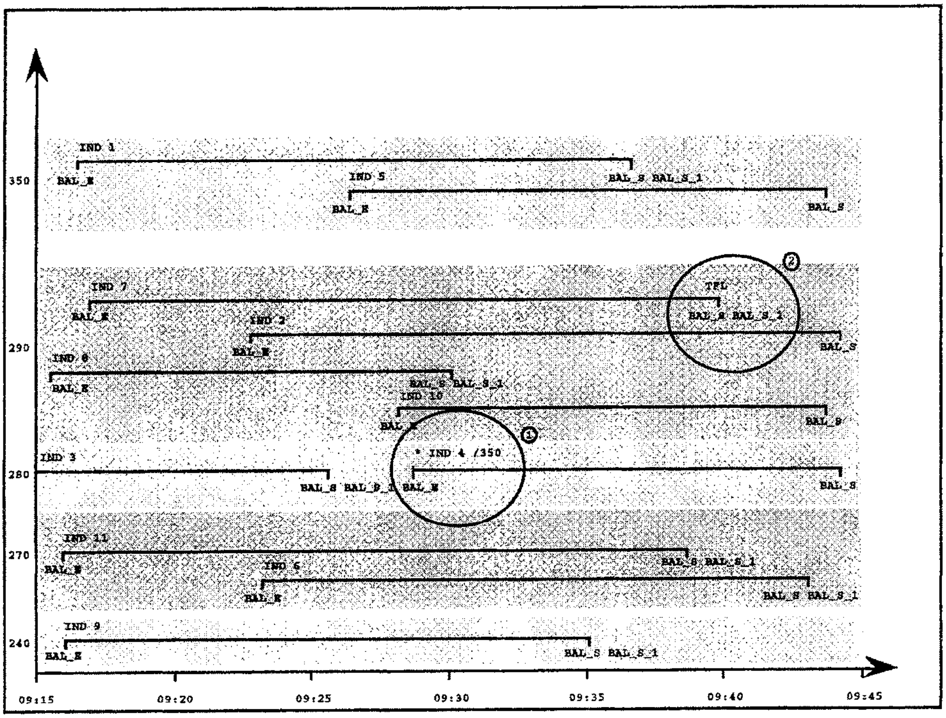

Figure 14. Strategic assistance interface, aircraft information.

5.2. THE PLAF INTERFACE

The purpose of the PLAF interface are:

- to help the organic controller to predict the traffic and the radar controller workload,
- to justify dynamic task allocation defined by PLAF.

This type of representation allows to respect the duality, between the precision and controller informational overload on the one hand, and on the other hand, between the representation purposes and usual one.

The traffic is displayed along two axes, one for the flight level and the other for time. The time axis is graduated to predict the traffic within thirty minutes. On the flight level axis, levels are represented, but only levels where there are planes (Figure 14).

Each flight is illustrated by a boundary line at the entry and exit beacons as well as others pertinent information, such as the difference between the Clear and Request Flight Level (the level ordered by the controller and the level requested by the pilot), and the Clear and Transfer flight level (the level ordered by the controller and the level at which the plane is to be transferred from one sector to an other) (Figure 14 point 1 and point 2).

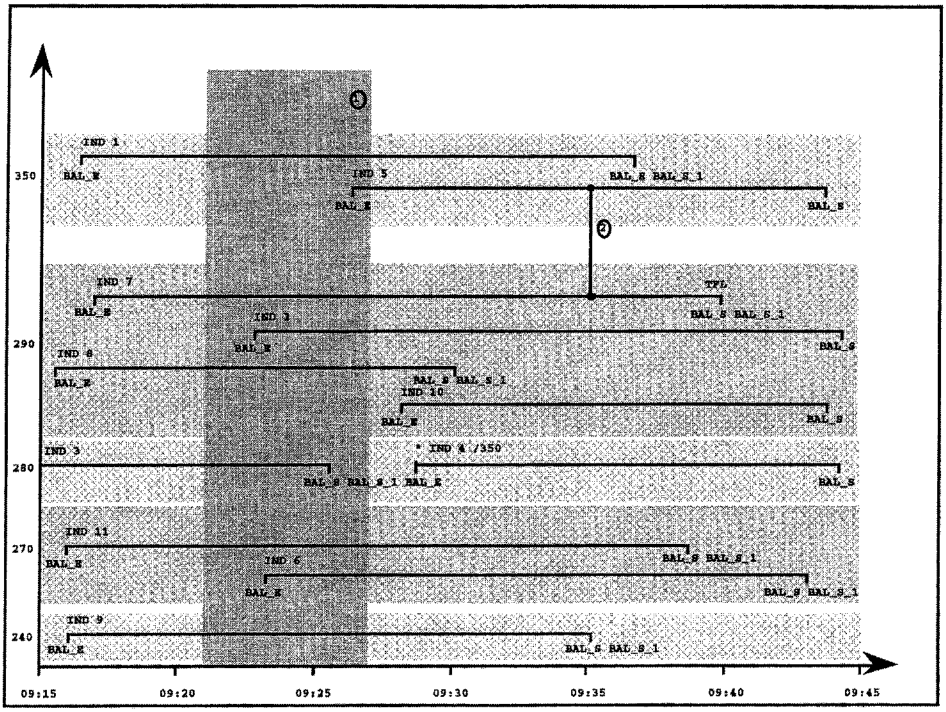

Figure 15. Strategic assistance interface, overload and conflicts detections.

The relevance of this interface is the prediction given by the strategic assistant about conflicts and the period of overload of the radar controller. A conflict is indicated by a red line joining flights in conflict (Figure 15 point 2). An overload period is represented by a zone covering all levels and limited by a beginning and an end date of overload (Figure 15 point 1). Thus, the organic controller has criteria to allocate conflict resolution to SAINTEX or to the radar controller, and both controllers have all information concerning the decision of the dynamic task allocator in the assisted explicit mode.

This interface would thus allow controllers to achieve better cooperation with assistants. The radar controller knows what the expert system is doing. This is necessary because interactions between a plane managed by the radar controller and an other plane managed by SAINTEX can occur. For the transfer of conflict, the organic controller has information on the radar controller workload, but he/she must be careful that the system does not disturb the operator in his/her conflict resolution. If planes allocated to the system do not provoke conflict with planes allocated to a human operator, the radar controller will have confidence in it, even if SAINTEX's resolution is not optimal. The major difference with the preceding experiment is the presence of the organic controller who supervises and corrects SAINTEX's acts. So, human-human cooperation, supported by the communication

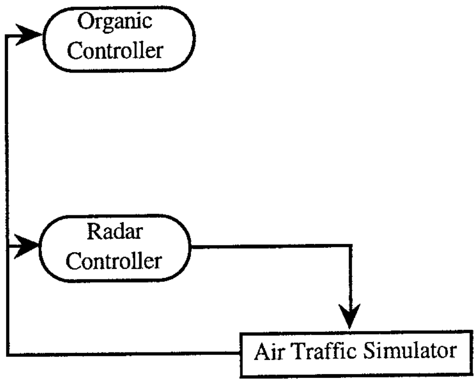

Figure 16. First experimental setting.

between radar and organic controllers, must involve human-machine cooperation, i.e. the cooperation between the radar controller and SAINTEX.

5.3. The Experimental Context

An additional experiment has been arranged to test the new organisation with strategic assistance (Lemoine et al., 1994a). Several traffic scenarios were built, three for training, and three others for experiments, with heavy traffic to evaluate the efficiency of the assistance tools.

For this experiment, three experimental settings are required to obtain objective results. The first experiment puts controllers in a work station similar to the current one, i.e., without help (Figure 16). For the moment, controllers use radar 'scope' and paper strips. Moreover, the platform SPECTRA V2 does not simulate the communication between sectors and with pilots. But our control suite is similar to the future control room work station, with radar and interactive electronic strip interface, and the scenarios are close to real traffic.

This setting is the reference setting for analysing the other experimental settings.

The second experimental setting implements the explicit mode with the integration of tactical assistance (Figure 17). The organic controller allocates conflicts to the radar controller or to SAINTEX. The only information given is conflict detections and all of SAINTEX's propositions.

The third experimental setting presents tactical and strategic assistances in an assisted explicit mode (Figure 18). When a conflict is detected, the strategic assistance, PLAF, allocates it to the radar controller or SAINTEX. The information displayed on the strategic assistance interface explains the reasons for the allocation (prediction of conflicts, overload). But the organic controller could change the allocation and give the conflict to the radar controller.

The experiment took place during three weeks in the East En-Route Control Centre of France, with three couples of qualified controllers. To avoid sequence

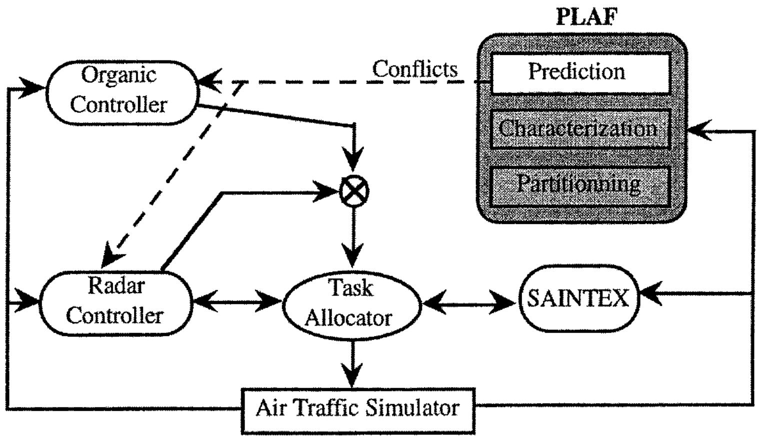

Figure 17. Second experimental setting.

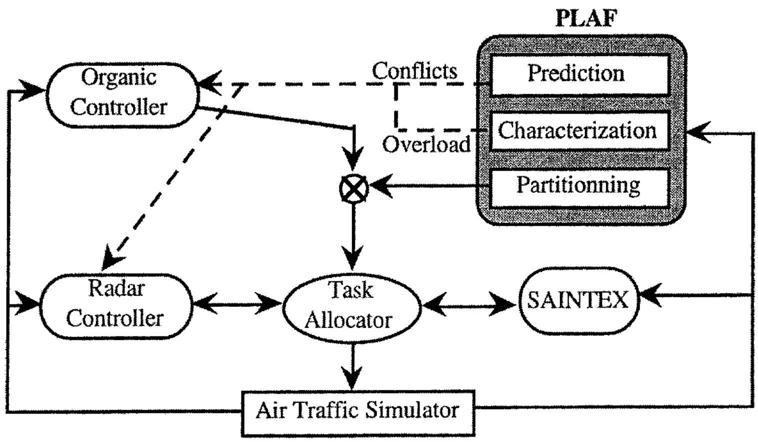

Figure 18. Third experimental setting.

effects, the three experimental settings were permuted with three scenarios. They have been built with parts of real traffic of the East sector of the French Space. The controlled sector groups together nine sectors of the East En-Route Control Centre. The experimental protocol was conceived as follow (Table I).

It takes one half day to make one experiment with one couple in one setting. Immediately after the end of a simulation run, the organic and radar controllers made free recall in different rooms. Just after free recall, the organic controller filled in a specific questionnaire suited to the situation of the experiment (one of the three settings) and, at the same time, the radar controller commented on the replay. The replay presents the traffic situation and all actions taken by controllers and assistance tools. And, finally, we reversed the radar and the organic controller.

Table I. Experimental protocol

	1st couple	2nd couple	3rd couple
1st passing	1st condition 1st scenario	2nd condition 2nd scenario	3rd condition 3rd scenario
2nd passing	2nd condition 3rd scenario	3rd condition 1st scenario	1st condition 2nd scenario
3rd passing	3rd condition 2nd scenario	1st condition 3rd scenario	2nd condition 1st scenario

Questionnaires, free recalls, and replay verbalisations have been recorded to be transcribed.

5.4. Some Results

The results have been derived from studying the answers of organic and radar controllers to the questionnaires. Their answers about the experimental context, the platform, and the scenarios are the same. A difference appears when the discussion deals with the assistance offered by SAINTEX. It is due to the different approaches of strategic and tactical work.

5.4.1. *The realism of the experimental situation*

The realism of the situation depends on the context and the scenarios. The controllers exhibit different interest in the experiments but two thirds of the subjects assert that they have performed the control task with the same interest as in a control room. The work situation is different because of the platform with its two work stations and, especially, the electronic strip board given to each controller. In real settings, they work side by side with a single board of paper strips. The positioning of the strips on the board occupies a significant part of their work but in the experiment this work is doubled because each controller has to arrange his/her own board. Furthermore, positioning is difficult due to the size of the sector. Usually, controllers link a strategic part of the sector (which can be defined as a conflict point) with a particular part of the board. In the experiment, there were many conflict points, and because plane transit took a long time, the controller had to update his/her board very often.

On the one hand, controllers' workload can thus be increased because of electronic stripping, but on the other hand the organic and radar controllers' work takes less time. In this experiment, there were no verbal communication between the organic controller and the adjacent sectors and between the radar controller and the pilot, and orders for the flights were transmitted through interfaces.

The disappearance of verbal communications and paper strips seem to produce a loss of written and auditory memory. Positioning symbols on an electronic strip with a mouse is a different activity than the writing of symbols on the paper strip with a pen. And the controller seems to loose auditory memory because he/she does not overhear verbal exchanges with pilots and with the controllers of the adjacent sectors. If he/she wants this information he/she has to find it on the strip, and this search can take more time.

This lack of communication brought about a new organisation of work because the controller cannot ask the adjacent sector to have a plane earlier to resolve a conflict. In addition, today, when a pilot calls the controller listens to the pilot, finds the strip, and answers the pilot by verifying the route of the plane and giving an order. In the experiment, a pilot's call is simulated by a flag and a sound. So controllers did not have to answer quickly to the call from the plane and did not have to check the route. This change made controllers make errors.

But it is not the only possibility of making an error. Scenarios were also source of errors because we built high-density traffic scenarios with about sixty planes per hour, and airways are not always like that in reality. But the size of the sector and the number of planes were a necessity to raise controllers' workload.

These problems have been brought up by controllers but they explained that these points are details and in their work they quickly got used to unusual environment.

5.4.2. *Tactical assistance*

The remarks made by controllers change with the context. If a controller imagines that SAINTEX can be implemented in the actual work station, he/she deems that it is useless and inapplicable. It is useless because today traffic is distinctly less serious, and the number of conflicts is not sufficient for a controller to give tasks to the assistant without putting himself into a low load situation. Furthermore, SAINTEX is inapplicable, because even if it can solve some conflicts which are significant of real control situation, it can only do so under ideal conditions. Actually, SAINTEX does not take into account several categories of information such as meteorological conditions, military zones, breakdown of planes, or the behaviour of pilots. These remarks could be taken into account in a future assistance tool but they do not prevent the experiment from revealing many indicators of importance to the study of human-machine cooperation.

If they remain within the scope of the simulation, the controllers recognise that giving remote conflicts to SAINTEX is a pertinent help. Usually, conflicts have been allocated by the organic controllers and therefore the radar controllers respect their decisions and leave the conflicts to SAINTEX; this allocation allows a decrease of the radar controller's workload and allows her/him to concentrate on resolving the more difficult conflicts. Nevertheless, according to controllers, SAINTEX should suggest more refined solutions, because as it is planes are penalised in terms of fuel consumption and duration of the flight. The radar controllers delegated one third of the sector's traffic to SAINTEX but they continued to verify SAINTEX's actions. They compare this problem with their actual work situation where they are always checking actual automatic systems (radar view, automatic coordination between two sectors, etc.).

5.4.3. *Strategic assistance*

The assistance tool allows the organic controller to allocate a conflict to SAINTEX or to leave it to the radar controller. It is an interface which displays several kinds of information. The tool presents about thirty minutes of traffic, predictions of conflicts and of the radar controller's overload. One radar controller out of three took the time to watch the interface of PLAF and to know of all the conflicts which are shareable. And two organic controllers out of three used this information to detect conflicts and to know whether traffic is increasing or decreasing. Even if this interface seems difficult to read, because of the density of information, the idea to use a third screen to present assistance tools' information appear to be useful because radar and strip views already display too much data and the controller can look for the information if he/she has the time and if the need arises.

Moreover, conflict detection seems difficult with the new interfaces. Today, a controller detects a conflict by means of paper strips. The positioning of the strip board allows the controller to detect if two planes fly over the same beacon at the same time. The controller can confirm the conflict by watching the radar screen. But in this experiment, such type of detection is not possible because the route is only defined by no more than two beacons. This problem comes from SAINTEX which can only detect and solve conflicts if routes are straight.

The organic controllers allocate a conflict to SAINTEX if SAINTEX's solution allows them to avoid the conflict, does not generate other conflicts, and if the radar controller is overloaded. The experiments confirm the hypothesis that conflict allocation is a part of filtering entering traffic work realized by the organic controller at the strategic level. Nevertheless, organic controllers would like to have a more flexible assistance tool allowing them to modify the time the order will be sent or change the conflict resolution strategy.

5.4.4. *Human-human cooperation*

The mode of the dynamic task allocation tested in this experiment seems to be accepted by controllers: task allocation seems to be a part of the organic controller's activity, and the radar controller has confidence in the organic controller.

In the East En-Route Control Centre, the tasks of the radar controller and the organic controller are different and complementary. In an other control centre the organisation can be different. Two couples of controllers were used to work together and as far as the third couple is concerned we noticed that the two controllers, even though they had not worked together before, could work in perfect harmony, due to their training, each controller minding his/her own tactical or strategic tasks. All radar controllers prefer that the organic controller allocates conflicts to

SAINTEX, because he/she has more information and has it at an earlier point in time and, perhaps, more time than he/she has. Furthermore, the organic controller prepares the radar controller's work. He/she detects conflicts and informs the radar controller by underlining the symbols of the involved planes on the radar screen. Moreover, he/she marks items of information on strips, such as the Transfer Flight Level or Requested Flight Level, if they had to be changed. For instance, he/she will underline the destination in green if the plane has to descend and in red if there is a problem with the descent. Controllers appreciate such possibilities of communication but it is difficult to get time to remove the indicators from the screen.

6. Conclusion

The results of the SPECTRA V1 experiment emphasise the relevance of a tactical assistance tool, but the task allocation in explicit mode increases operator workload. The SPECTRA V2 experiment aims at studying a new organisation where dynamic task allocation between the radar controller and the conflict resolution system is implemented, and where the strategic level ensures task allocation.

The first results of SPECTRA V2 point to several interesting aspects. They seem to show the utility of the multi-level cooperative organisation and indicate the aspects we have to modify in more flexible assistance tools. These aspects mainly concern human-machine cooperation at the tactical and the strategic level.

In the future, these results will be supplemented by additional data concerning controller workload, conflicts, activation of the safety net, orders, etc.

In the same way, with the help of a team of psychologists, we will try to analyse how the tactical assistance tool changes the radar controllers' activities, and how the task allocation modifies the cooperation between the two controllers.

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