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EACAC 2001 REAL-TIME EXPERIMENT

INITIAL EVALUATION OF LIMITED DELEGATION OF SPACING TO THE FLIGHT DECK

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TITLE:

EACAC 2001 REAL-TIME EXPERIMENT

INITIAL EVALUATION OF LIMITED DELEGATION OF SPACING TO THE FLIGHT DECK

Volume I

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Abstract:

The report presents the analysis of the EACAC December'01 experiment. The objective of this 3 week experiment was to extend the scope of previous experiments towards more insight on the impact of delegation on controller activity (workload, monitoring, situation awareness) in E-TMA and make an initial assessment of its use in approach (transfer and co-ordination, flows integration). Six controllers from different European countries participated. The airspace simulated was part of Paris area, and consisted of four measured sectors (two E-TMA and two simplified approach sectors). The feeling from controllers is positive: the delegation is perceived as satisfying, and should enable a workload reduction. The acceptance is also revealed by the significant rate of use.

Subjective analysis of workload (ISA and NASA-TLX) tends to show that delegation reduces controller workload. Previous results were confirmed: delegation allows for a significant reduction in the number of manoeuvring instructions and for an earlier building of the sequences. The sector configuration has an impact on the use of delegation. Monitoring task was analysed through the use of eye movement tracking techniques. Results tend to show that, in very high traffic situations, delegation enables the focus to be maintained on the early part of the sector, that is on the sequence building area. Delegation does not modify the frequency of monitoring per aircraft. The situation awareness assessment method needs to be improved. In terms of safety, delegation does not induce more losses of separation but more stable and regular transfers. Delegation errors are mainly related to the set up of initial applicability conditions.

During the implementation phase, air traffic control systems and procedures will have to cater for, and assimilate mixed MODE S and classical transponder equipped flights, and maintain the interoperability between MODE S equipped and non MODE S equipped ground stations.

EXECUTIVE SUMMARY

The report presents the analysis of the EACAC December'01 experiment. The objective of this 3 week experiment was to extend the scope of previous experiments towards more insight on the impact of delegation on controller activity (workload, monitoring, situation awareness) in E-TMA and make an initial assessment of its use in approach (transfer and co-ordination, flows integration). Six controllers from different European countries participated. The airspace simulated was part of Paris area, and consisted of four measured sectors (two E-TMA and two simplified approach sectors). The feeling from controllers is positive: the delegation is perceived as satisfying, and should enable a workload reduction. The acceptance is also revealed by the significant rate of use. Subjective analysis of workload (ISA and NASA-TLX) tends to show that delegation reduces controller workload. Previous results were confirmed: delegation allows for a significant reduction in the number of manoeuvring instructions and for an earlier building of the sequences. The sector configuration has an impact on the use of delegation. Monitoring task was analysed through the use of eye movement tracking techniques. Results tend to show that, in very high traffic situations, delegation enables the focus to be maintained on the early part of the sector, that is on the sequence building area. Delegation does not modify the frequency of monitoring per aircraft. The situation awareness assessment method needs to be improved. In terms of safety, delegation does not induce more losses of separation but more stable and regular transfers. Delegation errors are mainly related to the set up of initial applicability conditions.

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PROJECT WEB SITE

www.eurocontrol.fr/projects/cospace/

ABBREVIATIONS

Abbreviation	De-Code
ADS-B	**A**utomatic **D**ependant **S**urveillance – **B**roadcast
API	**A**ircraft **P**roximity **I**ndex
ART	**A**nalysis and **R**eplay **T**ool
ASAS	**A**irborne **S**eparation **A**ssistance **S**ystem
ATC	**A**ir **T**raffic **C**ontrol
ATM	**A**ir **T**raffic **M**anagement
ATWIT	**A**ir **T**raffic **W**orkload **I**nput **T**echnique
CDTI	**C**ockpit **D**isplay of **T**raffic **I**nformation
CNS	**C**ommunication, **N**avigation and **S**urveillance
CWP	**C**ontroller **W**orking **P**osition
EACAC	**E**volutionary **A**ir-ground **C**o-operative **A**TM **C**oncept
EATCHIP	**E**uropean **ATC** **H**armonisation and **I**ntegration **P**rogramme
EEC	**E**UROCONTROL **E**xperimental **C**entre
ETA	**E**stimated **T**ime of **A**rrival
E-TMA	**E**xtended **T**erminal **M**anoeuvring **A**rea
EXC	**Ex**ecutive **C**ontroller
FIR	**F**light **I**nformation **R**egion
HMI	**H**uman **M**achine **I**nterface
IAF	**I**nitial **A**pproach **F**ix
ISA	**I**nstantaneous **S**elf **A**ssessment
N/A	**N**ot **A**pplicable
NASA-TLX	**NASA** **T**ask **L**oad **I**ndex
PLC	**Pl**anning **C**ontroller
SID	**S**tandard **I**nstrument **D**eparture
STAR	**S**tandard **T**erminal **A**rrival **R**oute
STCA	**S**hort **T**erm **C**onflict **A**lert
TIS-B	**T**raffic **I**nformation **S**ervice – **B**roadcast
TMA	**T**erminal **M**anoeuvring **A**rea
UIR	**U**pper **I**nformation **R**egion
WPT	**W**ay**p**oin**t**

1. INTRODUCTION

The purpose of this document is to present the analysis of the EACAC '01 experiment, conducted in November and December 2001. This experiment aimed at assessing the limited delegation of spacing task from controllers to flight crews in terminal area, using sequencing applications. The document is organised as follows:

- Section 2 introduces the principles of delegation;
- Section 3 introduces the experiment objectives and the method of analysis;
- Section 4 describes the experiment environment;
- Section 5 discusses the experiment results;
- Section 6 summarises the main findings;
- Section 7 draws some recommendations.

2. PRINCIPLES OF DELEGATION

2.1. BACKGROUND

The delegation of spacing tasks from the controller to the flight crew is envisaged as a possible option to increase controller availability, and beyond, to increase safety and/or capacity. The EACAC study focuses on near term applications taking place in current ATC organisations for both en-route airspace and terminal areas.

In the scope of defining a new task distribution between controllers and flight crews, from the onset of the project, two key constraints were identified and adopted. The first one is related to human aspects and can be summarised by “minimise change in current roles and working methods of controllers and flight crews”. The second one is related to technology and can be expressed by “keep it as simple as possible”.

Starting with the analogy of visual separation, the proposed task allocation relies on the delegation of spacing tasks in which the flight deck is tasked to implement a solution defined by the controller. Restricting the delegation to implementation tasks (as opposed to decision making tasks) is expected to preserve controller authority and understanding of the situation (“mental picture”). The delegation of spacing is at controller initiative, who can decide to end it at any time. The flight crew however can only abort it in case of problem onboard such as a technical failure. The delegation applies to pairwise situations: one aircraft is “delegated”, the other being “target”.

The delegation takes advantage of emerging CNS/ATM technologies in pre-operational state (ADS-B or TIS-B) along with additional avionics such as a Cockpit Display of Traffic Information (CDTI) or an Airborne Separation Assistance System (ASAS)[1].

The motivation of delegation is neither to “transfer problems” nor to “give more freedom” to flight crew, but really to identify a more effective task allocation beneficial to all parties. It is expected that the increased controller availability could lead to improved safety, which in turn could enable better efficiency and/or, depending on airspace constraint, more capacity. In addition, it is expected that flight crew would gain in awareness and anticipation by taking an active part in the management of the situation with respect to the concerned aircraft.

[1] Note that an ASAS is *not* an ACAS (Airborne Collision Avoidance System). Indeed, whereas an ASAS will support delegation of spacing task within an appropriate time horizon, an ACAS is only designed for extremely short term collision avoidance.

2.2. PRINCIPLES

The delegation covers two classes of application: sequencing operations in terminal areas, and crossing and passing applications in en-route airspace. For the sequencing applications that we will focus on during the simulation, in-trail and merging situations are proposed along with three levels of delegation (Table 1). For an extensive presentation of the applications, the procedures and the phraseology, see EACAC (2001a). Essential information were summarised in an aide memoire (Annex A).

Table 1: Sequencing applications

Delegation level	In-trail	Merging
Report separation	*Report in-trail distance*	*Report merging distance*
Maintain separation	*Remain behind*	*Merge behind*
Resume then maintain separation	*Heading then remain behind*	*Heading then merge behind*

The delegation is composed of three phases:

- Identification, in which the controller indicates the target aircraft to the flight crew of the delegated aircraft;
- Instruction of delegation, in which the controller specifies the task delegated to the flight crew;
- End of delegation, which marks the completion of the task delegated.

For illustration purposes, an example of the "Heading then merge behind" procedure is given in (Figure 1). In the example, DLH456 is the delegated aircraft, and AFR123 is the target aircraft. The two aircraft are flying along merging trajectories in descent with compatible speeds. The controller gives a heading instruction to initiate the spacing, and instructs the flight crew: ❶ to report when the predicted spacing at the merging point reaches the desired spacing; ❷ to resume own navigation to the merging point, and ❸ to adjust speed to maintain the desired spacing.

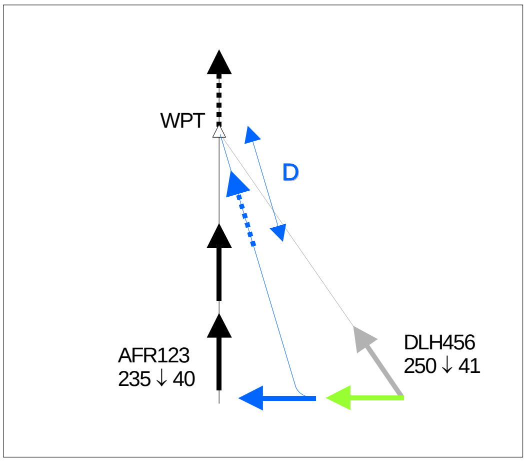


Figure 1: "Heading the merge behind" scenario

In terms of technology, no change on controller working positions, no controller-pilot data-link communication, no intent information from aircraft, no automation on-board, no coupling to the auto-pilot nor to the flight management system are expected at this point – although they could be of interest. There is no need to have a full traffic picture on board the aircraft. The minimum includes the display of relevant target aircraft information. An example of the display used in the EACAC pilot-in-the-loop experiments is presented on Figure 2.

Figure 2: Navigation display

Navigation display with the representation of the target aircraft (same converging situation as in Figure 1). The target aircraft is represented by the white chevron. The merging configuration is highlighted by a double dashed line linking target and delegated (own-ship) via the converging point. The symbol represents the position on the trajectory where the spacing will be acquired. The spacing scale in the left side indicates current (8.3Nm) and required spacing (magenta bug), spacing trend (yellow arrow) and closure rate (18kts IAS), and tolerance margins (amber bar). A suggested IAS (302kts) is also indicated below own-ship. In order to limit the clutter of the screen and also to avoid request from pilots, it is suggested to display only the target aircraft.

2.3. PREVIOUS EXPERIMENTS

A first small scale real-time experiment took place in June 1999. The main objective was to get feedback from both controllers and pilots, in order to assess the operational feasibility and potential interest of the concept as well as the proposed phraseology. Beyond, the objective was also to identify needs, other possible applications and evolutions, as well as indexes of evaluation for future experiments.

The results were qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses. The overall feeling about the method was "promising" with a "great potential", and could reduce workload. The notion of "flexible use of delegation" should enable a gradual growth of confidence and would also provide flexibility to use the method under different conditions (e.g. traffic, airspace, practice level).

A second larger scale experiment took place in 2000. It consisted of two sessions of two weeks each: one in June, the other in November. 12 controllers from different European countries were involved. The main objective of this second larger scale experiment was to validate the concept in a more realistic environment and get a first quantitative evaluation of the expected benefits in terms of workload reduction for the controller and flight optimisation for the pilot. Flight deck issues were also addressed through the connection of a cockpit simulator.

Controllers' feedback confirmed June '99 feeling. They stressed benefits in terms of workload, anticipation and quality of control. Objective analysis showed a reduction of manoeuvring instructions, an anticipation in the building of sequences in E-TMA or in the resolution of lateral conflicts in en-route airspace. Regarding flight efficiency, delegation had a minor positive impact.

For more details, see the complete report on the Web site www.eurocontrol.fr/projects/cospace/

3. EXPERIMENT OBJECTIVES

3.1. HIGH LEVEL OBJECTIVES

The implementation of the concept of delegation requires a validation process to be followed. Typically (and quite basically), the validation follows three main steps: the definition of concept objectives, the identification of acceptance/rejection criteria and the assessment of these criteria. The main high level objectives proposed in ATM2000+ strategic objectives and by MAEVA methodological framework are safety, economics, capacity and human involvement. Following suggestions issued in the NUP2 TT COOPATS validation plan, the economics objective is translated into efficiency and an additional objective defined as design and feasibility is considered.

Even though a direct relation between the above mentioned objectives and metrics enabling their assessment is far from existing, the present section proposes a first step, consisting in listing our assumptions in terms of expected benefits and limits of delegation. Derived from these assumptions, we will describe four low level objectives used to structure the experiment analysis.

We expect delegation to enable a **better organisation of task**, where actors' expertise is appropriately used. Typically, we assume controllers are in the best position to analyse the situation and define strategy (i.e. how to sequence aircraft) while flight crews are more appropriate to implement actions (e.g. perform speed adjustments on a regular basis).

However, involving the flight crew into part of the controllers' task requires a clear definition of the task domain. Understanding such limits is essential to avoid role confusion. Typically, it is important for flight crews to understand that delegation is nothing more than the execution of an instruction. No questioning of controllers strategy or decisions should be allowed. From the controllers' perspectives, the message also needs to be clear. Controllers are responsible for delegating clean situations, that is spacing actually possible to maintain by the flight crew. Whereas it is flight crew responsibility to comply with the instruction, it is still the controller responsibility to ensure that separation is maintained. Consequently, delegation is expected to provide availability in reducing the load in terms of active control rather than monitoring. Whereas it should reduce the number of instructions given, it should not modify the frequency and the quality of the scanning patterns. Whether it is feasible and whether it provides benefits to reduce active control without reducing monitoring load is a question.

Delegation should benefit to **situation awareness** on ground and in the air. Keeping controllers in charge of the decision making should enable them to be aware of the initial situation and to predict how it should evolve. In addition, the availability possibly gained with delegation could be used to monitor and assess if the situation evolves. In the flight deck, the goal-oriented instructions should help understanding the context and improve the task management with flight crews no longer reacting to unexpected speed and heading instructions, but rather planning them. However, delegation might influence the content of situation awareness and how it is updated. Typically, controllers might no longer apprehend single aircraft or dual configuration, but starts considering chains of aircraft as basic entities. Because we can not decide a priori if such changes are positive or negative in terms of safety, their assessment is necessary. Degraded scenarios requiring detection and recovery of problems could be used in order to assess the respective efficiency of different practices.

In addition to reducing peaks of unacceptable workload for the controllers, delegation provides **redundant monitoring and loops of control**. It should improve error management in enabling controllers and flight crews to detect and recover errors. Typically, controllers should be in a position to assess if aircraft behaviour are consistent with their expectations, whereas flight crews might detect erroneous target identification, erroneous applicability conditions or unexpected target behaviour.

However, we identify risks of **over-trust between controllers and pilots**. If delegation, within acceptable applicability conditions, enables pilots to successfully conform to controllers instructions, is there a risk, if delegation works as expected most of the times, that controller start reducing their monitoring of delegated aircraft? What about the risk of delegating non feasible situations, expecting from the flight crew more than what they can technically perform? Because responsibility remains on the ground, is there a risk that flight crews expect too much from the controllers in terms of recovery? In terms of **mistrust,** controllers and pilots may sometimes have doubts regarding their respective willingness to co-operate. If they doubt about pilots conformance to instructions, would controllers check too frequently the flight crews actions and consequently spend too much time monitoring? In providing contextual information to the flight crew, do we enable pilots to question controllers decisions? This could lead to additional workload in the flight deck and between air and ground due to discussing decisions.

Last of all, the issue of expertise, and more generally of training in a new method is important. Because delegation is based on current practices, no changes in working methods should occur. In addition, we expect controllers to use existing heuristics. However, the use of a new instruction such as delegation might induce a loss of skills in using conventional instructions, still necessary in degraded situations. Similarly to flight crew regularly performing manual tasks, it might be envisaged, when in operation, to force controllers to use conventional instructions in order to maintain their skills.

3.2. LOW LEVEL OBJECTIVES

Whereas the validation activities includes both ground and air, it shall be noted that separate air and ground experiments were conducted to address respectively controller and flight crew perspectives. From now on, the report will only address the controller perspectives, investigated in the context of the latest experiment.

The above mentioned expectations can be structured around four main objectives, defined in terms of assessing the impact on:

- Concept acceptability;
- Controller activity: workload, active control, monitoring, situation awareness;
- Control effectiveness: quality of control, transfer conditions, flight crew pseudo activity, flight efficiency;
- Safety: conflict analysis, transfer conditions, spacing accuracy, separation infringements and tracing of potential delegation related errors.

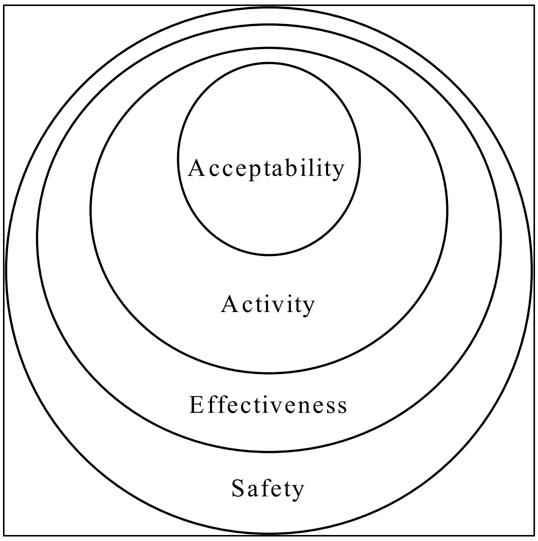


Figure 3: Assessing the impact of delegation from procedures acceptability to safety

The present experiment aims at validating delegation from controllers perspectives. Figure 3 illustrates how the continuous increase in the granularity of analysis should provide a wider image of the impact of delegation. The **acceptability** level informs about the relevance of the concept and the possible context for its application. It reflects how controllers perceive and implement it. The **activity** level investigates the integration of delegation within the overall control activity. It assesses the compatibility with existing tasks, procedures and strategies. Typically, it informs about the impact on active control and monitoring tasks. The **effectiveness** level questions the consequence of using delegation on the quality of control performed. In other words, it assesses the impact on the results of the controller activity, at a more systemic level, including interaction with adjacent sectors as well as with flight decks. Last of all, the **safety** level analyses if induced changes are acceptable in terms of safety, in assessing the risks induced and the mitigation means. Results from each level need to be combined and interpreted jointly. Whenever possible, we will confront results with our baseline results.

A subsidiary objective was the initial assessment of the **usability** of delegation in:

- Approach (transfer and co-ordination, capability to integrate flows);
- Non-nominal situations such as mixed equipage and unexpected events (detection and recovery).

3.2.1. Concept acceptability

This first objective addresses how acceptable the method is in principles and in operations. Based on current practices, delegation should be nothing more than the use of a new instruction. It does not change controller strategy and its use is at controller appreciation. We can not identify, at the very outset, reasons for concept rejection. However, we assume that depending on the context, some delegation instructions might be more or less relevant, as well as more or less easy to use. We describe acceptability as the combination of acceptance and usability.

Practice might induce a progressive increase in the rate and duration of use:

- Acceptance is subjectively informed by controllers answers to questionnaires and comments during debriefing about benefits and possible limitations of the concepts;
- Usability is assessed with objective indicators, which are the rate and duration of delegation use, the type of application used and the number of delegation-related errors, possibly reflecting difficulties in using the delegation. However this last item will be addressed in the safety section.

3.2.2. Controller activity

The major expected benefit is an increase of controllers' availability, mainly in terms of cognitive resources. This increased availability is expected to improve safety and possibly efficiency and capacity, if airspace constraints permit. Although measuring the potential increase in terms of capacity would be a final objective, at this early stage of investigation it is beyond the scope of the experiment. Therefore, we focus on the impact of delegation on controller activity. To address controller individual activity we considered the impact of delegation on active control, monitoring, situation awareness and workload. To address impact on collective activity, we considered interactions at a same position (between executive and planning controller) and inter sector co-ordination. Typically, regarding the second point, we analysed the workload on the approach position and correlated it with the workload perceived by controllers manning the previous sector.

In E-TMA, controller activity can be characterised by two main goals, which are sequencing aircraft (including the definition of sequences, the identification of strategies enabling sequences to be built and maintained) and controlling over-flying and departing aircraft. To do so controllers combine active control tasks and monitoring. We assume active control to be composed of defining strategies and issuing resulting instructions. Whereas simulation data provides direct access to instructions number and type, only their analysis by operational expert enables strategies to be inferred. Appropriate and efficient decision making requires situation awareness, built up and maintained through a continuous monitoring of elements of the environment. This monitoring is both visual and aural, and includes both direct traffic information (e.g. radar label, strips annotations) and social information (e.g. actions performed by planning controllers). In addition to instructions, verbal information can be exchanged between controllers and flight crews. In the context of our experiment a first attempt at analysing such exchanges consists in analysing the number and duration of R/T communications. To assess the possible impact of delegation on monitoring, we used eye tracker devices worn by the executive controllers.

3.2.3. Control effectiveness

3.2.3.1. Quality of control

Delegation is expected to improve the quality of control in enabling more homogeneous flows of aircraft resulting from increased controller availability and more accurate or finer speed adjustments performed by the flight crew.

To assess a possible impact of delegation on throughput, we considered the number of transferred aircraft (indirectly informing about rate of arrivals) and the transfer conditions (value and stability of spacing at transfer).

3.2.3.2. Pseudo pilot activity

Though the major expected benefit relies on the controller side, it is essential to check if delegation is also beneficial to the flight deck. In addition, it is necessary to assess if benefits are equally distributed between all aircraft, as opposed to delegation being beneficial to some aircraft and detrimental to other.

We used the number of instructions per aircraft as an objective indicator of impact on the flight crew activity. However, it needs to be stressed that this provides only a partial view. It informs about the distribution of instructions among aircraft, but not about the actions and workload associated to these instructions. Only pilots in the loop simulations could provide such data.

3.2.3.3. Flight efficiency

We do not expect delegation to induce a major improvement of flight efficiency. We used the fuel consumed, the time and the distance flown, in the measured areas as objective indicators of flight efficiency. In addition, the possible impact of delegation on speed and descent profiles will be analysed.

3.2.4. Safety

Because the concept of delegation is based upon current practices, we expect it to be easy to understand and usable, which could facilitate its acceptance by controllers. However, although we expect delegation to reduce the risks of errors, new forms of errors might be induced by delegation. Safety assessment has two objectives:

- Assess if current level of safety is improved or at least maintained (including the verification that existing mitigation means are preserved);
- Ensure that potential new risks induced by delegation are mitigated.

To do so, in addition to analysing possible indicators of unsafety (e.g. loss of separation, unfeasible delegation), a typology of delegation-related errors, including possible causes and mitigation means needs to be proposed. Subjective feedback is provided by controllers' comments, collected in questionnaires and during debriefing sessions, as well as events observed during the simulations. Objective indicators used when analysing the system recordings are separation infringements, Aircraft Proximity Index (API), transfer conditions (spacing infringements) and number of delegation errors.

Note: the low level objectives will drive the in-depth analysis, whereas the high level objectives will be informed while synthesising the results.

4. EXPERIMENTAL PLAN

4.1. INDEPENDENT VARIABLES

Three variables with two values were introduced in the experimental design: use of delegation, level of traffic and sector configuration.

Our main independent variable is the use of delegation. The assumption is that delegation will induce modifications in terms of controller performance, efficiency and possibly safety. Therefore each exercise will be played by every controller twice, i.e. with and without delegation.

The level of traffic was either high or very high. We expected the delegation to improve the controller activity in spite of higher traffic. However, we had to make sure that delegation is still valuable and beneficial even with very high level of traffic.

To assess if the sector configuration influences the benefits of delegation, we simulated two different sectors. The first one consists of one early converging point while the second one is composed of one early and one late converging points. Typically, we expect the existence of a late converging flow to reduce benefits of delegation in reducing the opportunity to build early sequences of aircraft[2].

4.2. DEPENDENT VARIABLES

From the low level objectives we derived a set of dependent variables to be measured. The variables are listed in the Table 2 below, and gathered according to the low level objectives they inform.

Table 2: From low level objectives to dependent variables

Dimensions	Metrics	Measures
Concept acceptability	Acceptance	Subjective feedback
	Usability	Use of delegation, application usage
Controller perspective	Individual workload	Subjective feedback
	Situation awareness	Subjective feedback
	Controller activity (EXC/PLC)	Communication (radio occupancy, …)
		Active control (manoeuvring instructions, …)
		Monitoring (fixations, scanning patterns, …)
	Collective activity (TRM, inter-sector)	Task distribution executive / planning controllers
		Co-ordination with adjacent sectors
Effectiveness	Quality of control	Control errors
		Rate of arrival
		Transfer conditions
	Pseudo pilot perspective	Instructions per aircraft
	Flight efficiency	Time and distance flown, fuel consumed, speed profiles, …
Safety	Control errors	Loss of separation, unstable transfer, omissions, …
	Delegation-related errors	Non respect of applicability conditions, misuse of delegation

2 Results from previous experiments showed that the delegation enabled controller to be relieved from sequences maintaining and provided them with some anticipation.

4.3. RUN PLAN

The 2×2×2 design required each controller to play 2 traffic levels, on the two different sectors, with and without delegation. We split the 6 controllers in 2 teams of three, composed of each nationality. We insisted in mixing controllers of different nationalities for two reasons. First, basically to ensure that communications would be understandable, and second to confront controllers with possibly different practices. We expected this mixing to help them stepping back, reconsidering their own practice and being open-minded.

Because we had 3 controllers per sector, the run plan required 24 measured runs. Note that same traffic sample was never played successively without and with delegation. A same controller would not play two successive exercises at the same position: they would alternate executive, planning and approach position.

5. METHOD OF DATA COLLECTION AND ANALYSIS

For measurement purposes, two groups of data (objective and subjective) were collected.

Objective data consisted of:

- Radio communications, aircraft data and pilot input (controller instructions) recordings;
- Monitoring and scanning patterns with eye tracking (see Figure 4) of radar controllers.

Subjective data consisted of:

- Workload with the Instantaneous Self Assessment (ISA) device and NASA Task Load Index questionnaire;
- Situation awareness through explicit queries at the end of exercises;
- Questionnaires and debriefings.

Figure 4: Eye tracker. SMI EyeLink System © Copyright 1995 SensoMotoric Instruments GmbH, Teltow, Germany, All Rights Reserved

5.1. OBJECTIVE DATA

The objective analysis consisted in three parts:

- A first quantitative analysis consisted in automatic processing of relevant traffic data to provide statistical figures;
- A second quantitative analysis which consisted in processing eye movement data allowed to investigate more specifically the monitoring tasks;
- A “human” analysis helped understanding controllers’ strategies and activity. Hours were spent by an expert controller analysing the exercises with the EEC Analysis and Replay Tool (ART) displaying aircraft plots and controllers’ instructions. (All the instructions given by controllers are automatically recorded from the pseudo-pilot positions.) This corresponds to a “qualitative” analysis.

5.2. SUBJECTIVE DATA

The subjective analysis performed is based on different sources of information. The first source is the questionnaires given to the controllers before, during, and after the simulation. A second source of information is the collective debriefings conducted at the end of each day. While the questionnaires and the debriefing sessions investigate multiple aspects (relevance of the method, acceptability of the procedures, safety and workload issues), two other sources (ISA, NASA-TLX) exclusively focused on workload assessment. The main difference between the two subjective techniques used during the simulation is their temporal dimension. Whereas the NASA-TLX collects a global assessment of the workload perceived during an exercise, the ISA technique gathers continuous assessment over the whole exercise. Last of all, at the end of each run, a blank map was used to assess executive controller awareness of the situation.

Three types of questionnaires were presented to controllers:

- Pre-simulation (given at the end of the briefing session);
- Post exercise (short questionnaire given after each exercise with delegation);
- Final questionnaire (given at the end of the simulation).

The questionnaires are presented in annexes H, I and J.

The final questionnaire consisted of over 90 items, requesting controllers to choose the most appropriate answers among the ones proposed. Moreover, controllers were encouraged to provide as much comments as possible to justify their answers. They aimed at a subjective evaluation of the following elements:

- Simulation characteristics (familiarity with airspace, traffic and interface, realism of the simulation);
- Relevance of phraseology;
- Task analysis (identification of solutions, preparation of delegations, decision of delegation, communication of delegation instructions, monitoring of delegations, mental integration of delegations in the traffic, co-ordination of delegations with adjacent sectors, task sharing between planning and executive);
- Benefits analysis (effects and consequences of the delegation);
- Concept assessment (relevance, usability, impact on capacity and safety);
- Usability of the marking functions provided on the interface (understandability, ease of use, readability, complexity and suitability for the task).

5.2.1. Workload

5.2.1.1. Instantaneous Self-Assessment

Instantaneous Self-Assessment (ISA) is a technique originally developed by the UK Civil Aviation Authority to evaluate controllers' subjective workload, through periodic self-report. ISA is a relatively unobtrusive real-time device, whose main advantages are its simplicity and the possibility it offers to collect continuous on-line measures of subjective workload. Similarly to ATWIT (Air Traffic Workload Input Technique, ISA is an online measure that requires controllers to indicate at set times, their perception of their current workload. Contrary to the NASA-TLX, which breaks workload in multiple dimensions (e.g. mental, physical), ISA tends to cover overall workload. Moreover, the continuous assessment of workload with ISA enables variations along the experiment to be identified as opposed to the final assessment provided by the NASA-TLX.

As configured for this experiment, on each control position, a small box equipped with 5 buttons labelled “Very High”, “High”, “Fair”, “Low” and “Very Low” was available. Each controller received standardised instructions and training on the use of ISA during the experiment. At two minutes intervals throughout the measured exercises, the controller was prompted by a flashing red light to press one of the five buttons corresponding to his/her perceived workload during the previous two minutes. The light flashed for 30 seconds, during which the controller had to respond. At each interval a record was written of the button selected and the delay in responding so that by the end of the exercise a history was available about the variation of each controller's perceived workload.

Experience acquired during previous Eurocontrol simulations shows that selection of either button 4 or 5 (respectively “high” or “very high” for more than 40% of an exercise means that the participant is likely to reject the organisation.

5.2.1.2. NASA-TLX

The NASA Task Load Index is a multi-dimensional subjective workload rating technique. In NASA-TLX, workload is defined as the cost incurred by human operators to achieve a specific level of performance. It consists of 6 questions requiring subjects to rate the mental, physical, and temporal demands as well as performance, effort, and frustration levels perceived. The NASA-TLX is presented to subjects at the end of each exercise and therefore collects subjects' assessment of the overall exercise. Even if it is supposed to provide an indication of the workload perceived along the exercise, it might reflect only part of the session (the most salient, or the latest one).

5.2.2. Situation awareness

Situation awareness so essential to ensure appropriate decision making and actions is still a difficult concept to address. Typically, its definition and even more crucially its measurement are still open and issues. As described by Endsley (1994), it consists of three levels: the perception of elements of a situation, their integration in order to comprehend the overall situation and the "ability to forecast future situation events and dynamics". Whereas expertise is essential for level 2 and 3, only available time enable the situation awareness process to be efficiently conducted. Even though this needs to be validated, we assume that it reflects regular even if less frequent monitoring, assessing if everything works as expected. This could correspond to a continuous updating of situation awareness.

To assess situation awareness, we included dedicated items in both post run and final questionnaires. In addition, at the end of each run once the screen were switched down (and paper strips removed) we asked controllers to reproduce on blank maps of their sector what they would considered as the "hot spots", as opposed to a systematic description of the traffic. Resulting description was later compared to real traffic situation, as displayed on the replay tools.

5.2.3. Usability

Collective debriefings were conducted daily. Their objectives were to discuss on previous runs, typically helping controllers understanding why delegation had been correctly applied or not. We used the EEC analysis and replay tool (ART) to confront controllers with their daily performances and invited them to provide comments, suggestions and critics. The simulation team took part in discussions only to clarify issues, correct if explanations were wrong and also confirm when they were correct.

These debriefing, conducted around the replay of previous runs work as a support for continuous training. It also enabled the identification and preliminary understanding of delegation-related errors.

6. DESCRIPTION OF THE EXPERIMENT

6.1. ORGANISATION

The experiment lasted three weeks (including general presentation, training, simulations and debriefings). It was split into three distinct sub-sessions: training (or familiarisation), high and very high traffic. The detailed programme is presented in annex F. The simulated airspace was a part of Paris Southeast area, and was thought to be representative of a dense area and generic enough to allow an easy assimilation by the controllers (only 1 out of the 6 controllers was familiar with the airspace). Four existing sectors were selected and combined into two E-TMA sectors. In addition two simplified Orly and Roissy/CDG approach sectors were added (see annex D for detailed sector maps).

The grouping (which is applied in reality when traffic permits) allowed for a handling of a majority of flights from cruise to IAF by the same sector. Thus, the delegation process could be simulated and analysed during a significant period of time. In addition, direct instructions to IAF that were intensively used specifically for merging applications did not require any co-ordination.

6.2. MEASURED SECTORS

Four measured sectors (two E-TMA and two INI) and two feed sectors were simulated at a time. Each E-TMA measured sector was manned with two controllers (one planning and one executive). Each initial approach sector was manned with one controller.

After two training exercises, each controller played two measured exercises (high and very high level) as executive controller on each measured sector in nominal situation.

Each controller also played exercises dealing with mixed equipage and “unexpected events”. These exercises were simulated only with delegation.

6.3. EXERCISES

Each measured exercise was simulated twice: without delegation (i.e. conventional control), with it. A same exercise was not systematically played without first and with delegation second (nor the opposite). A same exercise was never played successively with and without. We did alternate traffic samples, in order to reduce risks of learning the traffic. It should be stressed that, although controllers remembered the callsigns, they rarely remembered situations and solutions adopted.

6.4. TRAFFIC SAMPLES

The traffic samples were derived from traffic recordings representing traffic flow in the morning and the afternoon. Low traffic samples were available for training purpose. List of aircraft are presented in annex E.

For E-TMA, the traffic sample were slightly increased and adjusted to create clusters of aircraft. The resulting traffic was close to a real high-density traffic. For approach, one normal flow was combined with a simplified second flow (only 1/5 aircraft).

6.5. USE OF DELEGATION

All the traffic was equipped to receive delegations, thus offering maximum opportunities to use delegation. However, although controllers were invited to use delegation, they were not forced to.

6.6. PARTICIPANTS

Six controllers (2 French from Paris and Aix-Marseille ACC, 2 Italian from Brindisi and Roma ACC, 2 Swedish from Malmoe ACC) and 4 pseudo-pilots participated.
The detailed schedule of the simulation is presented in annex.

6.7. WORKING ENVIRONMENT

The working environment replicated the current one: progress strips, short term conflict alert and flight list, but no arrival manager (sequencing tool).

Specific markings have been developed enabling to display the different states of the delegation process. They consist essentially of markers set around the position symbols of both delegated and target aircraft (permanent display) and of a link between them (conditional display), see Figure 5.

Two delegation states have been identified:

- Target given: markings displayed in orange (to remind the controller s/he still has an instruction to issue;
- Delegated: markings displayed in green (situation to monitor only).

For mixed equipage exercises, non-equipped aircraft were indicated using a specific flag (ø).

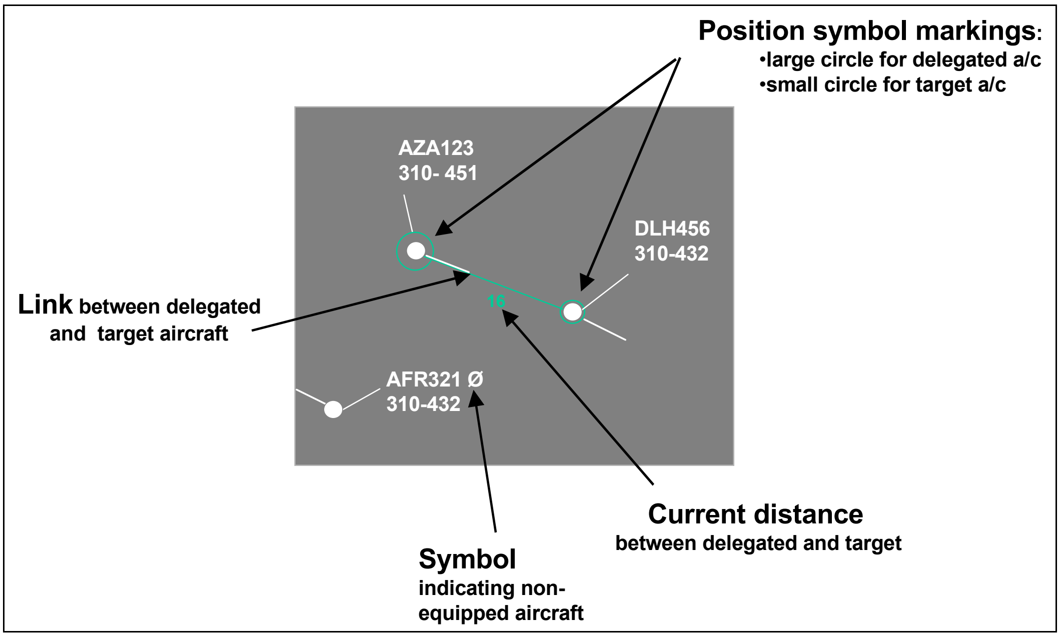


Figure 5: Example of a delegation marking

6.8. EXPERIMENT EXECUTION

Three main phases characterise the experiment:

- Training;
- Measured exercises;
- Debriefing.

6.8.1. Training

Studies on problem solving (Bisseret, 1994) showed that experts happened to fall back to novice behaviour when confronted to a situation they do not recognise as a known one. Even if previous strategies are still valid, they need time to figure it out. Therefore, because we expect such risks of expert destabilisation to initially occur with delegation, a special attention has been paid to training issues.

6.8.1.1. Ab initio training

Controller handbook presented an overview of the concept, of the simulation objectives and of the sectors. The training consisted first of a presentation of delegation principles (briefing room), and then of hands on practice of delegation at a working position. Initial training exercises enabled controllers to progressively get familiar with the sectors, the traffic flows and the delegation concept. Training exercises were also played at mid-sessions, when controllers switched measured sectors.

6.8.1.2. Continuous improvement

Every day a collective debriefing aimed at understanding how controllers felt about delegation, as well as identifying preliminary problems encountered. Whereas controllers did comment their respective performance, the role of the team members was rather to explain situations and confirm how the concept could be used (or should have been). These debriefing worked as a continuous improvement in the use of delegation.

6.8.2. Measured

Six different traffic samples at two different levels of traffic (3 high and 3 very high) were used. High traffic corresponds to 27 arrivals per hour and very high traffic to 31 arrivals per hour. The fifteen first minutes of the exercises were used to build up the traffic. We finally had 60 minutes of fully measured exercise. Eye tracker data were collected over 45 minutes. Results were considered by exercise, by sector, by level of traffic and by week. During the first week (H1 and V1) controllers were manning a given sector (either AO or AR), and manned the other sector the following week (H2 and V2). H and V refer to the level of traffic (high or very high). Table 3 summarises the four sessions.

Table 3: Traffic sample matrix. In each of the four sessions, 3 different traffic samples are used.

		Level of traffic	
		High	**Very high**
Week	**1**	H1	V1
	2	H2	V2

6.8.3. Debriefing

In addition to the daily debriefing, a final one took place on the last experiment day. The objective was to collect a more synthetic feedback on the overall experiment. Whereas questionnaires aimed at collecting systematic comments on more than 90 questions, the debriefing aimed at discussing the results of the experiment, as well as possible perspectives.

7. RESULTS

Preliminary note: because of the exploratory nature of delegation in TMA, only subjective data can be presented. Furthermore, the manning by E-TMA controllers might impair the relevance of data.

Most of the metrics were applied to the two E-TMA sectors (AO and AR). Unless specified, they were not applied to the INI sectors.

For each metric, two sets of results were obtained: with all aircraft (including overflying) and with arrival aircraft only. In addition, in order to ensure comparability with eye tracker measurements, we distinguished results for the whole exercise length (75 minutes) and then for 45 minutes only (starting after 15 minutes and then over 45 minutes).

Initial data analysis seemed to show that during the first two measured session (H1 and V1) controllers were still learning how to use delegation. Therefore, although results from this session were used to identify typical errors, they were not included in the mean results presented in this section. Unless specified, results correspond to the last two sessions (H2 and V2).

7.1. INTRODUCTION

7.1.1. Factual data

Only summary of data is presented here (Table 4). For more detailed figures, see annex G.

Table 4: Facts and figures

	Overall total
Measured runs	24
Hours of control	16:35:50
Number of aircraft controlled	2025
Flight hours	586
Number of delegations	510
Duration of delegation (hours)	95

7.1.2. Statistical significance

We performed statistical tests to study the independence of variables main characters. Because samples are reduced, we used the non parametric χ^2 test.

Let consider the null hypothesis:

H_0 : “Characters A and B are independent”.

The χ^2 test provides a decision rule to assess the validity of hypothesis H_0 relative to the independence of two characters A and B.

Let $\hat{\chi}^2$ be the value of the observed criteria, $\chi^2_\alpha(\nu)$ the critical value at α level of significance and ν degree of freedom.

If $\hat{\chi}^2 < \chi^2_\alpha(\nu)$ the null hypothesis can not be rejected at level α;

If $\hat{\chi}^2 > \chi^2_\alpha(\nu)$ it means that less than α times out of 100 would give this value of $\hat{\chi}^2$ though variables are independent, thus characters A and B are dependent at level α.

The following hypothesis have been tested:

- Is the use of delegation independent of the exercises?
- Is the type of instructions independent of the exercises (level instructions are not considered)?
- Is the type of instructions independent of the delegation?
- Is the geographical repartition of instructions independent of the exercises?

We get the following results (detailed results are presented in annex):

- The use of the delegation is independent of the exercises (the influence of the exercises is not significant at a level of 0,05);
- The repartition of the manoeuvring instructions (delegation/heading/speed) is independent of the exercises (the influence of the exercises is not significant at a level of 0,05);
- The repartition of the manoeuvring instructions is dependent of the delegation with a probability of 0,95;
- The geographical repartition of the manoeuvring instructions is dependent of the exercises with a probability of 0,95.

Note: because the tests were performed late in the analysis process, they could not be considered when interpreting the results.

7.2. CONCEPT ACCEPTABILITY

7.2.1. Acceptance

We considered the controllers assessment of the usefulness of delegation, of their understanding of the delegation and of the compatibility of delegation with their current practices. For most of the controllers (5 out of 7[3] answers) the delegation is considered as generally or totally useful. The most useful applications are the merge (6 out of 6) and the remain (5 out of 6). They all rated the delegation as mostly (4/6) or completely (2/6) understood. For all of the them delegation is a workload reduction (6/6) rather than a loss of control (1/6) or a concern (1/6). For all of them, delegation is compatible with their working method and with the sequencing tasks.

[3] It happened that a same controller gave two different answers (e.g. if the final answer is between quite and very, both will be selected).

7.2.2. Usability

7.2.2.1. Rate and duration of use

Since controllers were not forced to use delegation (but rather "invited to", if they feel it could be helpful), we considered the rate of use as an indicator of usability: a low rate could either reflect difficulties or reluctance to use delegation. We analysed both the percentage of delegated aircraft, and the duration of delegation. To reflect the duration of delegation for a given controller, in charge of a given sector, we decided to consider the time spent on frequency, rather than the time spent in geographical sector.

Results show a similar rate of use for both sectors during the first week and a higher rate for AR during the second week (Figure 6). In addition, these results suggest a stronger impact of the controller than of the sector: controllers in charge of AO the first week (and manning AR the second week) seemed to be using delegation more than the other team.

Due to the sectors configuration, delegation was previously identified as more frequent in AR. According to our baseline, the maximum possible rate implemented by a controller expert in the delegation concept is, in very high traffic condition 60% for AO and 75% in AR. Mean results obtained for the very high sessions (V) reflect a comparable rate of use. However, the difference between the first and the second week tends to confirm the learning status of the first week.

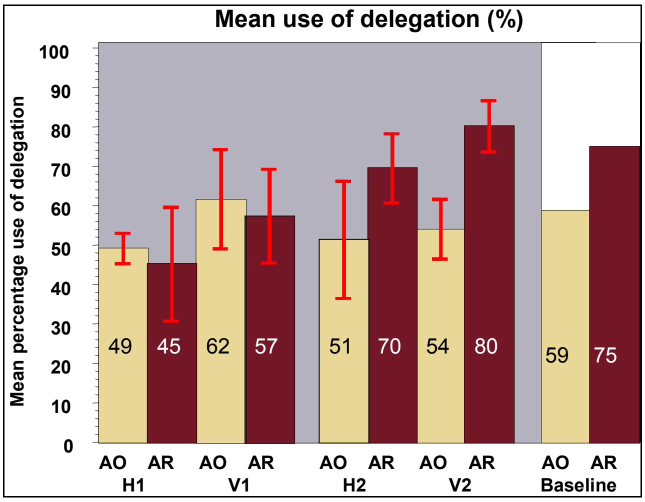


Figure 6: Mean use of delegation:
number of delegation compared to number of concerned aircraft

In addition to considering the number of aircraft delegated, we analysed the mean duration of delegation (Figure 7). Similarly to the rate of use, results are comparable to last year: delegation lasted longer in AR than in AO, but duration was similar in high and very high traffic. First week results are questioned and put in relation with training effect. Results from the second week, in very high traffic are comparable to our baseline: our expert controller could delegate up to 50% in AO and 73% in AR.

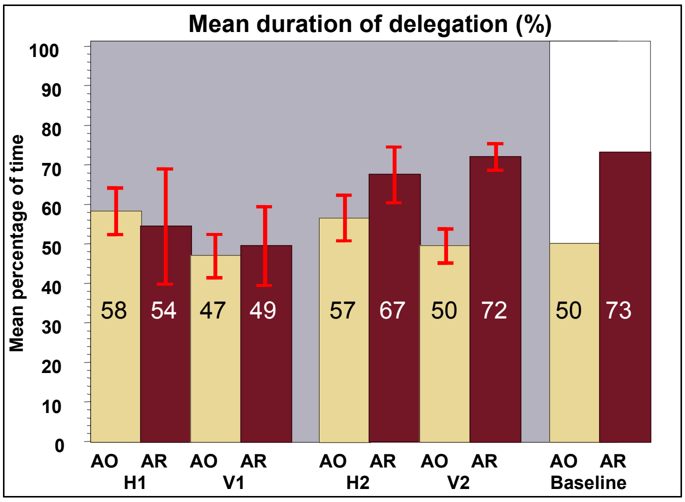


Figure 7: Mean duration of delegation:
duration of delegation compared to delegated aircraft flight time

7.2.2.2. Application usage

To identify the appropriateness and possibly relative ease of use of each application (remain, merge, heading then remain, heading then merge), we analysed their respective rate of use (Table 5 and Figure 8).

The most used application was the "merge" (more than 70% of the cases), while the "heading then remain" was not used at all. Differences in the usage of "heading then merge" were questioned. The analysis of V1 results shows that the usage of the "heading then merge" is related to controllers preference rather than sector configuration (indeed AO controllers in V1 were AR controllers in H2 and V2). These figures confirmed our observations: "heading then remain" application seemed difficult to implement, because of its applicability conditions (limited to aircraft on same trajectory). The limited use of the “heading then merge” is probably due to the unpredictability of the resuming trajectory. The "merge" application was easier to use. Controllers prefer to vector the traffic, decide of the appropriate time to resume and then give a merge instruction.

It is interesting to notice that the controller usage of merge is consistent with their assessment of its usefulness, but their usage of the remain is not.

Table 5: Respective use of the four applications.
Results correspond to the gathering of the H2 and V2 sessions. The most used applications are highlighted in bold, the less used in italics

	Remain	Merge	Heading then remain	Heading then merge	Total
AO	3 (4%)	69 (93%)	0	2 (3%)	74
AR	6 (6%)	61 (56%)	0	41 (38%)	108
Total	9 (5%)	130 (72%)	0	43 (23%)	182

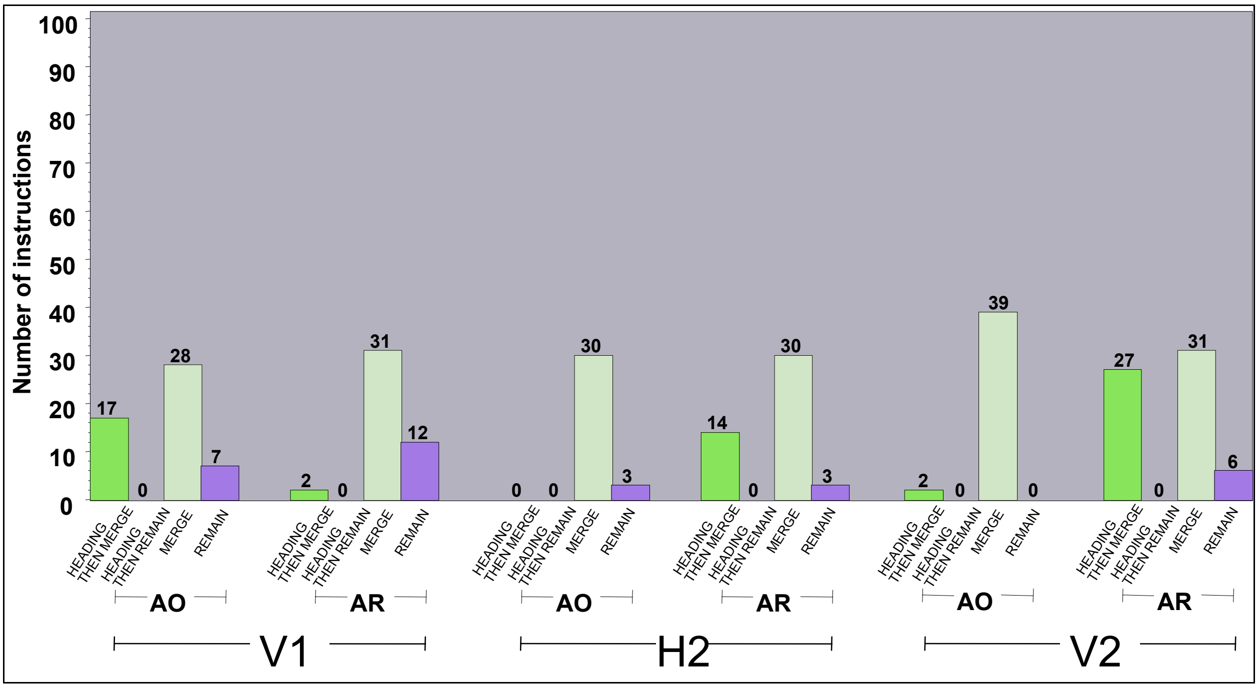


Figure 8: Applications usage

7.2.3. Synthesis on acceptability

Controllers perceived the concept as useful and the procedures as easy to use. The sector structure and the familiarity with delegation influence the delegation rate of use. The most usable and used application is the merge. Other applications induce constraints such as need for same trajectory ("remain") or perceived uncertainty about aircraft behaviour ("heading then").

7.3. CONTROLLER ACTIVITY

7.3.1. Workload

7.3.1.1. Subjective assessment

Feedback gathered in the questionnaires is that for the six controllers, delegation induces a workload reduction. However, the integration of aircraft in delegated sequences is still a demanding task. We asked the controllers to rate between very easy and highly complex the effort to perform the following delegation-related tasks: identify when a situation becomes delegable; make a situation delegable (set up applicability conditions), initiate the delegation process (select target), communicate delegation instruction, monitor delegation, remember current delegation, end delegation (Figure 9). The results show that the most demanding tasks are the flows integration and the building of sequences.

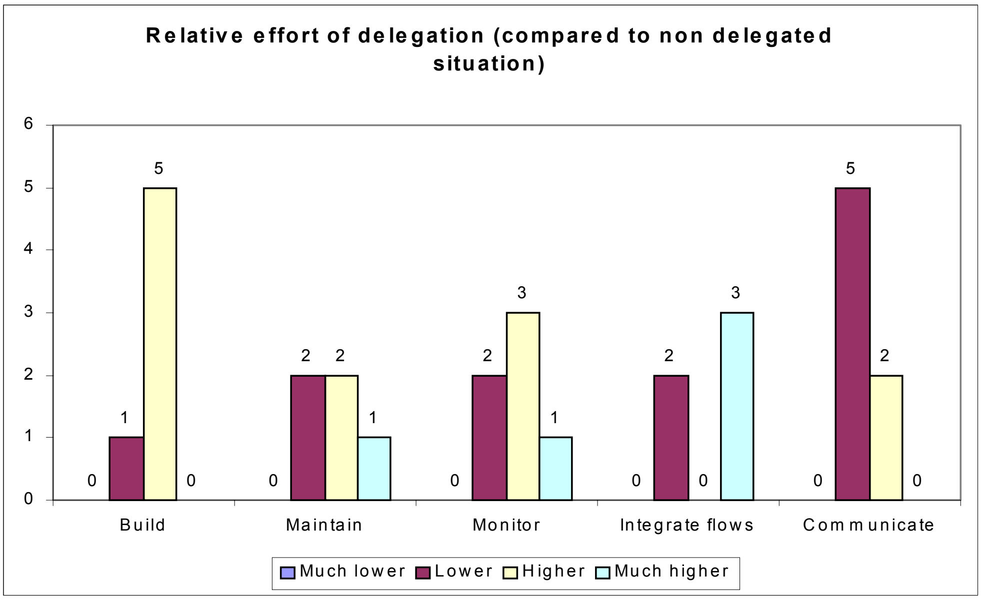


Figure 9: Controller assessment of the respective effort of delegation-related tasks

7.3.1.2. ISA ratings

The analysis of ISA ratings shows only a few cases of negative impact of delegation on workload. Negative impact only represents 12% of the exercises, and most of them occurred during the first week. Most of them concerned controllers at the approach position (13 cases, against 5 for planning and 5 for executive controllers). The main impact on executive controller was positive: either a reduction or similar workload was perceived. No real impact was noticed for most of the planning controllers' workload. 5 times the "high" rating went over 40%: 3 times without (H_AO_EXC, V_AO_EXC and V_AR_EXC) and 2 times with delegation (V_AR_EXC and V_AO_PC). These represent less than 7% of the cases. No impact of the sector was observed (similar rates and similar distributions for AO and AR).

Table 6 summarises the observations (details are available in annex). Table 7 proposes a synthesis of the results.

Impact of delegation on workload assessed with the ISA device. Arrows reflects how workload evolves between situations without and with delegation. Typically, an arrow pointing down means that workload is perceived as decreasing with delegation. Results are given per traffic sample. 1 refers to the first week, 2 to the second week.

Table 6: Impact of delegation

Traffic sample/week		AO			AR		
		EXC	PC	INI	EXC	PC	INI
3AM_H1	**1**	↑	↑	similar	↑	↑	↑
3AM_H1	**2**	↓	similar	↑	↓	similar	↑
3PM_H1	**1**	similar	similar	similar	similar	↑	↑
3PM_H1	**2**	↓	↓	similar	↓	similar	similar
3AM_H2	**1**	↓	similar	↑	↓	similar	similar
3AM_H2	**2**	similar	similar	↓	↓	similar	similar
3AM_V1	**1**	↑	similar	similar	↓	↓	↓
3AM_V1	**2**	↓	similar	↑	↓	similar	↑
3PM_V1	**1**	Similar (≠ period)	Similar (≠ period)	↑	similar	similar	↑
3PM_V1	**2**	similar	↓	↑	similar	similar	↑
3PM_V2	**1**	similar	similar	↑	↑	↑	similar
3PM_V2	**2**	↑	↑	↑	similar	similar	similar

Table 7: Synthesis of ISA ratings, per sector and per position

Impact	AO				AR				Total	%
	EXC	PLC	INI	Total AO	EXC	PLC	INI	Total AO		
No change	5	8	4	17	4	8	5	17	34	68%
Decrease	4	2	1	12	6	1	1	11	15	
Increase	3 (2H)	2 (1H)	7 (2H)	7	2 (2H)	3 (2H)	6	8	23 (9H)	32% (12%)

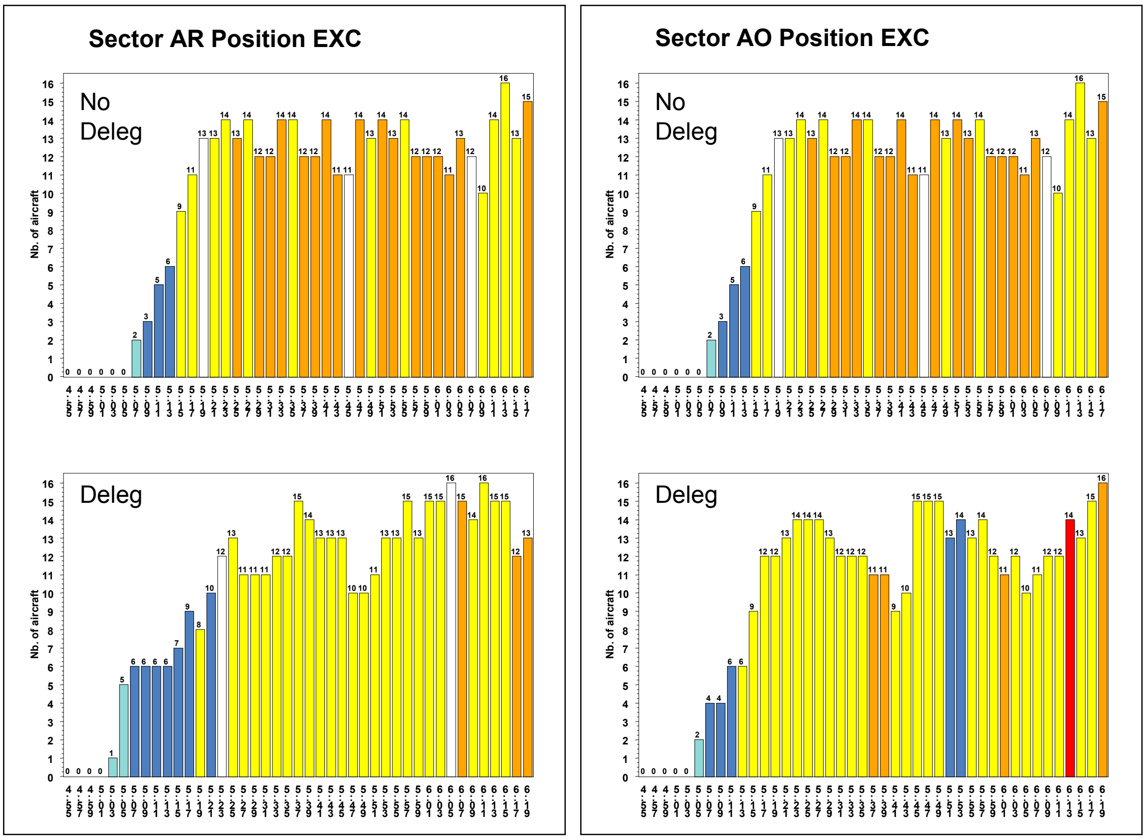


Figure 10: Examples of ISA recordings

Examples of ISA recordings, with very high traffic load. The five levels of workload are respectively: very low (light blue), low (dark blue), fair (yellow), high (orange) and very high (red). White reflects the absence of input caused either by a very high workload or simply a lack of attention. These examples illustrate a positive impact of delegation: workload decreases from high to fair level.

7.3.1.3. NASA-TLX ratings

Even though controllers assessed six dimensions (physical, mental, temporal, performance, effort and frustration), we focused our analysis more specifically on the mental and the temporal demand perceived by controllers.

Mental demand (Figure 11): In AO, the executive controller mental demand is similar in every conditions. The mental demand of the planning controller is similar for high traffic and slightly higher for very high traffic. The mental demand is higher for the approach position in both levels of traffic. In AR, mental demand is generally lower with delegation. For very high traffic, it is similar for the executive position and slightly higher for the approach position.

Temporal demand (Figure 12): In AO, with delegation the temporal demand is lower for the executive controller for high traffic and slightly higher with very high. For the planning controller, the temporal demand is similar for high traffic, and slightly higher for very high. For the approach controller, the temporal demand is lower for high traffic and similar for very high. In AR, for executive and planning controllers, the temporal demand is lower with delegation, at both traffic levels. For the approach controller, the temporal demand is lower for high traffic, and higher for very high.

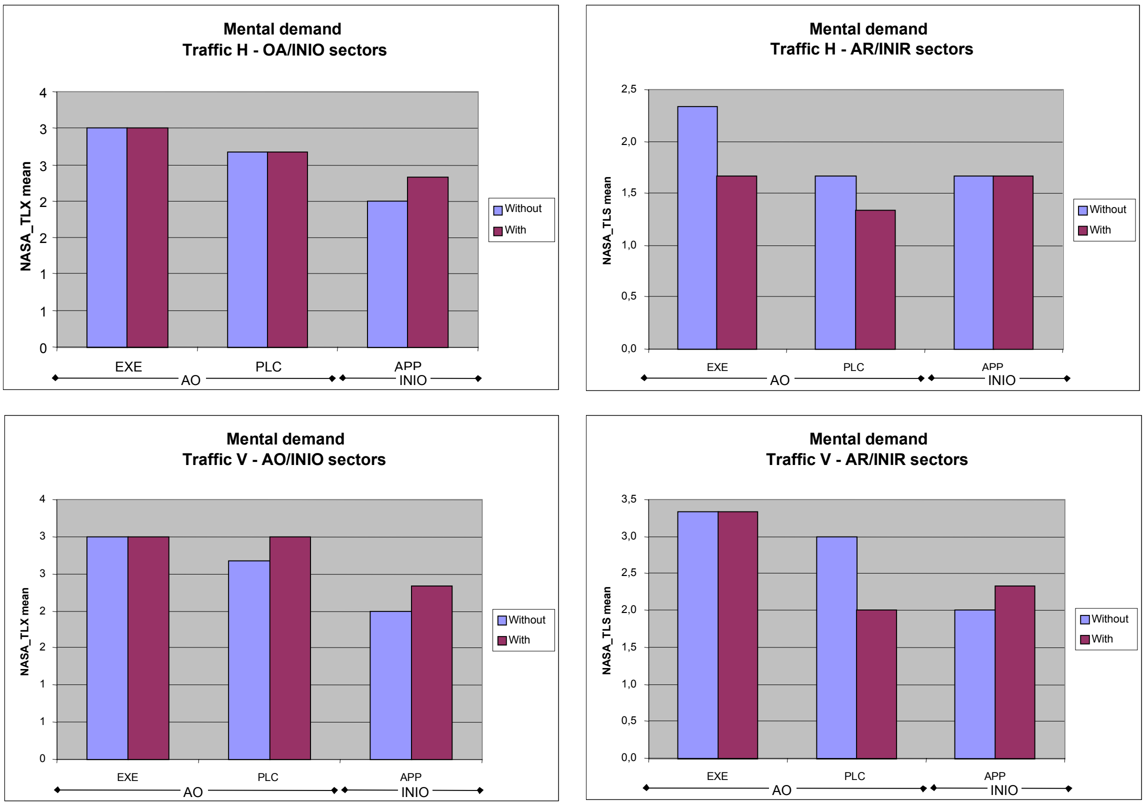


Figure 11: NASA-TLX mental demand

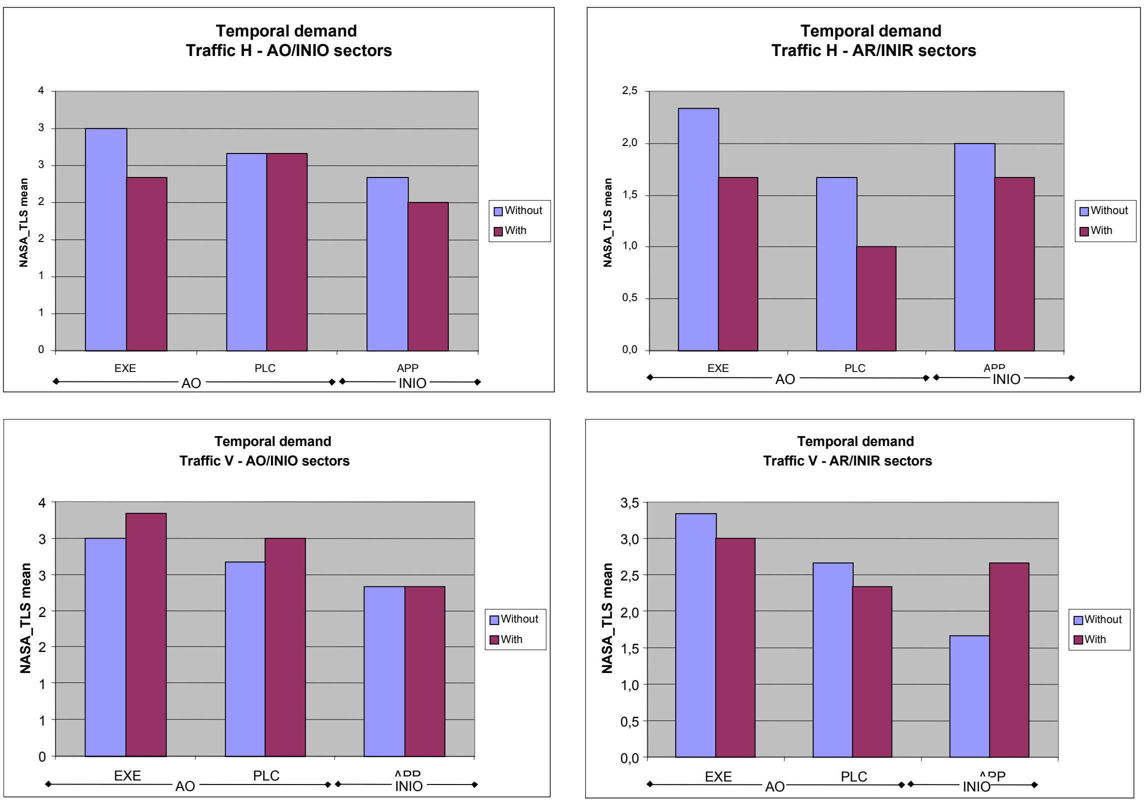


Figure 12: NASA-TLX temporal demand

7.3.1.4. Eye tracker data

The physiological data, acquired with the eye-tracker devices (blink rates and pupil diameter) do not show significant differences in the level of workload. However, when analysing the distribution of such data as a function of the geographical area, we notice a correlation between workload level and sector area. Typically, with delegation workload peaks are located around the merging point, whereas it is spread over the sector, and sometimes even in its second part without delegation.

7.3.2. Situation awareness assessment

As pointed out in many studies (Endsley, 1994), situation awareness is difficult to assess. In the context of air traffic control, it leads us to question controllers knowledge of the traffic. Typically, we do not expect controllers to remember exactly details about every aircraft (position, level, speed, status). We assume the necessary information to be the accurate location of areas where traffic still has to be acted upon and a more roughly location of areas where traffic is already sequenced or not conflicting.

The details about controller annotations on the blank maps have been summarised in the Table 8. It is difficult to draw conclusions from these data. First of all, some controllers had difficulty to fill the documents. Second, each case seems to be very specific, and no generic trend can be identified. The amount of information provided on the maps differed highly from a controller to another. However, for the most complete ones (for a same controller without and with) we tried to compare their annotations with the corresponding recorded situations. In some cases, similar level of details were provided without and with delegation. In other cases, more details were provided without delegation. The following figures (Figure 13 and Figure 14) show examples when more details are provided with delegation. We selected these exercises to illustrate what the positive impact of delegation could be in terms of situation awareness.

Example 1: AR sector

The analysis of the recorded situation shows that at the end of the exercise the controller had just sent the AFR3865 and not yet prepared the sequencing of the chain CSDNH to AFR2333 (2^{nd} part of sector).

Without delegation, information provided on the map is located in the second part of the sector. No details were provided around the converging point (first part of the sector). The lack of information around the converging point could suggest that the controller did not have time to analyse the situation to come, i.e. that he is no longer able to anticipate the traffic. With the delegation, the information is spread all over the sector, with more details on the traffic that still has to be manoeuvred.

Example 2: AO sector

Without delegation, controller provides details about time-critical situations located in the second part of the sector. Even though his situation awareness includes aircraft arriving from the adjacent sector, it seems limited to aircraft soon to be transferred. No information is provided about aircraft in the first part of the sector. It looks like the controller attention is focused on a subset of aircraft.

With delegation, even though less details about the aircraft are provided (only plots represent them), their location all over sector is accurate. This leads us to assume that with delegation, the controller can maintain an overall picture of the situation. Even aircraft arriving from the adjacent sector, and needing to be integrated are represented.

These two examples suggest a few points:

- Without delegation, for very high traffic, the controller situation awareness seems to be limited to the second part of the sector, where time pressure happens here to be the highest. This observation is consistent with eye tracker data, which showed that in these conditions, controller monitoring load is focused on this geographical area. In this situation, controllers do not provide information about traffic in the sector entry, whereas some monitoring still occurs there, as well as active control. The geographical distribution of instructions shows that time critical instructions (such as heading and speed) are still given to aircraft in this area. Indeed, the demanding nature of maintaining sequences reduces progressively controller availability and therefore opportunity to anticipate the most strategic part of his task (sequence building). As a result, building and maintaining of the sequences being done in the second part of the sector worsen the time pressure.
- With delegation, in the same conditions, controller can provide information about traffic all over the sector. Not only do they seem aware of early strategic information (aircraft involved in sequences building in the first part), but they can also mention aircraft soon to be transferred. Even though the monitoring load is reduced in the second part of the sector (eye tracker results), it is still sufficient for controllers to be aware of the current situation.

These results seem to confirm the benefits of delegation for very high traffic. In enabling controllers to anticipate and therefore remain ahead of their traffic, it seems to provide them with availability possibly used to focus on relevant tasks and information gathering. In such situation, with delegation controllers focus on the most time critical information, but still have time to continuously update their awareness of the overall traffic.

However, with respect to the impact of situation awareness on safety, two issues will have to be tackled. First, whereas controllers seem to have a general awareness of traffic location with delegation, is this awareness sufficient to perform efficiently their task? The analysis of quality of control might provide some answers to this question. In addition, the introduction of abnormal events (or diverting situations) might help us assessing controller ability to detect problems. Second, does delegation induces changes in the information collected? Typically, with delegation, we expect controller objects of attention to evolve from aircraft flight parameters (flight level, speed) to spacing information (distance between aircraft). The confirmation of this latest assumption might explain some difficulties encountered by controllers when dealing with successive chains of delegated aircraft. It looked as if the slow down effect induced by delegation was sometimes not detected soon enough by controllers.

This will need further investigation.

Table 8: Evaluation of controller description of traffic, as provided on the sector maps

Exercise	AO		AR	
	without	with	without	with
3AM_H1	Details exit	Not much details, but all over sector	Sector entry	Nothing
3PM_H1	Nothing	Middle of sector and entry, not much detail	All over sector (FL)	All over sector (FL)
3AM_H2	All over	Nothing	Entry & middle	Entry & middle
3PM_V2	Middle & exit	Much details all over sector	Nothing	Entry
3AM_V1	Entry & 2nd part	Entry & 2nd part	Plots 2nd part & transferred (figure 8)	Entry & sequences in 2nd part (figure 9)
3PM_V1	Entry middle	Nothing (difficult to know aircraft because they are delegated)	Detail all over sector except middle	Very detailed all over sector
3AM_H1	Plots all over	Plots 2nd part sector	Nothing	Entry & exit, not much detail (plots)
3AM_H2	2nd part, FL	All over sector, FL	Sector entry & expected routes	Nothing
3PM_H1	Exit, not much detail	Exit, really not much	2nd part (exit) call sign & entry	Exit & entry, call sign
3PM_V1	All over (FL)	All over (FL)	Sector middle, not much detail	2nd part not much
3PM_V2	Plots (+FL at exit)	Plots all over	Plots all over	Plots all over + links
3AM_V1	Middle, not much detail	Plots all over	All over call sign	Entry & exit, call sign & FL

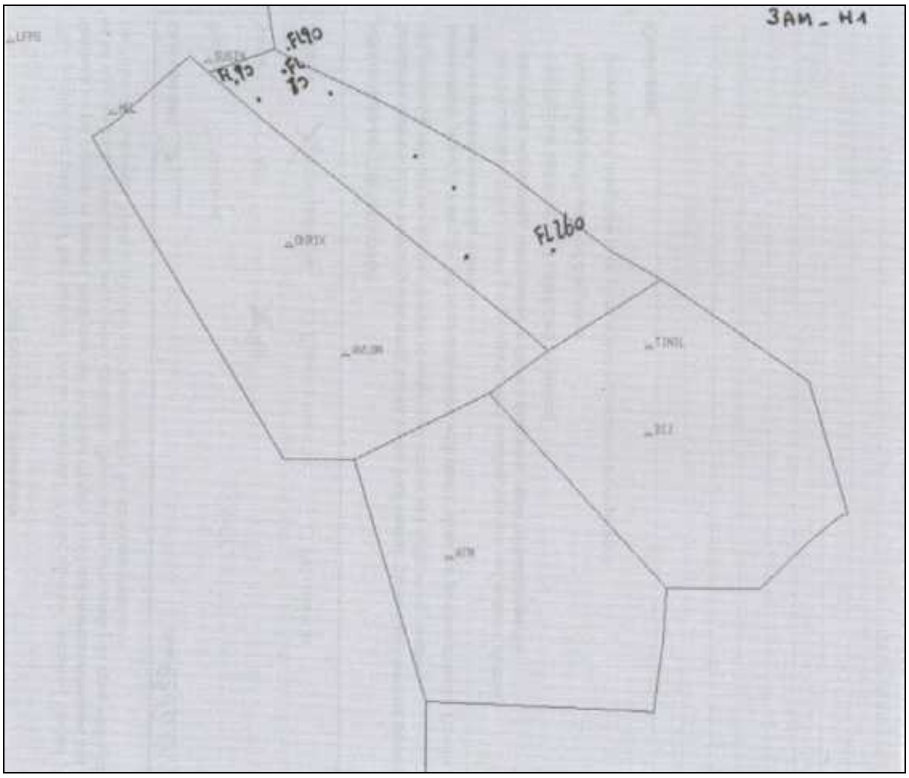


Figure 13: Situation awareness assessment. Example 3AMH1, AR sector, without delegation. Not much details about the aircraft

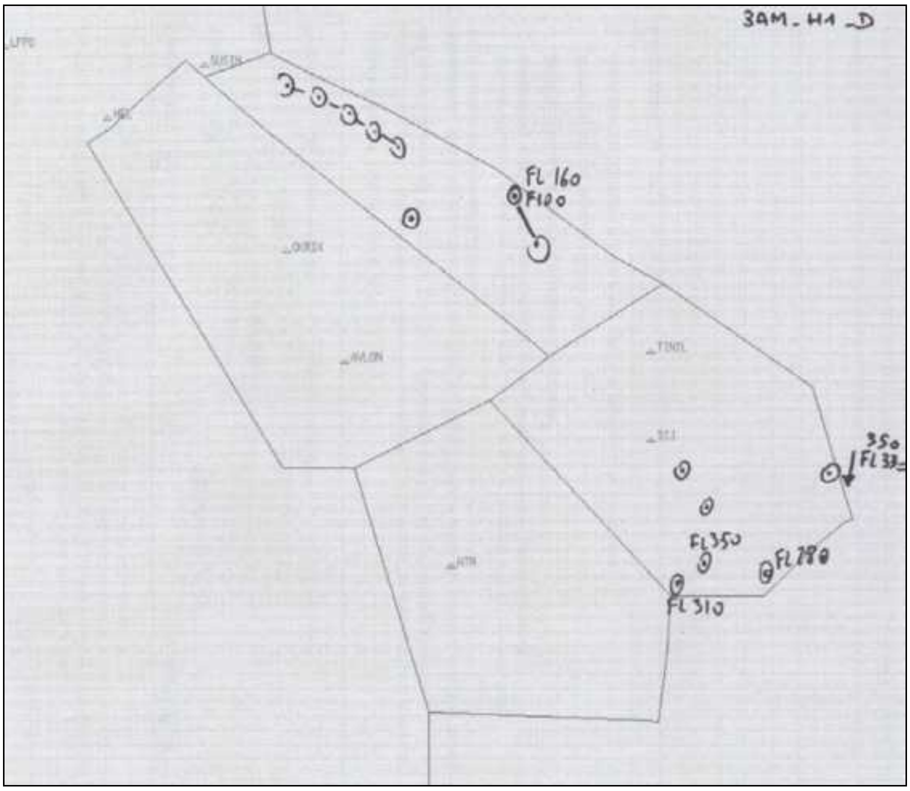


Figure 14: Situation awareness assessment. Example 3AMH1, AR sector, with delegation More details appear: the controller seems to have a better awareness of traffic at the sector entry, as well as of chains of aircraft transferred

7.3.3. Active control

In terms of active control, three aspects are considered: first the duration of active control, second the issuing of manoeuvring instructions (speed, heading, delegation) in terms of number, type, geographical and temporal distribution, and third the radio communication load.

Although controllers' activity continues after last manoeuvring instructions (typically in terms of monitoring, as discussed in the next section), we define as period of active control the period between the sector entry (transfer to frequency) and the last manoeuvring instruction given to an aircraft. Delegation seems to modify the duration of active control, whatever the sector and the traffic level considered (Figure 15). With delegation, the median value is between 0 and 5 minutes of active control, whereas without delegation the median value is closer to 10 minutes of active control per aircraft. These observations raise a few questions:

- In a shorter time interval, do controllers perform similar control (in terms of strategy)?
- Are decisions and actions taken in such a shorter interval similarly efficient?
- Is there a switch between active control and monitoring tasks?

We will try to answer these questions in the remaining part of the report.

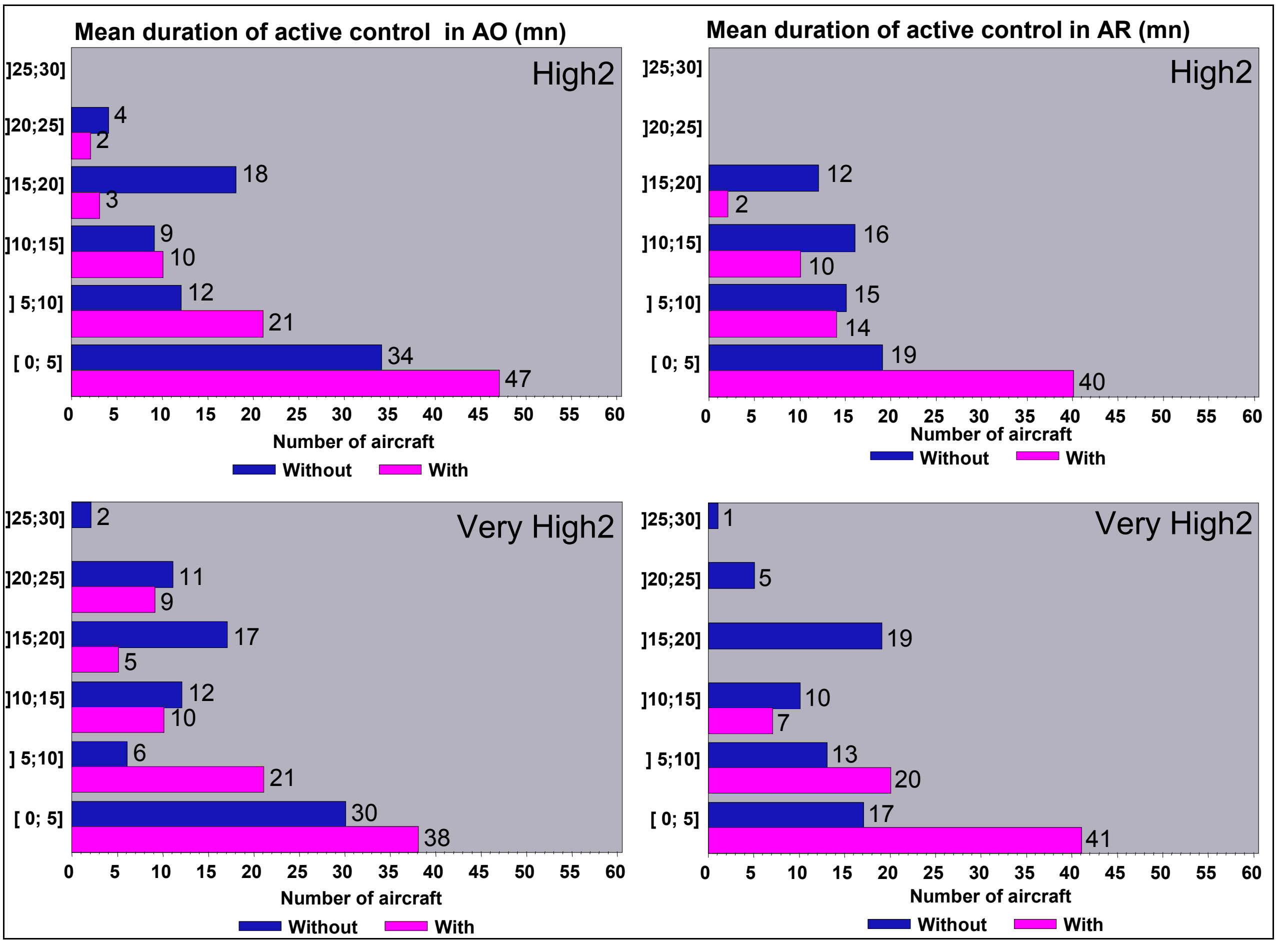


Figure 15: Mean duration of active control, for high and very high traffic

7.3.3.1. Number and type of manoeuvring instructions

Reminder: Delegation aims at transferring to the flight deck the speed adjustments required to maintain sequences. Therefore, the main assumption is that delegation would induce a reduction in the number of heading and speed instructions. The counting of manoeuvring instructions without and with delegation shows that delegation induces an overall reduction, in both sectors and for both traffic levels (Figure 16). The observed trends are comparable with the baseline (27% reduction) and in line with last year results. Globally, delegation induces a reduction of 22% of the instructions in high traffic and 28% in very high traffic. When including new instructions induced by delegation ("select target") we still observe a 16% reduction (Figure 17).

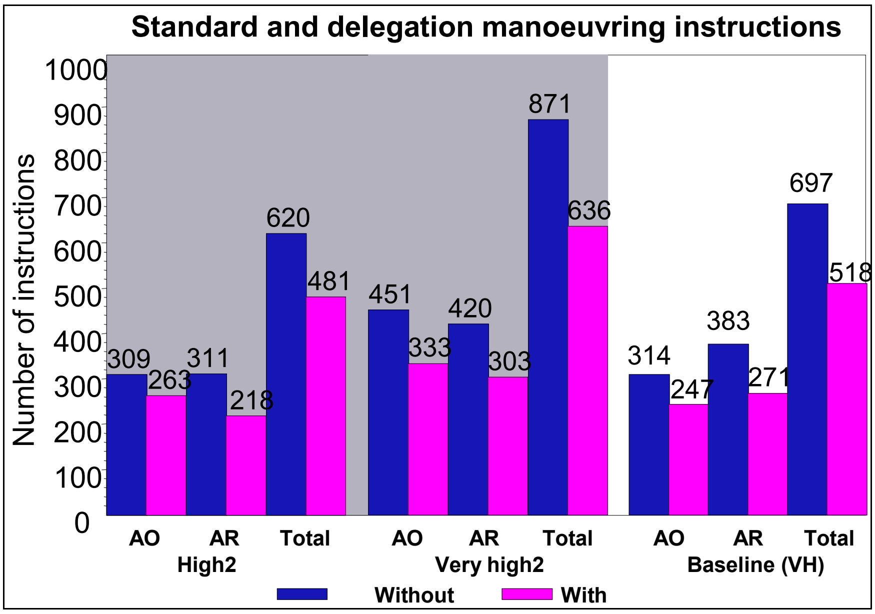


Figure 16: Total number of manoeuvring instructions used. Sessions H2 and V2

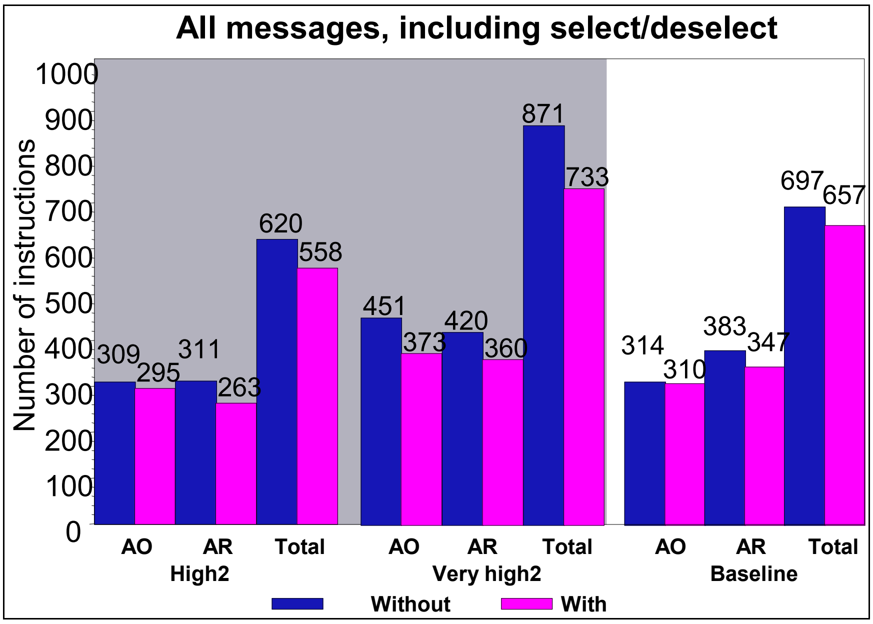


Figure 17: Total number of instructions, including target selection

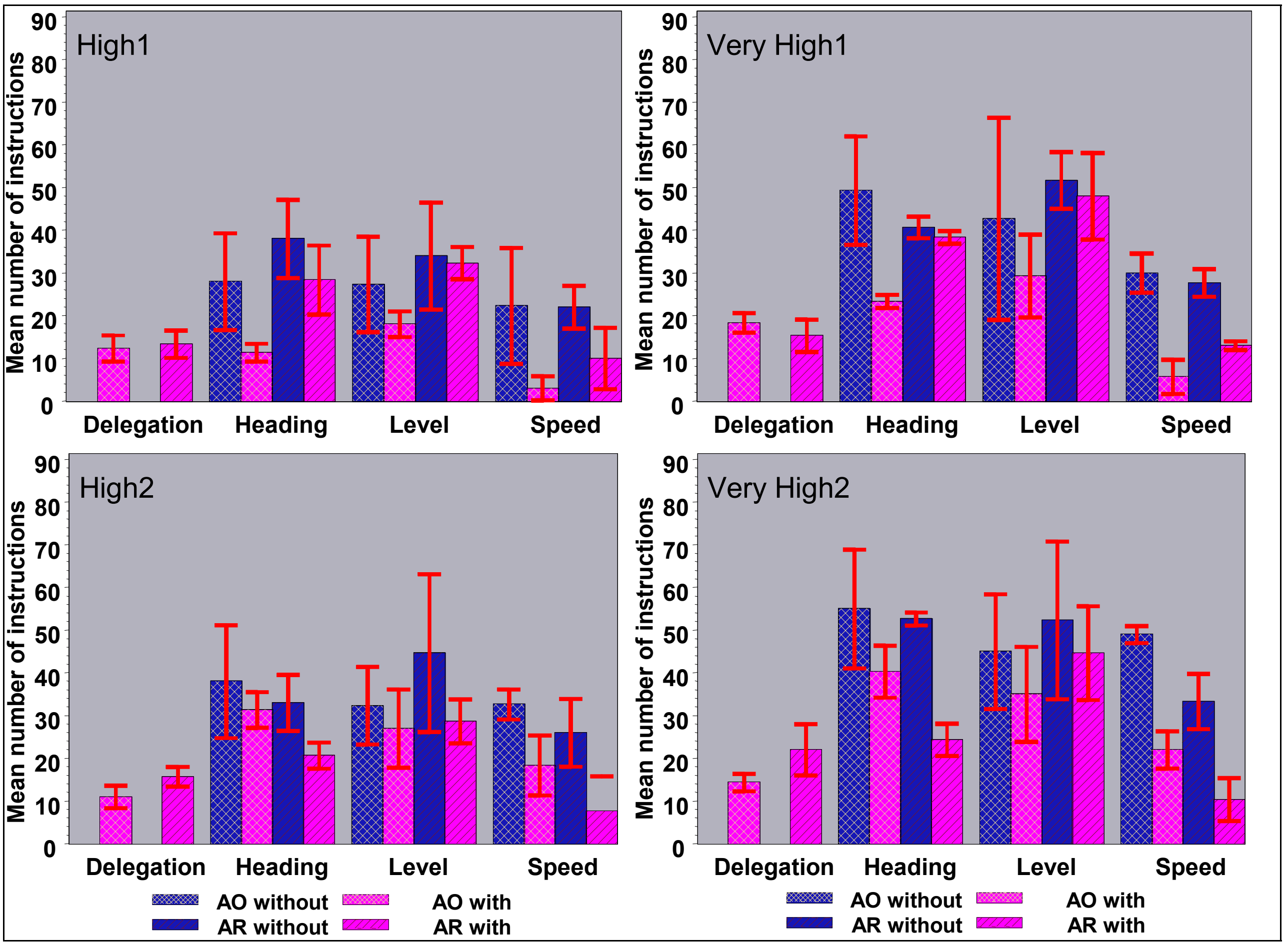


Figure 18: Type of manoeuvring instructions used. Sessions H1, V1, H2 and V2

Following this overall view, we questioned the impact of delegation on the type of instructions used by controllers in sequencing context. Indeed, a modification of the type of instruction could indicate a change in the strategy used by controller. The data show a general reduction, but no real change. When focusing on heading and speed instructions (Figure 18), we notice a drastic reduction of speed instructions, and an important reduction of heading instructions. If we compare the H2 and V2 sessions, the benefits are higher in the AR sector: for very high traffic, delegation enables a 53% reduction of heading instructions (only 27% in AO) and 68% reduction of speed instructions (56% in AO). The sector configuration might explain such a difference. However, when considering the V1 session, results show the opposite. Controllers might Therefore, here again, the controller involved might explain the difference, in terms of confidence with delegation, rather than confidence with the sector itself.

7.3.3.2. Geographical distribution of instructions

In order to improve our understanding of the impact of delegation, we plotted instructions over the sector manned. The density of spots (Figure 19 and Figure 20) shows the quantity of instructions given, as a function of their geographical location. Not only the density is reduced, but the reduction occurs in the second part of the sector (passed 120Nm from IAF in AR and 100Nm in AO).

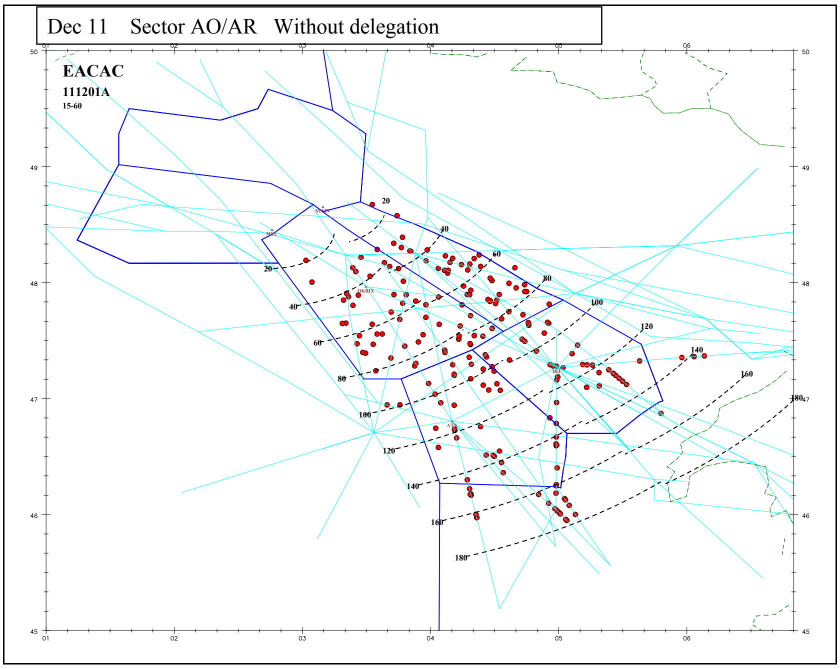


Figure 19: Mapping instructions over geographical sectors. Example of results, V2 session, without delegation. Many instructions are given, all over sectors

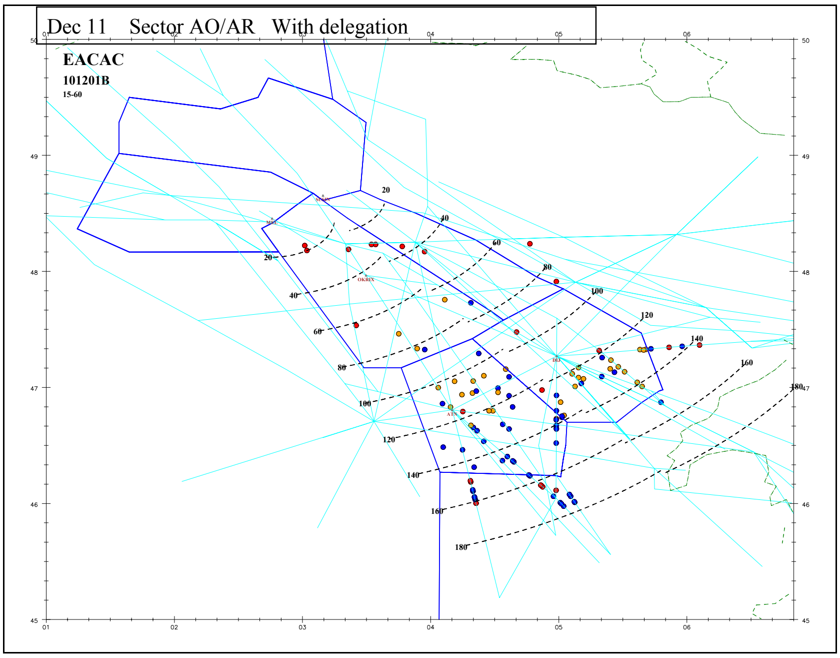


Figure 20: Mapping instructions over geographical sectors.
Example of results, V2 session, with delegation.
Few instructions, mostly given in first part of the sector (before 100Nm from the IAF)

A more synthetic view of the geographical repartition of instructions (Figure 21 and Figure 22) shows results comparable with EACAC'00. Whereas the traffic level had little effect, the sectors did have an effect: the impact of delegation is more noticeable in AR sector. Although sequence building is still reflected by early use of heading instructions between 120 and 160Nm from the IAF, no more speed instructions are given in the second part of the sector. It looks like controllers are no longer maintaining the sequences. In AO sector, delegation also induces a reduction of speed instructions in the second part of the sector. However, heading instructions are still used in the second part of the sector. The configuration of the sector may explain such a difference. Indeed, AO is composed of two converging points used to sequence aircraft. Whereas the first converging point is quite far from the IAF (ATN), the second one, called OKRIX is located around 60NM from the IAF. This late converging point is mainly used to integrate Eastern traffic transferred from the AR sector. As stated by controllers, delegation initiated earlier in the sector happened to be cancelled in order to integrate these Eastern flows. The main impact of delegation is a removal of speed instructions, and reflects the delegation of the maintaining task to the flight deck. Once, the sequences built, there is no need for the controller to issue further instructions, as the spacing is maintained by the flight deck.

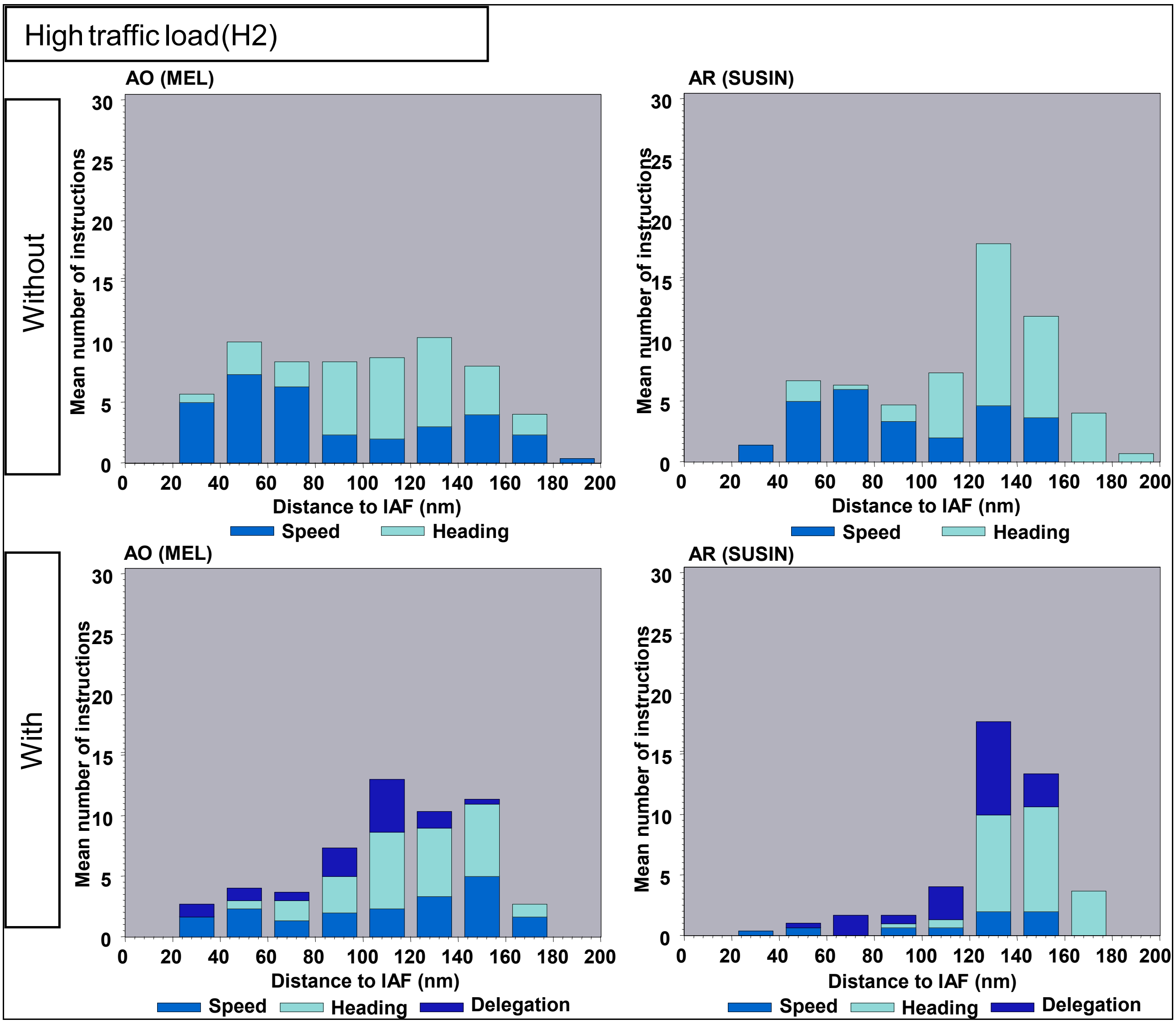


Figure 21: Geographical distribution of manoeuvring instructions. High traffic

As defined in previous experiment (EACAC'00), the geographical distribution of manoeuvring instructions reflects controller strategies. Typically, in case of sequencing activity, such a representation enables the distinction between the sequence building (use of heading instructions) and the sequence maintaining (use of speed instructions) without delegation. Results show that delegation modifies active control in reducing the number of instructions used, but does not modify controllers strategies. Heading (or equivalent delegation instructions) are used to build sequences, whereas speed adjustments are used to maintain them (even if they are no longer visible at controller level, but should be detected on the flight crew side). These results are comparable to our baseline observations and in line with our previous experiments: with delegation controllers remain in charge of the strategy (building of the sequences), and delegate to pilots its implementation (adjusting speed). Whereas these results are very positive in terms of activity, they raise two issues: first, is the absence of active control in the second part of the sector associated to an absence of monitoring and second, is the speed adjustment task acceptable from a flight crew perspective? Answers to the first question will be proposed in other sections of the report, whereas answers to the second question will come out of the flight deck experiment.

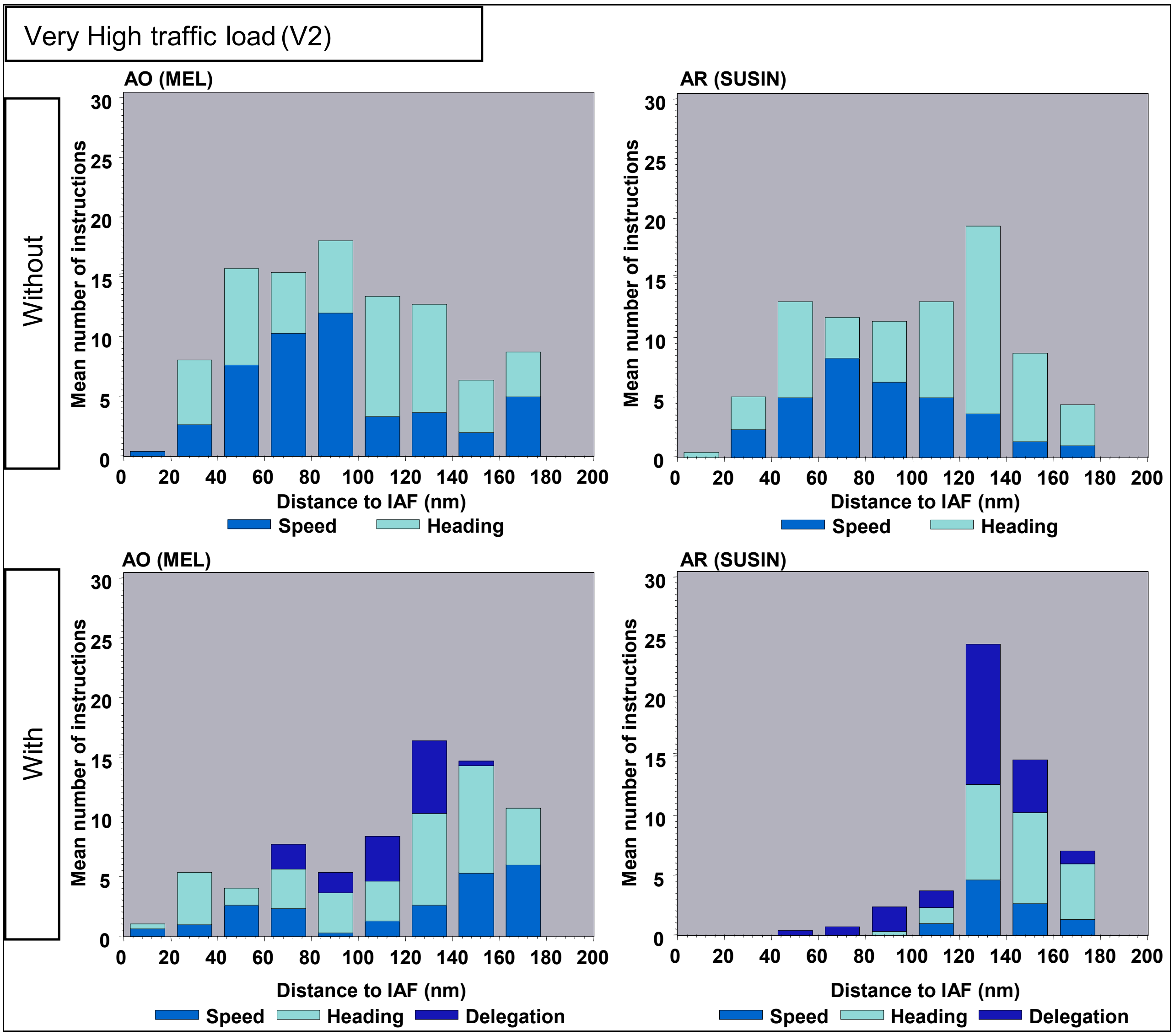


Figure 22: Geographical distribution of manoeuvring instructions. Very high traffic

7.3.3.3. Temporal distribution of instructions

Similarly to previous results, the delegation does not modify the distribution of instructions in time (Figure 23 and Figure 24). We expected delegation to help controllers smoothing their own activity: typically, peaks of instructions could have been replaced by more homogeneous instructions giving. However as illustrated on figure, in both conditions, and in both sectors, delegation did not induce any modification, either positive or negative.

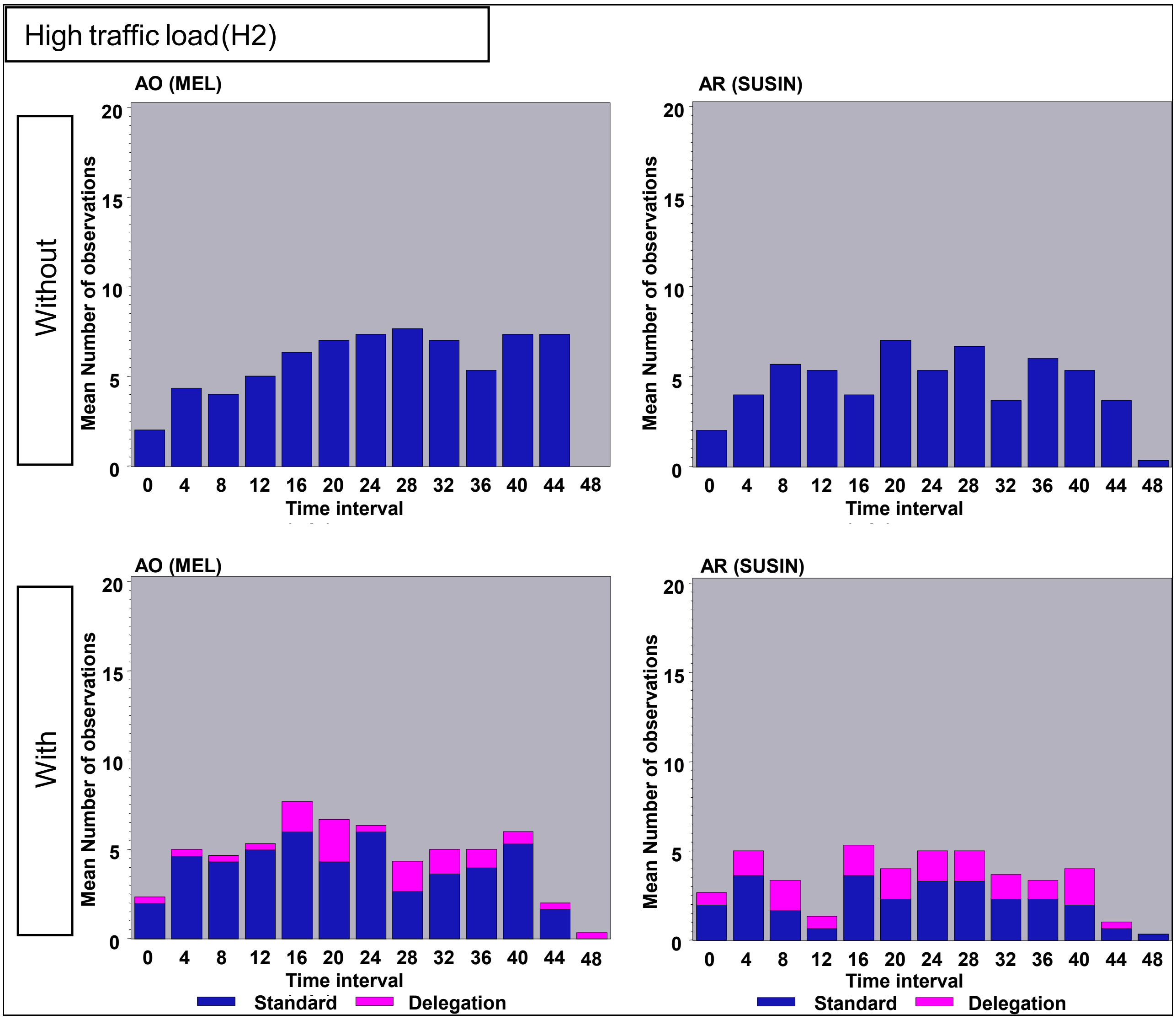


Figure 23: Temporal distribution of instructions. High traffic

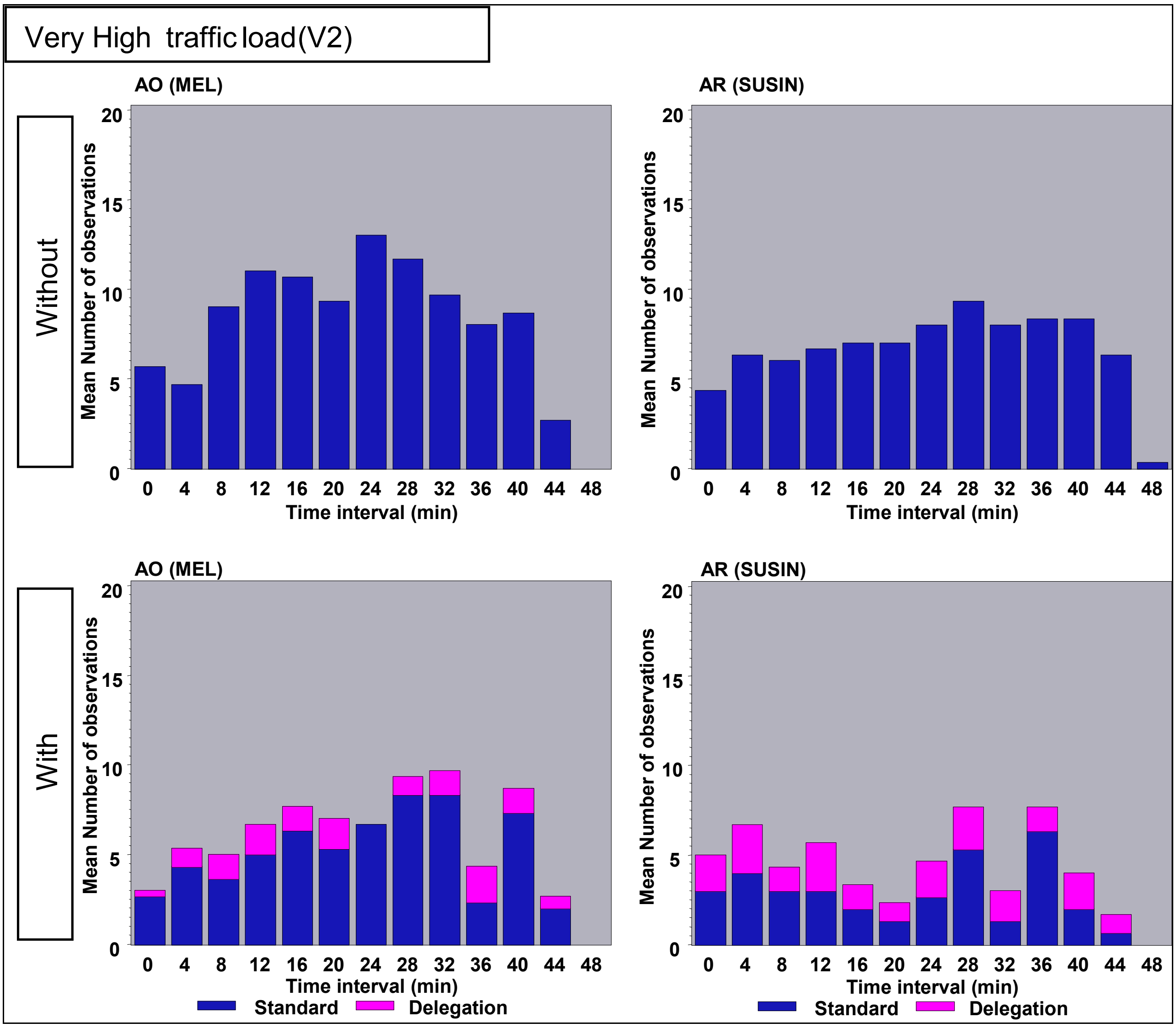


Figure 24: Temporal distribution of instructions. Very high traffic

7.3.3.4. Communications

Occurrence and duration of radio communications between controllers and pseudo pilots were systematically recorded. However, it did happen that a same communication actually concerned more than one exchange. Indeed, unlike in reality, simultaneous transmission is allowed. In cases of high workload, when controllers keep calling successive aircraft, it did happen that pilots kept the push to talk button pressed.

Despite our questioning of the quality of the communication data, summary data are presented here (Figure 25 and Figure 26).

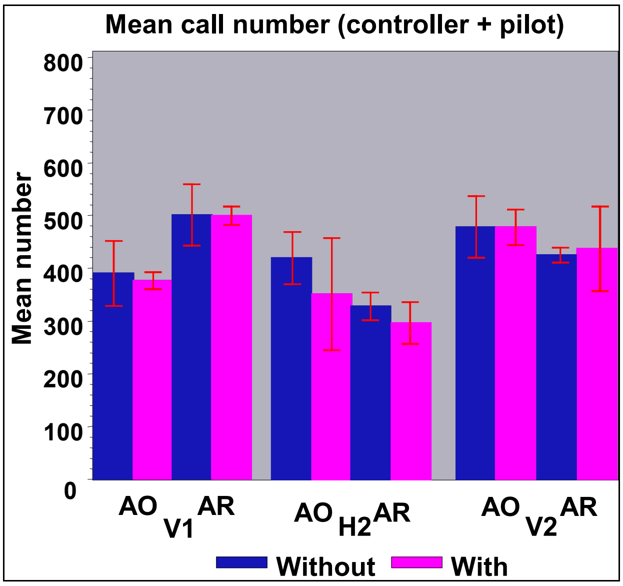


Figure 25: Mean call number in H2, V1 and V2

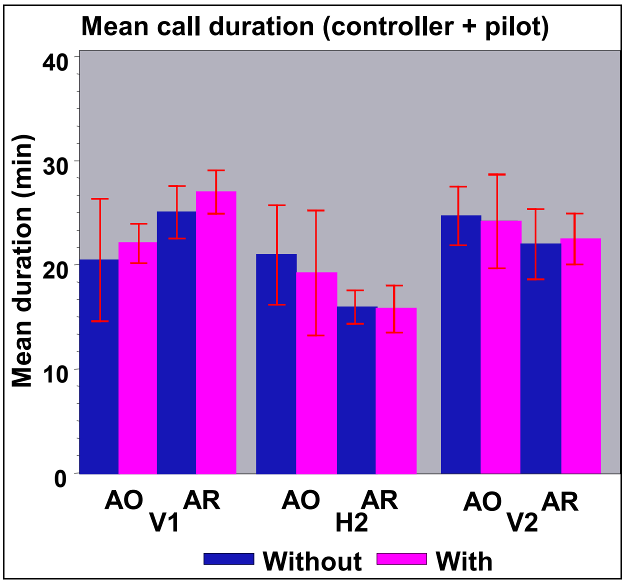


Figure 26: Mean call duration in V1, H2 and V2

In the second high session (H2), the call number was slightly reduced in both sectors. However, for very high traffic, no impact of delegation was observed. Similarly, no real impact of delegation can be identified in terms of call duration.

7.3.4. Monitoring

Subjective feedback from controllers was collected via questionnaires items. Controllers thought delegation modified their monitoring, typically in reducing its frequency. However half of the controllers thought the monitoring with delegation was more detailed, the other half more global.

Eye movement tracking technique provided more objective evaluation of the impact of delegation on monitoring. Unless mentioned, general results are statistically significant (Chi2-test, p<.0001). Summary resukts are presented in this section. For more details, see Novadis (2002a, 2002b and 2002c).

7.3.4.1. General characteristics of fixations

The initial investigation consisted in measuring the number and duration of fixations inside the radar screen as opposed to outside. In the AR sector (one converging point), with and without delegation, and for both traffic levels the controllers spent 80% of their time monitoring the radar. In AO sector (one early and one late converging points), they spent 70% of their time on the radar. The higher number of instructions given in this sector might require more analysis and annotations on strips, and possibly explains the reduced time spent looking on the radar.

Beyond measuring the influence of delegation on general characteristics of eye movements (number and duration of fixations), the objective is to understand the impact on controller monitoring tasks. The same analytical framework was applied to investigate the impact of delegation on the geographical occurrence of both instructions (active control) and fixations (global monitoring). In addition, contextual analysis of fixations aimed at determining if delegation modified the number, duration and frequency of fixation per aircraft (contextual monitoring).

7.3.4.2. Global monitoring

At a macroscopic level, we investigated if delegation influences the number and duration of fixations, and if, similarly to what was observed with instructions, there was a correlation between number, duration and geographical position of fixations. To address the overall monitoring, we analysed the geographical distribution of fixations (results for the AR sector on Figure 27). In high traffic situation, the global monitoring was similar without and with delegation: more fixations occurred around the converging point (35% with delegation and 25% without over the [120-140NM] area). In very high traffic situation, curves are completely opposite: with delegation, most of the fixations are concentrated over the converging area, while without delegation, they are concentrated over the second part of the sector ([40-80NM] from the IAF, i.e. near the sector exit): exactly where speed and heading instructions are still used.

It looks like without delegation, controllers are more in a reactive position, the building of sequences being no longer anticipated. With delegation, controllers seem to be focusing over the most important area, where sequences need to be built. Similarly to what was observed about active control, delegation impact is more noticeable in very high traffic situation.

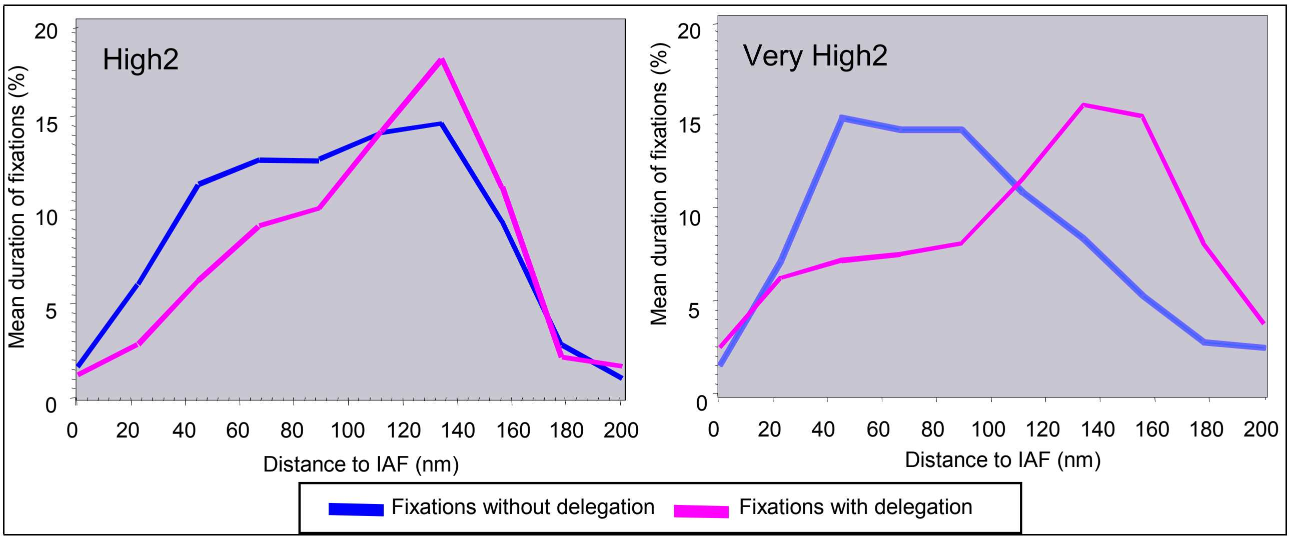


Figure 27: Distribution of fixations in AR sector
Relevant areas are: sector entry (200NM), sequences building (140NM) and transfer to next sector (20-40NM). High traffic (left) and very high traffic (right)

Beyond noticing the impact of the geographical area on the monitoring, we wondered if there was a relation between the fixations and the aircraft location in sector. To answer this question, we superimposed monitoring curves with the number of aircraft located in the given geographical areas (Figure 28).

What appears is that with high traffic, controllers seem to be looking where aircraft are located. Both monitoring and aircraft curves have similar shapes. With very high traffic, without delegation the peaks of fixations do not correspond to a peak in the number of aircraft monitored: whereas many aircraft are all over the sectors, fixations are concentrated near the transfer area.

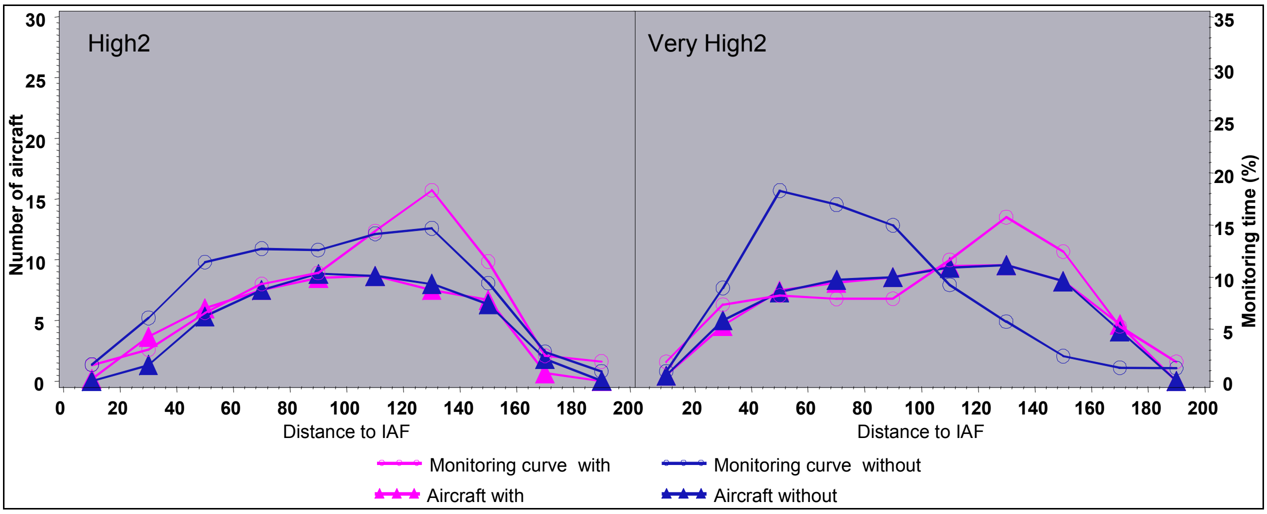


Figure 28: Geographical distribution of fixations and of number of aircraft. AR sector, high traffic (left) and very high traffic (right)

Another question was the possible relation between the aircraft status and the monitoring curve. In other words, are the delegated aircraft still monitored?[4] The geographical distribution of monitoring and the number of not delegated and delegated aircraft (Figure 29) shows that the monitoring curve and the not delegated aircraft curve have similar shapes. Our hypothesis is that once delegated (passed 120NM from the IAF) aircraft require less monitoring. Curves with opposed shapes seem to confirm it.

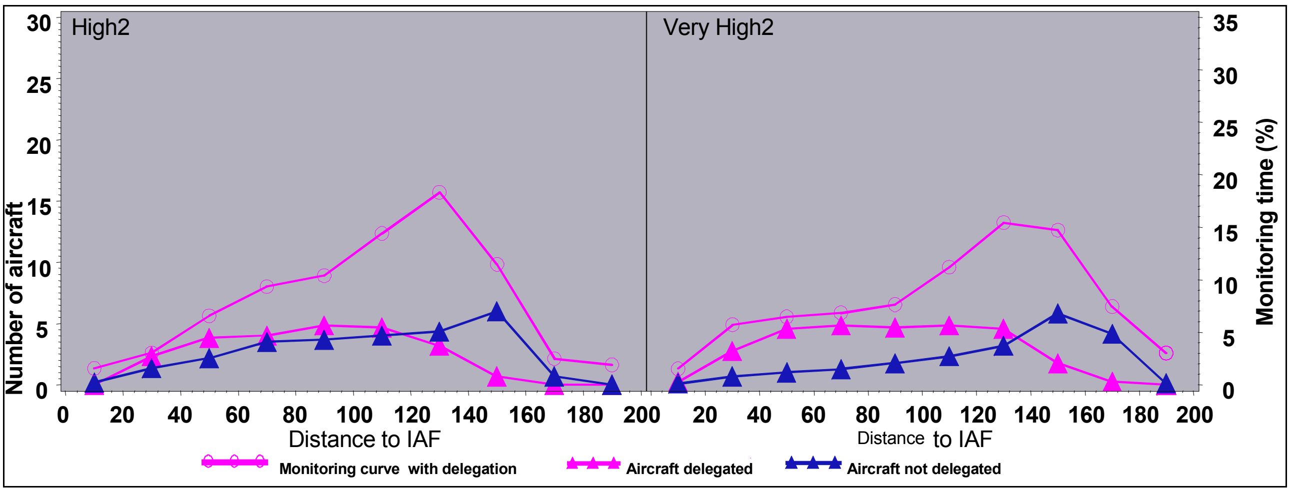


Figure 29: Geographical distribution of fixations and of number of not delegated and delegated aircraft. AR sector, high traffic (left) and very high traffic (right)

7.3.4.3. Contextual monitoring

The reduced monitoring in the second part of the sector with delegation raised the issue of safety: is the frequency of monitoring per aircraft modified? Are aircraft still monitored once delegated? Are changes equally impacting delegated and not delegated aircraft? To answer these questions, we conducted a "contextual" analysis of monitoring. It consisted in analysing the frequency of the monitoring of each aircraft, i.e. the interval between two consecutive fixations on a same aircraft.

[4] It should be reminded that the controller is still responsible for separation provision.

Average frequency of monitoring

As opposed to the previous analysis, the contextual one required a fine synchronisation between air traffic events and eye measures. Spatial and temporal synchronisation was ensured through controller mouse clicks on reference beacons every 15 minutes. An additional post processing synchronisation took place later. From these files, all the statistical computation was realised. In complement to analysing the distributions of fixations on the radar, we examined the frequency of monitoring of each aircraft, depending on its status (not delegated, in preparation[5] or delegated). The calculation of fixations per aircraft was made by allocating to every fixation one or several concerned aircraft (positions or labels). In other words, for each fixation point, we determined which aircraft was (were) looked at by listing all the aircraft close to the point of fixation. We considered that an aircraft was close to a point of fixation if it was within a circle of 100 pixels radius (approximately 10NM) centred on the fixation point. This led to obtain a temporal distribution of fixations for every aircraft (Figure 30).

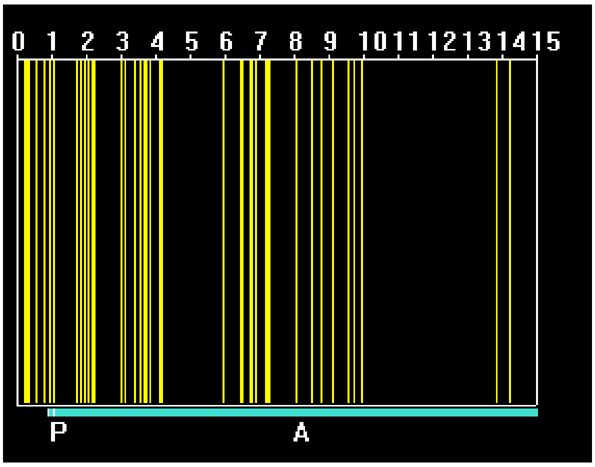


Figure 30: Example of a temporal distribution

Example of a temporal distribution (15 minutes) of fixations for a specific aircraft. Delegation is indicated by the blue line, delegation status (preparation or active) is reflected with the P and A letters. High density of lines reflects gathering of fixations on the aircraft, while lower density reflects less frequent fixations.

From this, we calculated the mean period of fixation (i.e. interval between two successive fixations on a same aircraft). No effect of delegation was observed. Typically, in AR, very high traffic, delegated and not delegated aircraft were fixed as frequently, approximately every 12 seconds (Table 9).

Table 9: Mean period of fixation. AR sector, very high traffic, second exercise, 100 pixels area around fixation

	Aircraft status	Mean period (s)
Without delegation	Not delegated	10.5
With delegation	Not delegated	12.0
	In preparation	14.4
	Delegated	14.4

5 In preparation refers to target selection phase, when the controller has prepared delegation but waits for the appropriate time to issue the delegation instruction. This usually corresponds to the building of sequences.

Less frequent monitoring?

In order to detect aircraft monitored less frequently, we analysed the distribution of the maximum period and more specifically extreme values (Figure 32). Results show a few cases with surprising periods of more than 6 minutes in both situations (delegated and not delegated aircraft). Does it mean that these aircraft are simply not monitored?

As a first attempt to answer we checked if these aircraft received instructions. This was the case, not only they received instructions all along their flight in the sector, but for two of them instructions given reflected a problem solving situation.

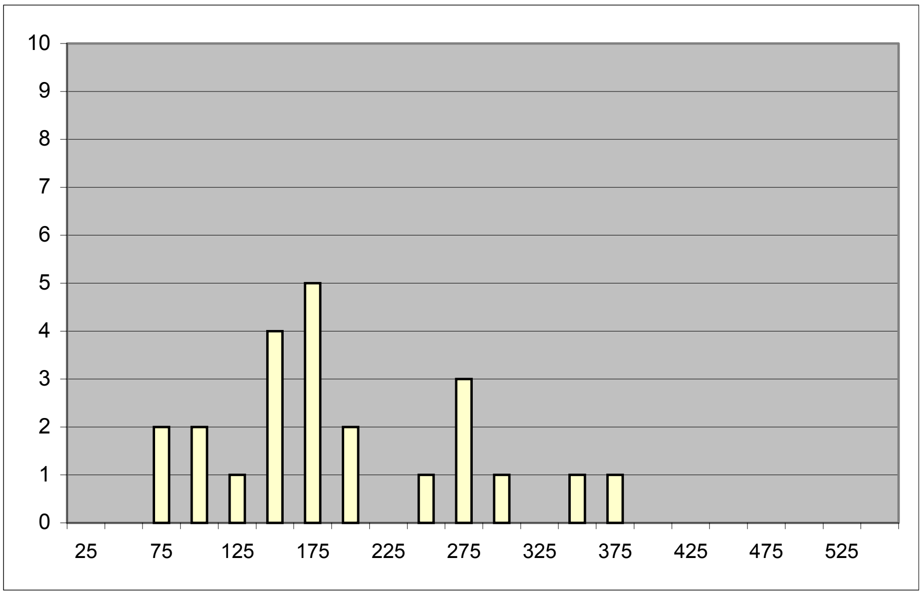


Figure 31: Distribution of maximum period. AR sector, very high traffic, second exercise, 100 pixels fixation area. Without delegation Delegation active (A), in preparation (P) and no delegation (O)

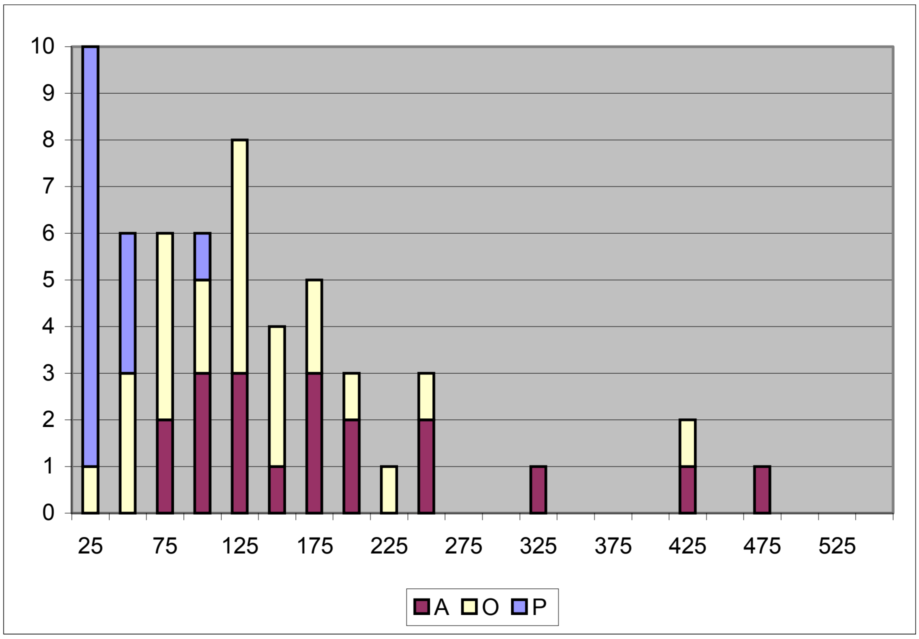


Figure 32: Distribution of maximum period. AR sector, very high traffic, second exercise, 100 pixels fixation area. With delegation Delegation active (A), in preparation (P) and no delegation (O)

The size of the "fixation area" (100 pixels) was thus questioned. A 200 pixels circle was used. However, there were still cases with large periods. In addition, the increased size led to the drastic reduction of the mean period, which did not seem realistic: controller can hardly perform a full scanning of all the aircraft in contact (typically 15) in 3 seconds (Table 10). The 200 pixels size clearly appeared as too large.

Table 10: Maximum and mean period of fixation. AR sector, very high traffic, second exercise, 200 pixels area around fixation

	Aircraft status	Mean period (s)	Mean period (s)
Without delegation	Not delegated	262	2.6
With delegation	Not delegated	419	3.4
	In preparation	55	2.4
	Delegated	211	3.8

We then questioned the definition of the area as a circle centred around the fixation. We used the eye tracker replay tool to understand the scanning of these aircraft with extreme periods. We could identify that fixations were located in between two or more aircraft (Figure 33).

Note: Although this requires further investigation, we think that results issued from the relative comparison of mean period without and with delegation are still valid: delegation does not modify the frequency of monitoring.

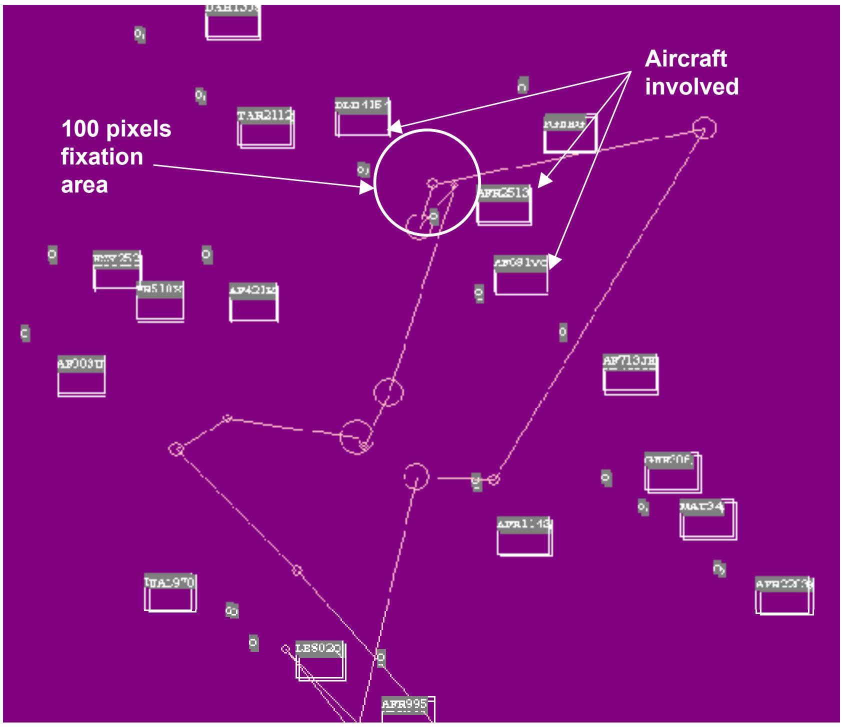


Figure 33: Example of fixation area excluding aircraft, which received instructions

Results lead us to question the possibility to identify maximum fixation period per object. Although we can know with certainty when fixations are detected, it is difficult to associate the non detection of a fixation with an absence of fixation: indeed, the absence of a fixation might be caused by a variety of factors, mainly the temporary loss of pupil.

7.3.5. Synthesis on controller activity

Subjective analysis (NASA-TLX and ISA) show that delegation seems to reduce controllers workload, and more specifically the temporal demand on executive controller in AR. In a shorter active control period, a reduced number of instructions is given. The control task is focused on the building of sequences, whereas sequences maintaining is no longer performed. The monitoring is focused on the building areas. Similar fixation periods are observed for delegated and not delegated aircraft. For very high traffic, delegation enables the focus to be maintained on the early part of the sector. Delegation enables anticipation in the building of sequences and reduces tasks time criticality. Typically, the most relevant application in terms of anticipation is the most used (i.e. merge).

The situation awareness could not be efficiently assessed. The technique used needs to be refined. The monitoring curves show that with delegation controllers spend most of their monitoring time focusing on the most strategic area, where relevant information need to be collected in order to make decisions. From our observations, we assume that with delegation, controllers are in a better position to collect information, interpret situations and make appropriate decision. Even though we can not say that delegation improves the situation awareness itself, it seems to support its process in enabling controllers to focus their attention on the most strategic area, where information is available and timely decisions need to be made. The reduced but still active monitoring on the second part of the sectors suggests that controllers keep collecting information about aircraft, delegated or not.

7.4. EFFECTIVENESS

7.4.1. Quality of control

7.4.1.1. Transfer conditions

In E-TMA, in addition to building sequences and maintaining safe spacing between aircraft, the controller objective is to transfer aircraft correctly spaced (here 8NM), not catching up and at a given altitude (here FL090). The transfer conditions could reflect the quality of control, but also unsafe situations. In the present section, we do not focus on unsafe transfer but rather consider low quality transfers, since they might induce workload increase for the receiving sector.

The distribution of current spacing value shows differences induced by delegation (Figure 34 and Figure 35). The main observation is the number of aircraft sent with a correct spacing for very high traffic. In AO, with delegation we notice 15 cases against 8 without delegation. In AR, with delegation we notice 13 cases against 10 without delegation.The Critical Interaction Analysis methodology (CRIA).

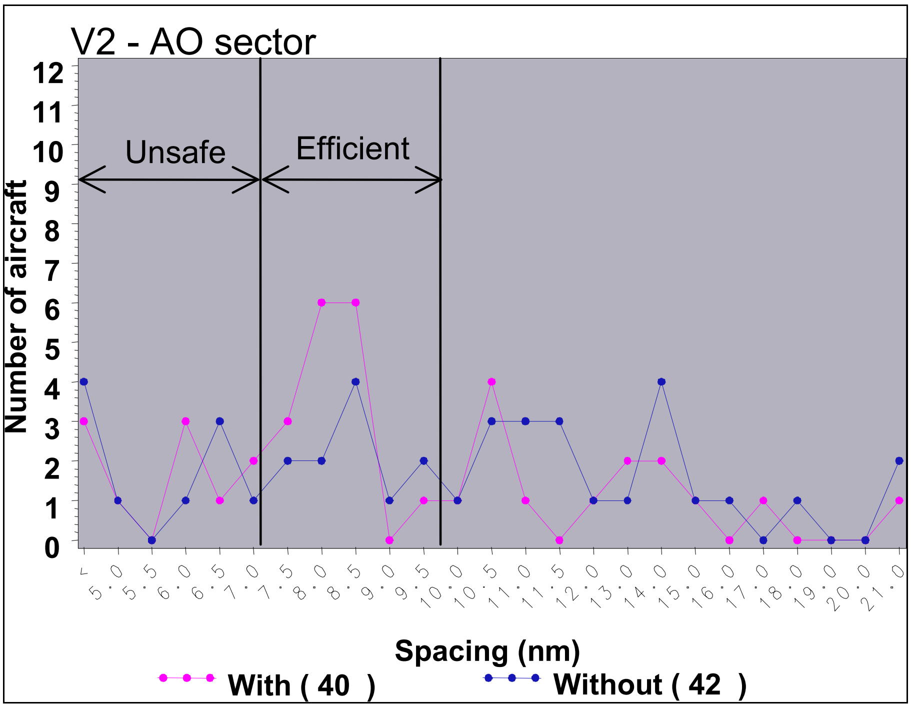


Figure 34: Distribution of current spacing value at transfer on the frequency. Very high traffic, AO sector

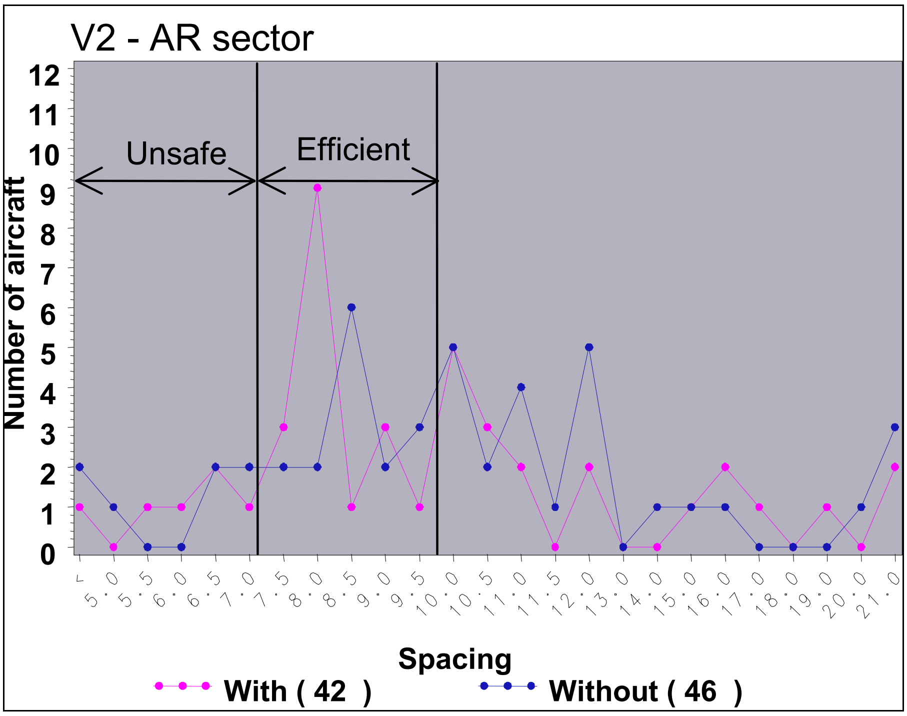


Figure 35: Distribution of current spacing value at transfer on the frequency. Very high traffic, AR sector

Table 11: Potentially unsafe (less than 5NM) and efficient (between 7.5 and 8.5NM) spacing at transfer Results are presented for the second week sessions and per sector.

		Spacing < 5		7.5 ≤ Spacing ≤ 8.5	
		Without	With	Without	With
H2	AO	0	0	4	11
	AR	1	0	5	11
	Total	1	0	9	22
V2	AO	4	3	8	15
	AR	2	1	10	13
	Total	6	4	18	26
Ratio (Total/Nb of aircraft)		7/165 4%	4/159 3%	27/165 16%	48/159 30%

Table 12 shows a limited impact of delegation on the number of unsafe transfers, but a more important one on the number of efficient transfers. The surprising number of transfers with spacing below 5NM with delegation led us to deepen our analysis. Two points needed to be considered carefully: first, aircraft might be currently correctly spaced but in a catching up situation and second, with delegation the spacing is expected at a geographical point located after transfer. Whereas the spacing value at transfer reflects a discrete event, it does not inform about dynamic aspects.

Unstable transfer

In order to measure conditions of transfer, we combined spacing indicators with closure rate indicators (basically speed differences between successive aircraft): we analysed the distribution of closure rates as a function of the current spacing values at transfer. Typically, we considered cases when the spacing is correct (e.g. between 7.5 and 8.5NM) but not stable (e.g. high closure rate between aircraft, as highlighted in orange circle on Figure 48). Depending on closure rates, we qualified the situations as either endangering safety (spacing soon to reach 5NM, which is the separation minima defined by air traffic regulation) or impairing the quality of control (spacing below 8NM, which is the agreed value of spacing at transfer).

Depending on the situation (and the spacing value), closure rates are more or less critical. Typically, 10knots for a spacing of 8NM is less critical than 10knots for a 5.5NM spacing. Therefore, the analysis needs to carefully consider two main situations: stability of spacing around 5NM (safety critical cases) and of spacing around 8NM (lower quality of control). The example provided on Figure 36 shows 2 safety critical cases without delegation and 1 with delegation (+20knots). They also show 2 low quality cases without delegation and 1 with delegation. However the case with delegation seems more serious (>40knots).

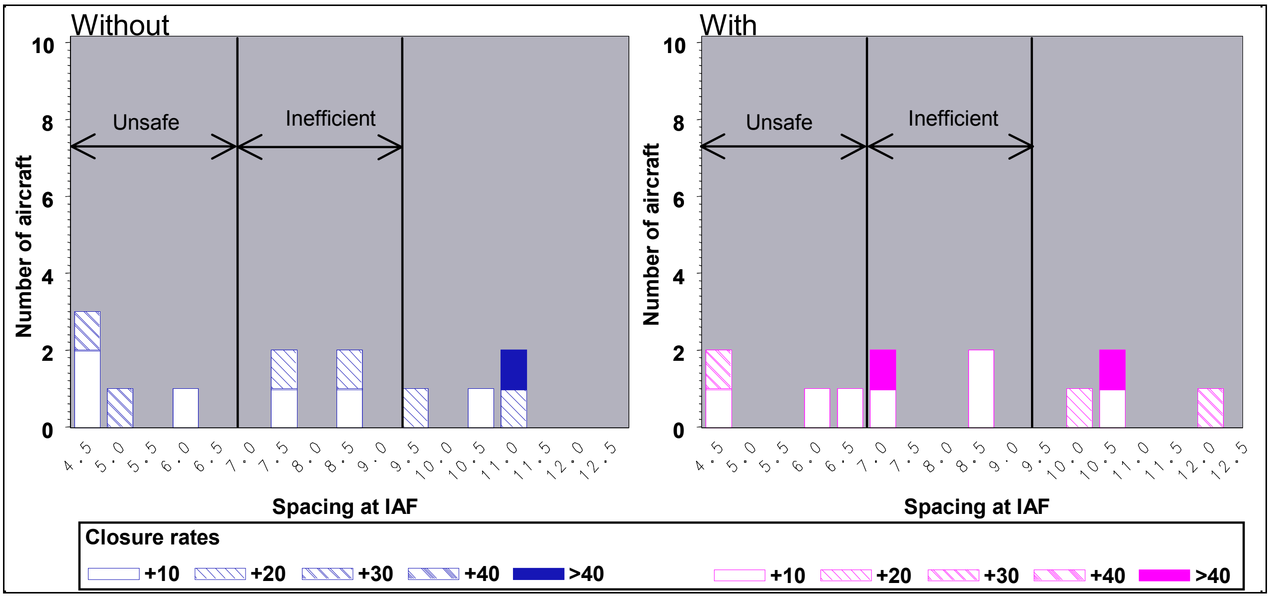


Figure 36: Distribution of closure rates as a function of spacing values. Very high traffic. AO sector, without delegation (left) and with delegation (right)

The overall analysis enabled us to detect the following cases, based on current spacing values (Table 12). Both in terms of unsafe and low quality transfer, the main influencing factor is the use of delegation. Delegation reduces the number of unsafe unstable transfers and the number of inefficient unstable transfers. None of the unsafe and unstable transfers with delegation concerned delegated aircraft.

Table 12: Number of potentially unsafe and of low quality transfer. Results are presented for the second week sessions and per sector

		Spacing < 5		7.5 ≤ Spacing ≤ 8.5	
		Without	With	Without	With
H2	AO	3	0	1	0
	AR	1	0	4	2
	Total	4	0	5	2
V2	AO	4	2	2	2
	AR	4	0	9	3
	Total	8	2	11	5
Ratio (Total/Nb of aircraft)		12/165 7%	2/159 1%	16/165 9%	7/159 4%

Delegation compelled at a waypoint

However, some types of delegation (e.g. merge application) induces the spacing to be obtained at a given geographical point, usually the IAF. Therefore, in addition to analysing the current spacing value at transfer, we also needed to assess it at the IAF. However, in our experimental set-up, the aircraft were transferred to manned approach sectors. Approach controllers, depending on the circumstances could modify the instructions and consequently the situations. Therefore, the spacing values at the IAF did not necessarily reflect what the E-TMA controllers planned.

As a result, based on aircraft current spacing and respective speeds when transferred, we predicted what the spacing could be at the IAF. Even though this introduces a bias and might not reflect what reality would have been, it enables us to detect cases of aircraft about to acquire the requested spacing, as well as aircraft possibly about to lose it. We analysed for every run the distribution of spacing when transferred and predicted at IAF. Each presumably unsafe case was analysed in depth.

Current spacing at transfer versus predicted spacing at IAF

The two previous observations led us to analyse the distribution of predicted spacing at IAF. When comparing the resulting distribution of spacing, we did notice numerous differences (Figure 37 and Figure 38). First of all, more losses of separation were predicted at IAF than detected at transfer, specifically without delegation. This reinforces our assumption that without delegation, aircraft were sent in a not stable situation (catching up situation). Second, a more homogeneous flow of sequenced aircraft is predicted at IAF than observed at transfer with delegation. This confirms the assumption that smaller number at transfer was due to the constraint of establishing the spacing at the IAF induced by delegation.

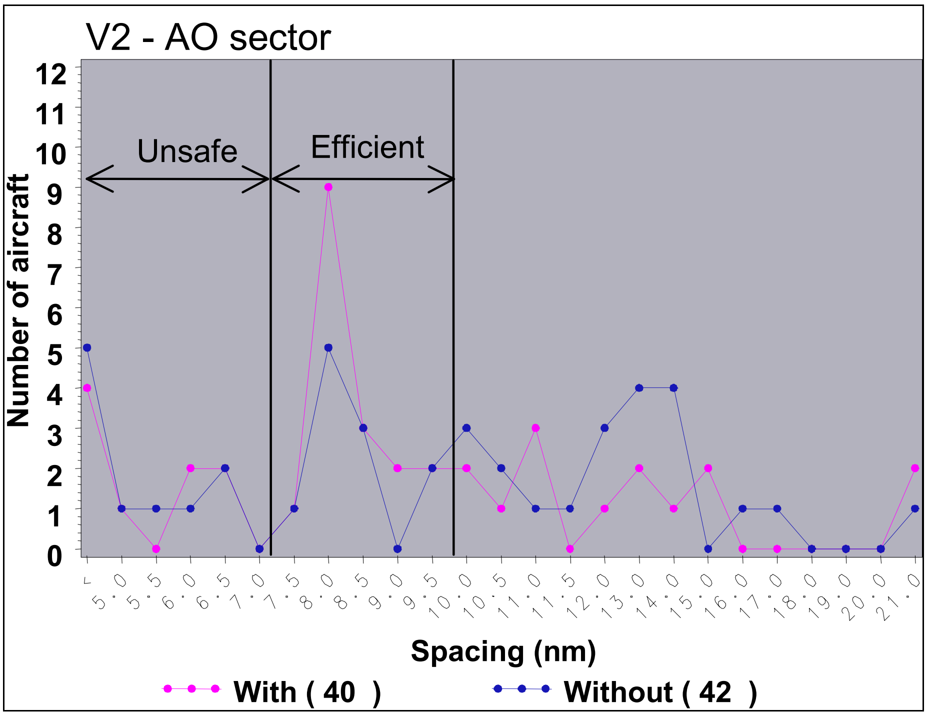


Figure 37: Distribution of predicted spacing value at IAF. Very high traffic, AO sector

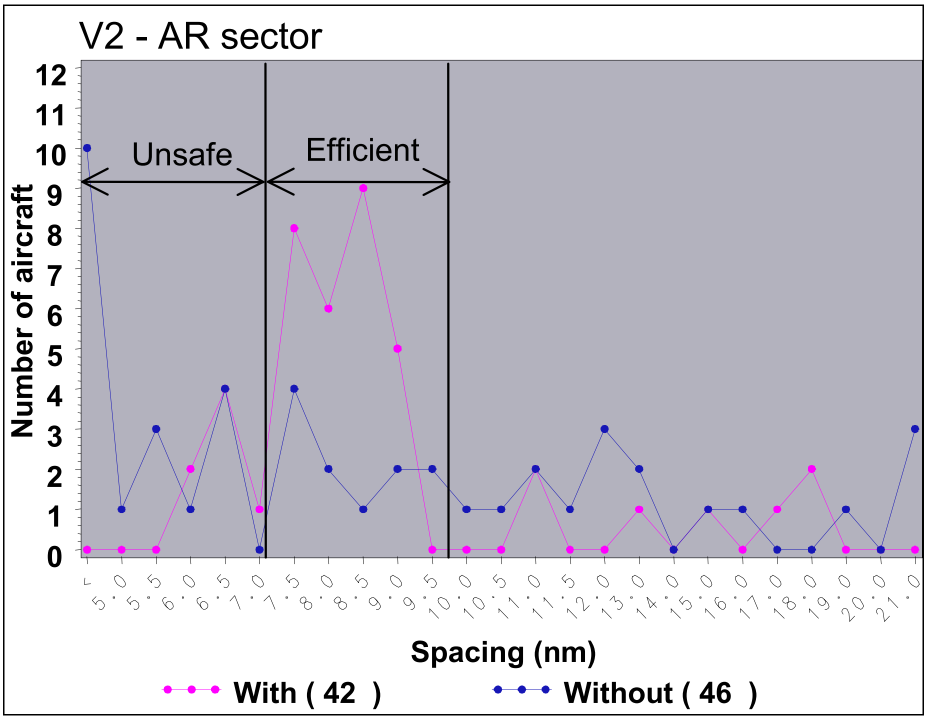


Figure 38: Distribution of predicted spacing value at IAF. Very high traffic, AR sector

Conditions at transfer correspond to a snapshot of the situation. Instantaneous speed value is then used to calculate predicted spacing at the IAF. Though this might not reflect an on-going speed reduction, according to us, the predicted distribution better reflects the transfer conditions. Therefore, the remaining of the comparisons will be based on it. Whereas we discuss in this section the respective percentage of safe and efficient transfer, the analysis of their possible causes will be the object of the next section focused on safety.

Table 13 summarises the number of aircraft with such a correct spacing, for the last two sessions (H2 and V2).

Table 13: Potentially unsafe (less than to 5NM) and efficient (between 7.5 and 8.5NM) predicted spacing at the initial approach fix
Results are presented for the second week sessions and per sector.

		Spacing < 5		7.5 ≤ Spacing ≤ 8.5	
		Without	With	Without	With
H2	AO	3	1	6	15
	AR	4	1	6	19
	Total	7	2	12	34
V2	AO	5	4	9	13
	AR	10	0	7	23
	Total	15	4	16	33
Ratio (Total/Nb of aircraft)		22/165 13%	6/159 4%	28/165 17%	67/159 42%

Effect of delegation

With delegation, more aircraft are sent with a longitudinal spacing between 7.5 and 8.5NM. In terms of safe longitudinal spacing at transfer, delegation enables the reduction of the number of aircraft sent with less than 5NM, from 13% to 4%. With delegation, only 1 of the aircraft transferred with an unsafe spacing was delegated. In this case, the applicability conditions were initially not respected. In terms of efficient spacing, delegation enables 42% of the aircraft to be transferred with a spacing between 7.5 and 8.5, whereas only 17% of them are sent with such a spacing without delegation.

It is necessary to assess the vertical separation provided between the aircraft at transfer: only 8 of the 28 aircraft sent with less than 5NM were vertically separated. Therefore most of the detected losses of separation (to be) were serious. Even though they were recovered by the receiving sector before their degradation, they reflect unsafe transfer conditions, which happen to be safety critical for the receiving sector. Such transfer conditions also increase risks of unsafety in inducing recovery actions (instructions) in the receiving sector, possibly creating increase in approach controllers' workload.

Effect of sector (AO versus AR)

When considering the impact of delegation as a function of the sector considered, we notice a difference. More cases of predicted losses of separation at IAF are predicted in AO (5 cases against 1 in AR). The number of aircraft sent with a spacing between 7.5 and 8.5NM is also higher in AR: 42 cases instead of 28 in AO. This could be explained by the anticipation enabled with delegation in AR. It is possible that in AO less efficient transfers reflect the difficulties of integrating a later flow, with a converging point close to the transfer area.

Effect of traffic level (high versus very high)

With delegation, traffic level has a minor impact on both safe and efficient transfers. Similar percentage of aircraft are transferred with a spacing between 7.5 and 8.5 (44% in high and 40% in very high). 3% of aircraft are sent with less than 5Nm in high and 5% in very high. Without delegation, the traffic level had an impact on the conditions of transfer. Twice as much aircraft were sent with less than 5NM in very high (17% against 9% in high).

7.4.2. Flight deck perspectives

7.4.2.1. Pseudo-pilot activity: Instructions per aircraft

Despite a limited realism of the flight crew perspective, it is nevertheless possible to have an initial insight on the impact of delegation on it. More precisely, it is essential to ensure that potential benefits for the controller (e.g. overall reduction of instructions) are not detrimental to some aircraft. For that purpose, we compared the distribution of instructions per aircraft without and with delegation (Figure 39 and Figure 40).

In very high traffic with delegation, most of the aircraft received between 1 and 6 instructions (only 3 aircraft received 7 or 8 instructions), while without delegation most of them received between 1 and 9 instructions (2 aircraft even receiving 12 or 13 instructions per flight). Focusing on speed instructions, we see that more than twice as much aircraft with delegation got no speed instructions, and only 2 received 2 speed instructions (against 19 without delegation).

Delegation does not seem to be detrimental to some aircraft. However, the next step will consist in a pilot-in-the-loop experiment aiming to assess the impact of delegation on flight crew activity, mainly in terms of speed actions and scanning patterns.

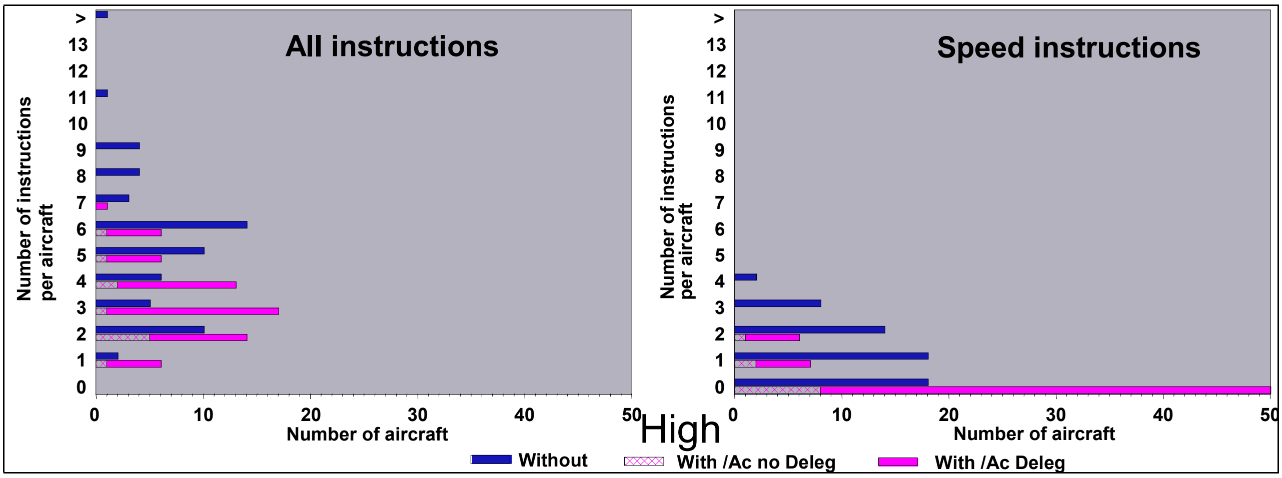


Figure 39: Number of instructions per aircraft. High traffic

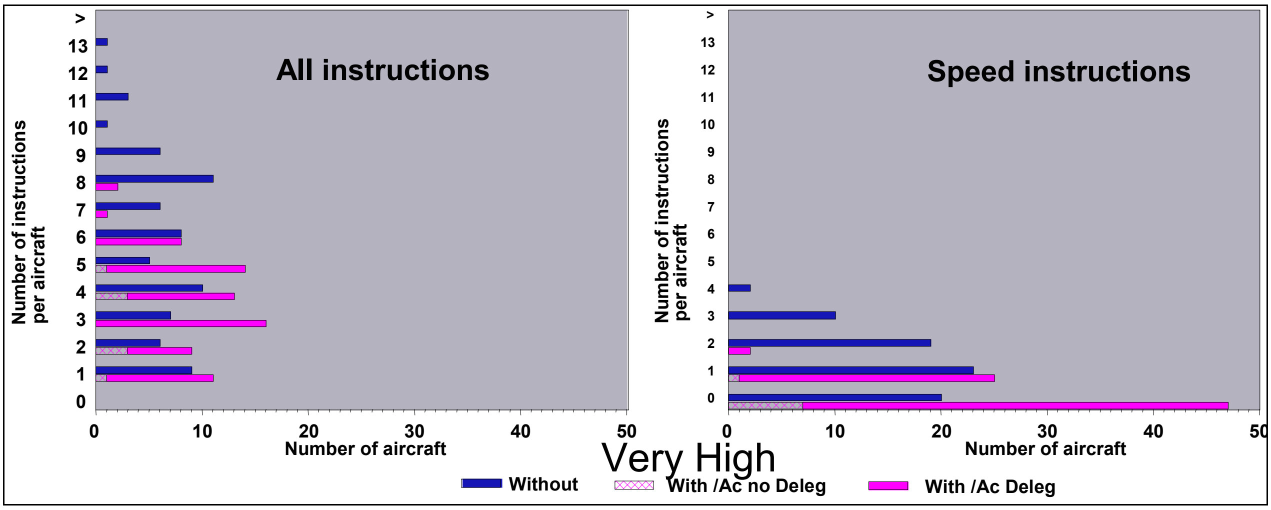


Figure 40: Number of instructions per aircraft. Very high traffic

7.4.2.2. Flight efficiency

The Figure 41 and Figure 42 provide an overview of the trajectories of aircraft distinguished according to their IAF. With delegation trajectories are more direct and most of the late alterations disappear.

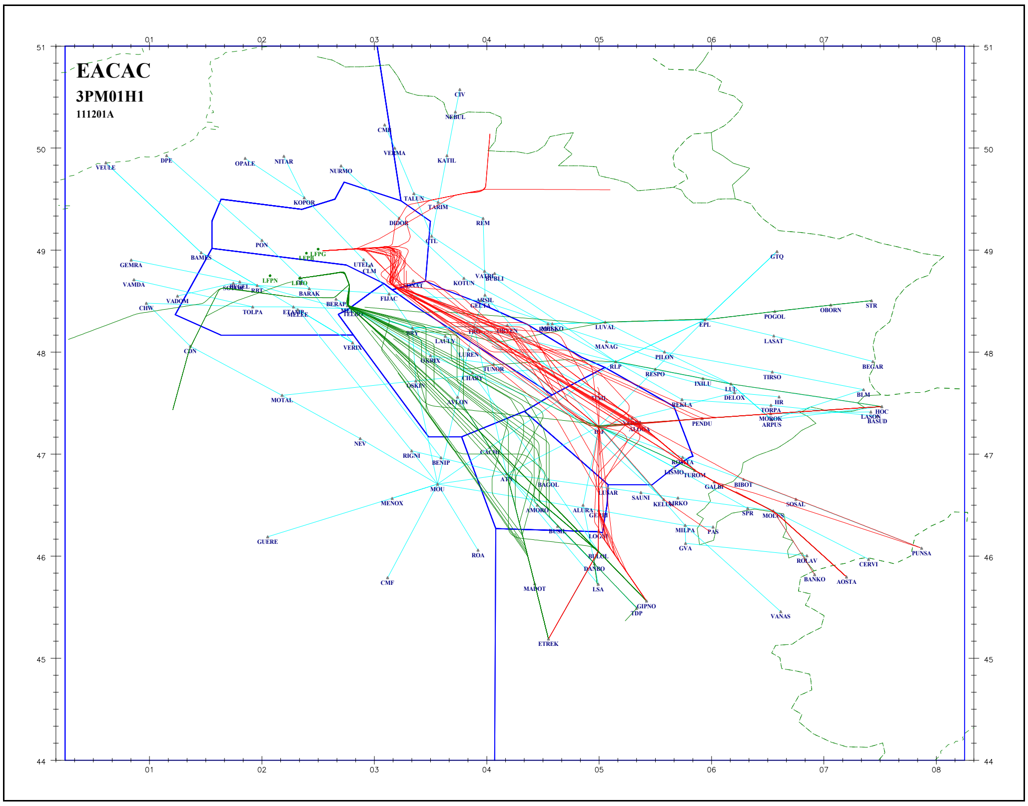


Figure 41: Aircraft trajectories without delegation

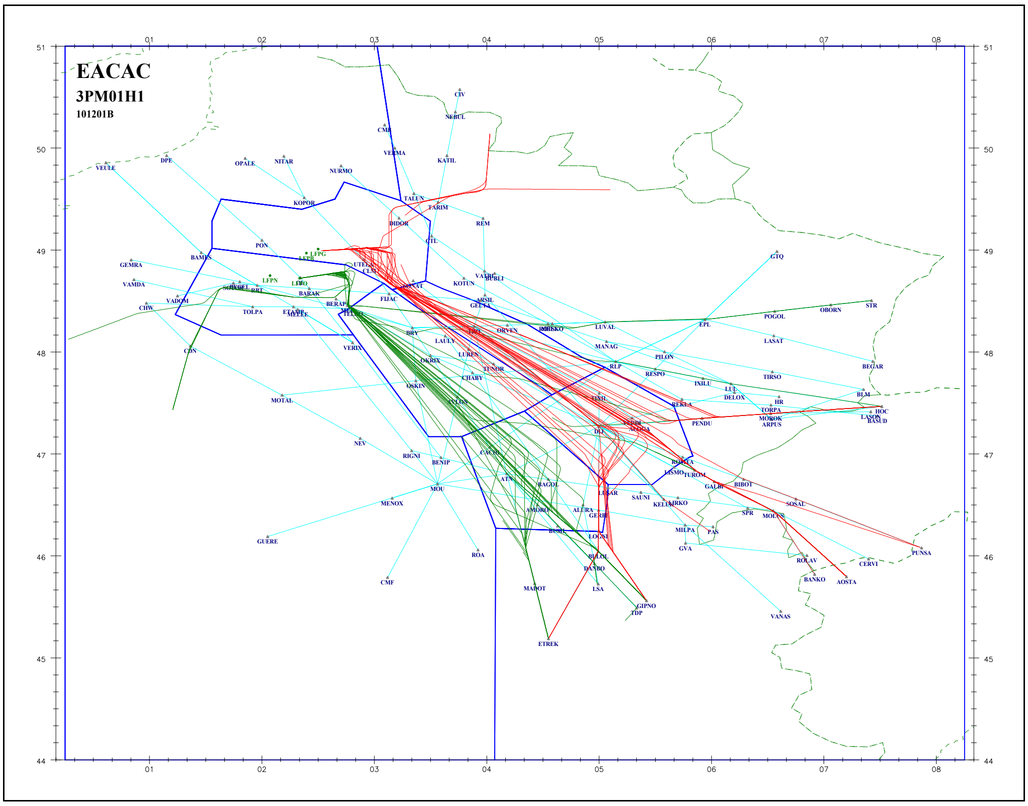


Figure 42: Aircraft trajectories with delegation

Initial estimation of the efficiency variations was made through the record of time, distance and fuel consumption (Table 14 and Figure 43). Similarly to 2000 experiments, a minor benefit of delegation emerges. Even though the benefits are still very light, it is important to stress that, at least, delegation has no negative impact on the flight efficiency.

Table 14: Mean values of flight duration, flown distance and fuel consumption.

	High traffic		Very high traffic	
	Without	With	Without	With
Time flown (hours)	5:41:33	5:43:45	7:00:13	6:58:37
Distance flown (Nm)	2416	2368	2899	2813
Fuel consumed (kg)	1368	1297	1440	1361

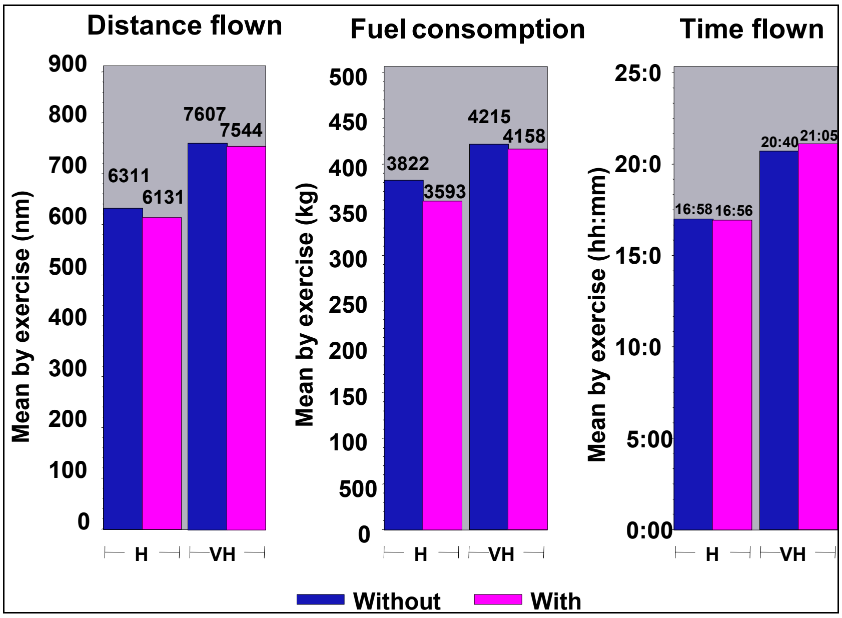


Figure 43: Distance flown, fuel consumed and time flown. Number of instructions per aircraft. Very high traffic

7.4.2.3. *Speed profile*

Effect of delegation

The aircraft speed profile was also considered as a possible indicator of the impact of delegation on flight efficiency. Ideally, it should be possible to superimpose the speed profiles with and without delegation for a same traffic sample. The continuous speed reduction should be observed at same periods (expressed in terms of distance from the IAF). However, we expect the distance-based spacing to have a negative effect. Typically, when descending, a target aircraft will impose a speed reduction on its delegated[6].

Delegation would therefore induce an earlier reduction of delegated speed, therefore modifying the mean speed profile. The more frequent delegation usage would induce a higher effect.

In order to assess if delegation would impact aircraft speed profiles, we compared the distribution of mean speed values in the second part of the sector (from 100Nm from the IAF until the IAF itself), passed the top of descent.

[6] We expect this negative effect to be compensated if using time based delegation.

Effect of sector (AO versus AR)

The comparison of speed profiles in both sectors shows a more important effect of delegation in the AR sector than in AO sector (Figure 44 and Figure 45). In AO, we observe similar values without and with delegation (Figure 44). This could be explained by a reduced use of delegation (only 50% of the aircraft over 50% of their flight time), compared to the use in AR. However, the larger standard deviation might reflect variations in the speed profiles induced by the use of delegation.

In AR (Figure 45), as expected, delegation induces slower speeds. Even though curves of the speed profiles have similar shapes, they reflect a general slow down effect, with mean values with delegation slower than those without delegation.

This hypothesis related to the expected advantage of time-based spacing needs to be validated later on, typically in comparing time based and distance based spacing.

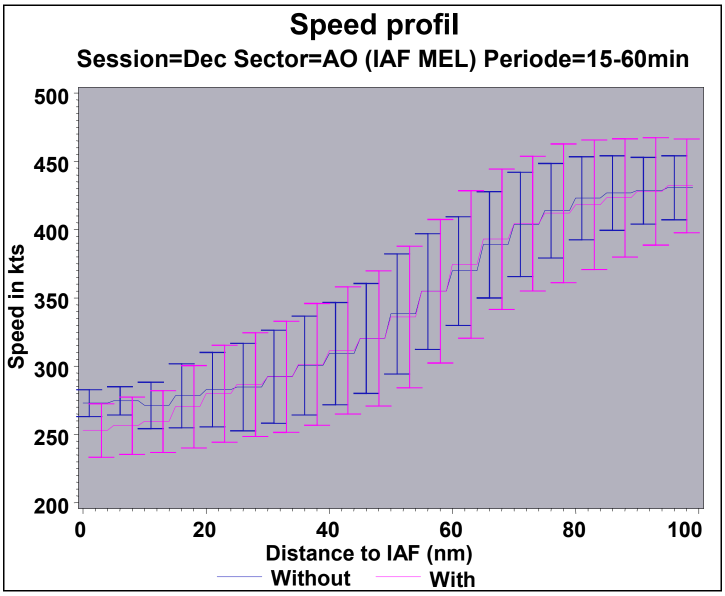


Figure 44: Mean speed profile in AO. Very high traffic

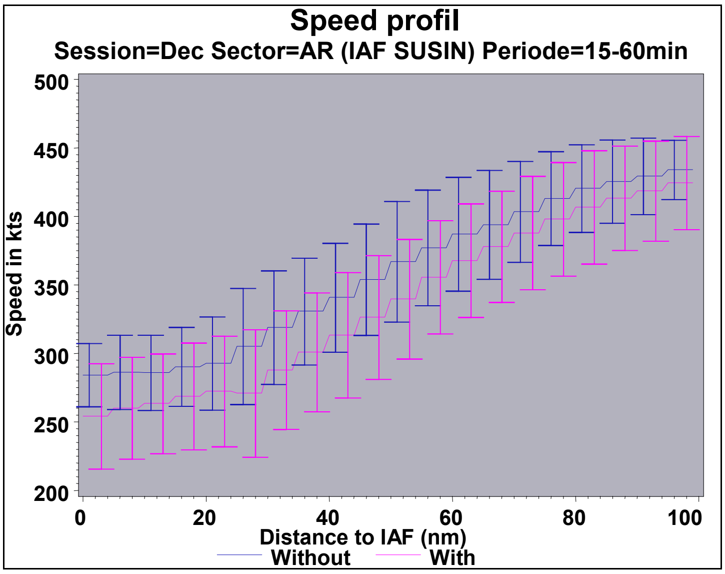


Figure 45: Mean speed profile in AR. Very high traffic

Effect of traffic level (high versus very high)

With delegation, for both traffic levels, the mean speed profile was following a similar curve. However, the deviations were higher in very high (Figure 46).

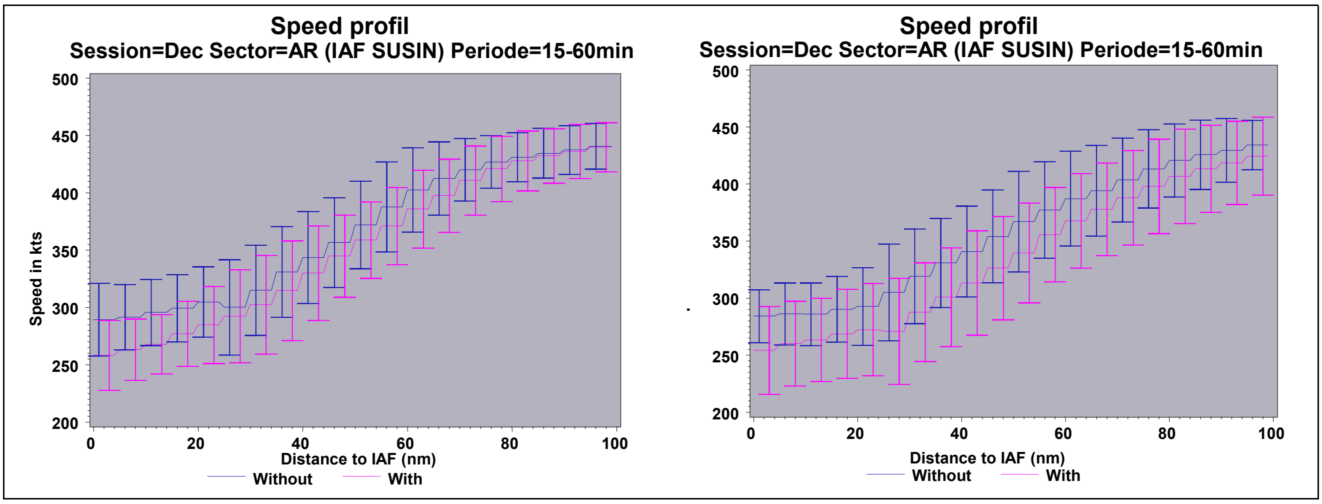


Figure 46: Comparing speed profile for high (left) and very high traffic (right). AR sector

Inappropriate use of delegation was also reflected when analysing the speed profiles. Typically, on Figure 47, with delegation, aircraft had to reduce drastically their speed during the descent phase. In addition to slower speeds with delegation, we could also notice larger deviations between mean values. Drastic speed reductions can be explained either by incompatible flight level (target too low) or by too much difference between target and delegated speeds. However, the speed profile itself does not enable us to determine the causes.

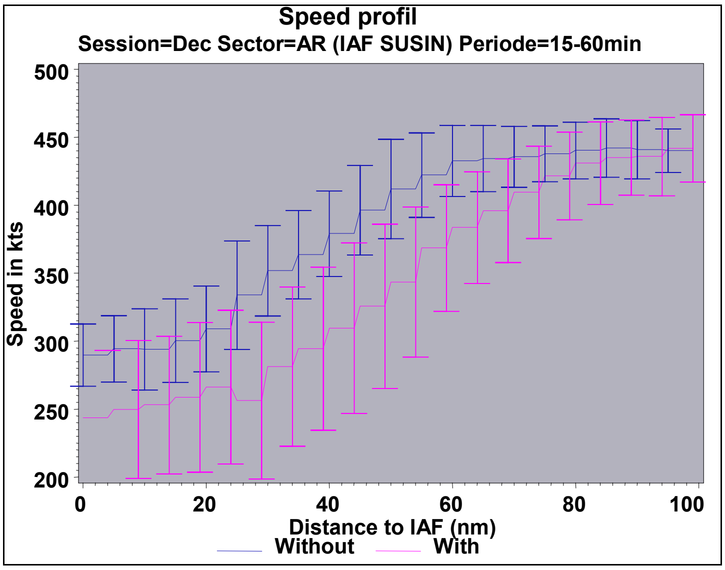


Figure 47: Inappropriate use of delegation, illustrated by drastic speed reduction in descent phase

7.4.3. Synthesis on effectiveness

> Delegation enables more regular intervals between transferred aircraft. The spacing between successive aircraft is closer to desired spacing. Delegation is not detrimental to some aircraft, as it enables a general reduction of the number of instructions per aircraft. Delegation has a slightly positive impact on flight efficiency. Current distance based delegation modifies the aircraft speed profiles, in inducing a slowing down effect.

7.5. SAFETY

7.5.1. Method

The objective of the previous section was to qualify the impact of delegation on the quality of control. We considered the number of failures (separation and spacing infringements) as indicators of quality of control, as well as outcome of delegation use. The objective of this section is to understand what caused inefficient or unsafe control.

We consider as indicators of safety (or actually unsafety) any event, action or effect different from what was expected. Depending on the context and on possible consequences, the safety criticality of these indicators might vary. Typically, we consider error as an initial event (e.g. wrong instruction given) which might lead, under certain circumstances to a major failure (loss of separation) that is visible at the system level. Our method of analysis followed three steps (Figure 48): we first defined indicators (Table 15), then indexed and counted occurrences and finally used replay tools to understand the context of these occurrences. In addition to identify failures (that is the observable events), the method followed aimed at understanding the succession of events that caused the failures. In addition to quantifying the occurrence of such unexpected events, we will try to go beyond and provide an initial typology of errors including their causes and potential means for their tolerance (see EACAC'00 report).

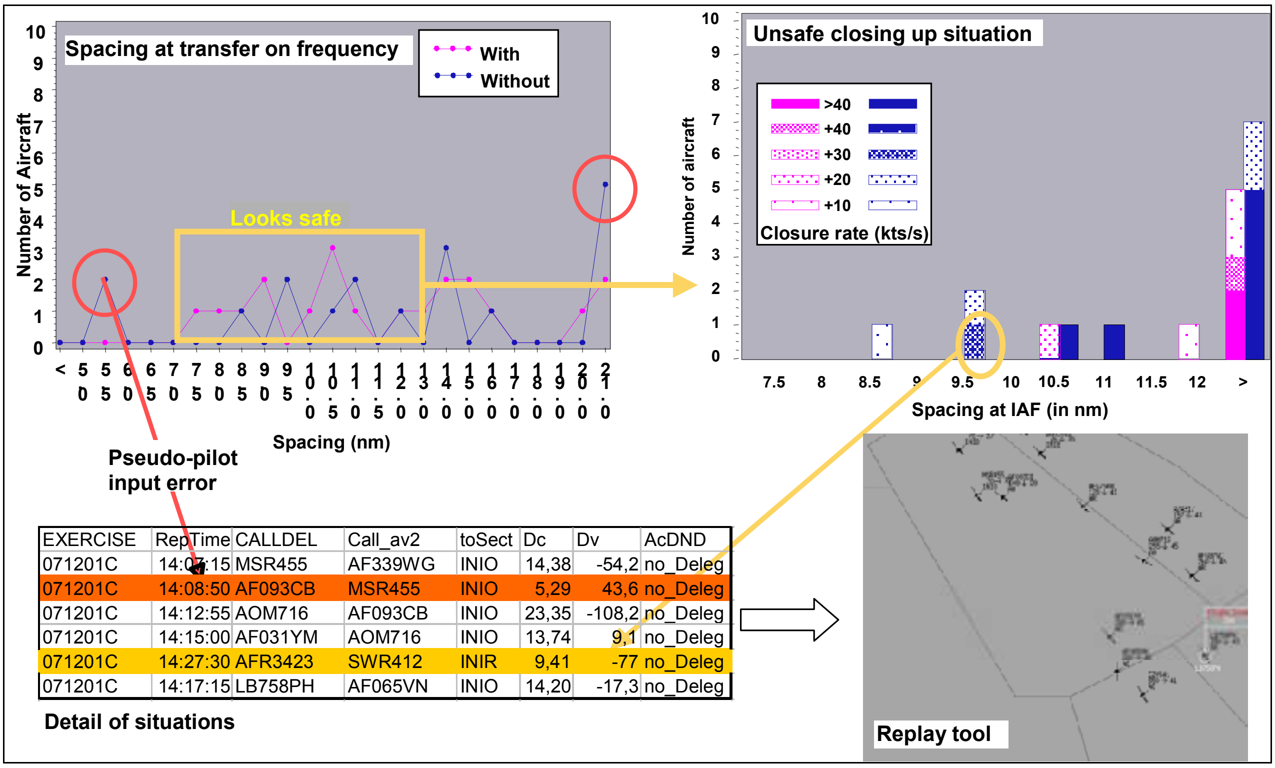


Figure 48: Microscopic analysis of transfer conditions

Table 15: Indicators of unsafety considered

	Errors	Indicator
Control	Loss of separation Loss of spacing	Distance between aircraft compared to minima (5NM) Distance between aircraft compared to required spacing
	Unstable situation	Closure rate at transfer
	Omission to descend aircraft	Relative flight level
	Omission to transfer	Distance from exit point when transferred
Delegation	Non respect of applicability conditions	Closure rate when delegated
		Relative trajectories when delegated
		Relative flight level when delegated
		Speed variation after delegation
	Misuse of delegation	Incompatible instructions (e.g. delegation and speed) Superfluous instructions (e.g. merge plus direct)

7.5.2. Results

7.5.2.1. Loss of separation

The first objectives of controllers work is to ensure the safety of traffic, essentially in maintaining a minimum separation between aircraft. Therefore, following traditional analysis in air traffic control experiments, we looked at the number of losses of separation between aircraft at same flight level. As discussed elsewhere in the document, we only considered results from the second sessions (H2 and V2). However results from all sessions are presented in Table 16. Delegation does not have a significant impact: with very high traffic, 1 minor loss was detected with delegation, against 2 without.

Table 16: Synthesis of losses of separation per sessions, as a function of the delegation and per sector

	Very Serious		Serious		Medium	
Exercise	**AO**	**AR**	**AO**	**AR**	**AO**	**AR**
H1_without	0	0	0	0	**1**	0
H1_with	0	0	0	0	0	0
V1_without	0	0	**1**	0	0	**1**
V1_with	0	0	0	0	0	**3**
H2_without	0	0	0	0	**2**	**1**
H2_with	0	0	0	0	0	0
V2_without	0	0	0	0	0	**2**
V2_with	0	0	0	0	**1**	**1**

7.5.2.2. Transfer conditions

In the previous section, we listed the overall number of losses of separation (still rare events) and showed no significant impact of delegation. In addition, we also discussed the transfer conditions, and typically highlighted cases when correct and stable spacing was not ensured at transfer (more frequent without). Beyond unsafety per se, unstable transfers may lead to a significant workload increase in the receiving sector. In the current working practices, the receiving sector is in charge of integrating 2 or more flows of aircraft. Although separation is lower in final approach, spacing and stabilising incoming aircraft might then represent an additional task. Once such cases were identified, their details were analysed. First of all, we investigated the overall context, including the aircraft concerned (given aircraft and possibly previous one), aircraft respective speeds, current and predicted spacing, respective flight levels (Table 17). Based on these data, we used replay tools to perform a contextual analysis of situations, in order to understand what initial decisions led to such events. This latest analysis required the expertise of an air traffic controller, highly experienced both in sequencing activity and in delegation.

Cases of unsafe spacing. Extract from the V2 session. Table provides details about a given aircraft and its leader: respective call signs, simulation time, sectors, delegated status, respective speeds, current spacing at transfer, respective flight levels, predicted spacing at the IAF and cleared flight levels.

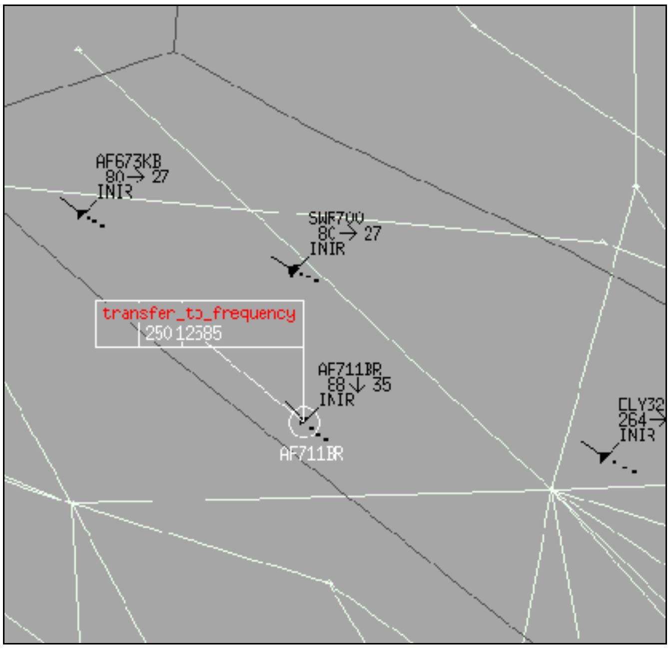
Table 17: Cases of unsafe spacing

Exercise	Delegation	Callsign delegated	Callsign target	Time	To sector	Delegation order	GS deleg.	GS target	Current spacing	AFL deleg.	AFL target	Predicted Spacing	CFL deleg.	CFL target
10	Without	AFR2203	GNF306	05:41:30	INIR		406	288	8,73	107	101	0,04	80	80
10	Without	CRL903	AF203DX	06:09:40	INIO		279	269	3,45	80	57	3,14	80	30
10	Without	SWR700	AF673KB	05:50:00	INIR		388	279	11,46	80	80	3,81	80	80
11	With	AF343HG	AF577LA	16:14:25	INIO		296	267	3,85	121	79	1,42	80	70
11	With	AF479XK	AF591ER	16:41:30	INIO	MERGE	338	274	2,33	135	70	2,62	80	70
11	With	CTM3826	AF343HG	16:17:40	INIO		278	279	4,49	79	80	4,51	70	80
12	With	AF043YM	AF571UQ	17:52:35	INIO	MERGE	274	238	4,48	70	91	0,94	70	70

GS deleg. = Ground Speed delegated
GS target = Ground Speed target
AFL deleg. = actual flight level delegation
AFL target = actual flight level target
CFL deleg. = Cleared flight level delegation
CFL target = Cleared flight level target

Let us consider for example the case of the SWR700 (in red in Table 17). What the table shows is that despite a current spacing of 11NM, the closure rate (more than 100knots) might cause a loss of separation at the IAF, with a spacing below 4NM. The simulation time enables us to locate the situation with the replay tool and study the whole process leading to the situation: initial conditions, decisions made (Table 18).

Table 18: Example of the sequence of instructions given to a pair of successive aircraft. Very high traffic.

	AF711BR	SWR700	Comments
		Direct to SUSIN	
	Direct to SUSIN		
	Mach		
		Mach	
AR		Descent FL080	
	Descent FL080		Descent with a constant mach number, i.e. a high ground speed at low altitude.
		Speed 250Kt	For sequencing behind AF673KB flying at 250kt
	Speed 250kt		The controller saw the problem too late
	Transfer		**Not safe**: descending to same FL, strong catching up
	Picture of the transfer		

A similar description was performed on every transfer identified as unsafe when considering the predicted spacing, in the very high traffic session. Details are provided in annex. Globally, 5 out of 16 predicted unsafe without delegation were actually unsafe. Only 1 out of 6 was unsafe with delegation.

However, the "not so unsafe" cases were usually spaced in level, or sent on parallel tracks. It happened too that on going speed reduction did enable the separation to be ensured at the IAF.

7.5.2.3. Omissions of instructions

We analysed if delegation led controllers to omit to descend and/or transfer aircraft. Typically, we measured the relative altitude between successive aircraft and the geographical location of aircraft transfers. No impact of delegation was noticed.

7.5.2.4. Delegation usage

An initial typology of delegation-related errors described their potential contexts of occurrence, causes (e.g. cognitive tunnel vision, slips, incomplete/incorrect knowledge) and possible means for their avoidance or tolerance. In order to automatically detect some of them, we defined indicators (Table 15). Once these events were detected and documented (exercise and aircraft concerned), an operational expert analysed the conditions in order to understand possible causes (lack of training, misuse of delegation, simulation pilot error).

Ensuring the feasibility of delegated tasks is part of the controllers' tasks. In addition to initially assess applicability conditions, controllers are in charge of maintaining them. The main items defined in the applicability conditions are compatible speeds (e.g. ensure a slow aircraft is not asked to catch up on a much faster one), compatible flight levels and compatible trajectories (e.g. ensure an aircraft is not asked to merge behind an aircraft following a diverging path). One of the difficulties induced by delegation is the mutual dependencies between delegated aircraft, and consequently the cognitive cost of maintaining appropriate situation awareness. For example, whereas it is quite easy for a controller to understand that an aircraft is reducing speed because its target is descending, it is harder to detect the consequence of speed variation of a target on the rate of descent of its delegated. In order to investigate systematically the conditions of delegation, we defined what were the applicability conditions in most of the expected situations: e.g. stable situation, descending target. Then, basic indicators, such as relative trajectories, relative speed, relative altitude were associated (and if possible combined) to each cases. The third step consisted in a contextual analysis, focusing on the applicability conditions for each delegation, from its start until its end.

The results show that the most frequent errors were related to the initial assessment of applicability conditions (incompatible speeds and target not direct to a waypoint). Because we focused on the qualitative analysis and understanding of delegation errors, we did not look for statistical data informing about their respective frequency.

Applicability conditions could be either not respected initially or not maintained in time. Non respect of initial applicability conditions was indicated by:

- Initial distance between aircraft below requested one;
- Incompatible speeds;
- Speed variations following delegation instructions;
- Not same trajectory in case of "remain behind" (calculating angles between target and delegated);
- Not merging trajectories in case of "merge" (assessing if both aircraft are direct to the same waypoint).

Non maintaining of applicability conditions was indicated by:

- Not compatible flight levels (detecting successive aircraft with large difference in altitude 60NM before IAF);
- Heading or speed instructions given to a target and not to the delegated aircraft in case of “remain behind”.

In addition, we also identified cases of misuse of delegation, typically indicated by heading or speed instructions given to the delegated.

The following figures illustrate cases of non respect of applicability conditions.

7.5.2.5. Incompatible speeds

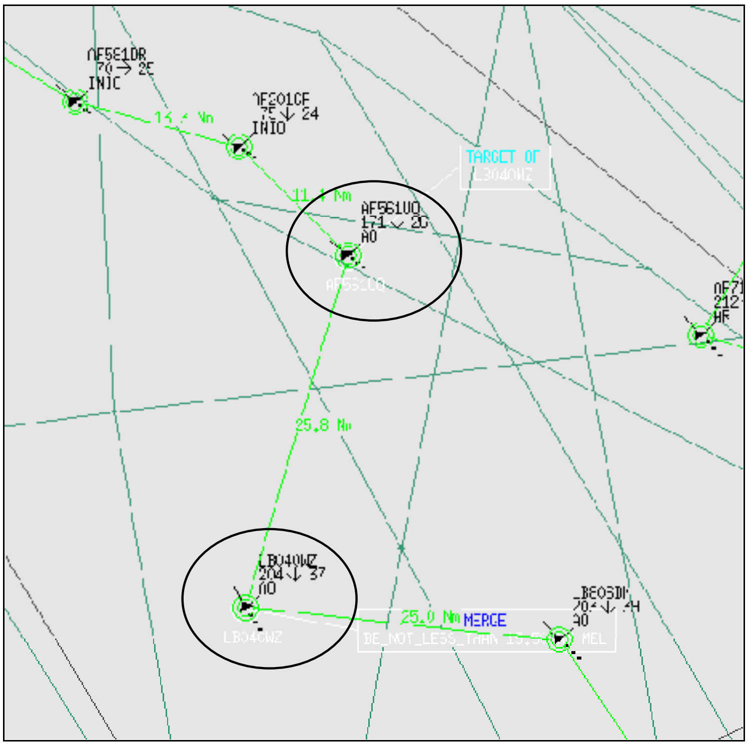


Figure 49: Incompatible speeds

In this case LB040WZ (370 kts) is much faster than AF561UQ (260kts) and already too close from it (less than 12NM).

Despite drastic speed reduction, the LB040WZ will not be able to comply with the instruction, even at the waypoint.

Even though such an error should not happen, in a more realistic environment, the flight crew would have detected the erroneous situation and inform the controller about the unfeasibility of this delegation.

7.5.2.6. Predicted distance below to required predicted one

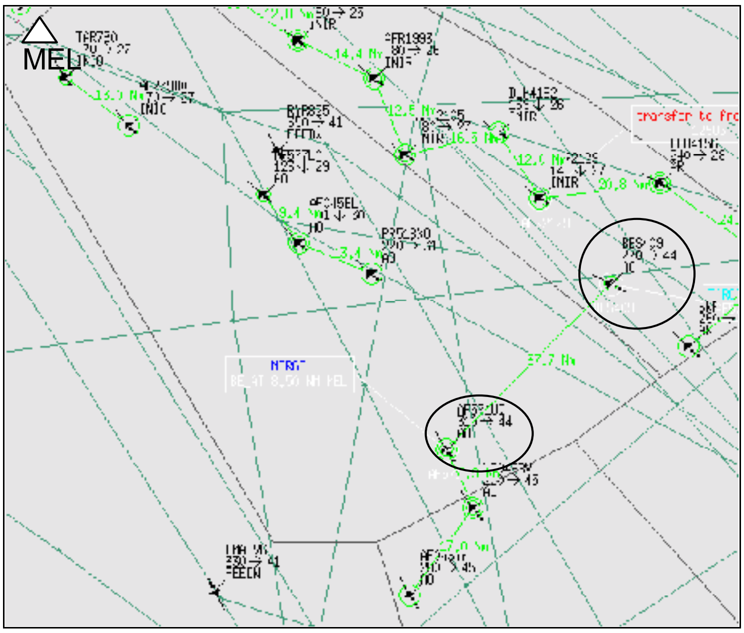


Figure 50: Predicted distance inferior to required one

The two aircraft (AF571UQ and BES409) have the same speed (440kts), but the predicted distance is far from required one.

The consequence is that the delegated will have to drastically reduce its speed. And even if the delegated (AF571UQ) takes minimum speed it will still not be able to reach the constraint.

Even if this could work for 2 aircraft, this will certainly not work for a long chain.

7.5.2.7. *“Exactly” versus “at least”*

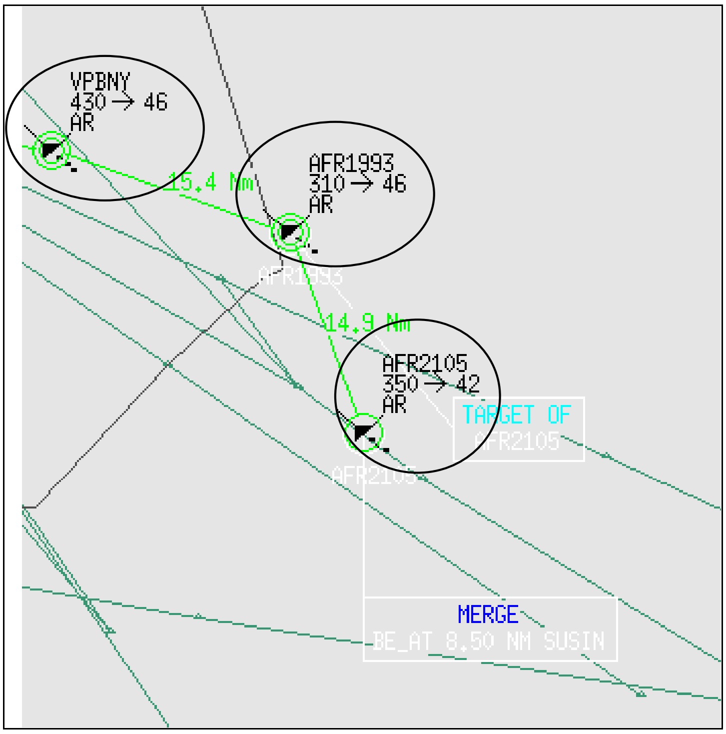


Figure 51: Exactly versus at least. Initial situation

The AFR2105 (420kts) was slower than the AFR1993 (460kts) and the predicted distance probably greater than 8NM (almost same trajectory and current distance 15NM).

The AFR1993 was itself delegated behind the VPBNY.

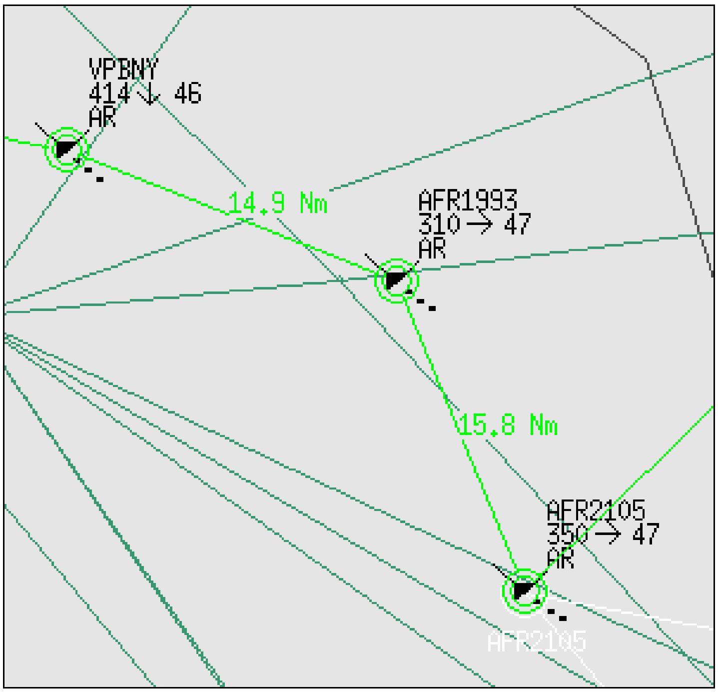


Figure 52: Exactly versus at least. Increasing speed to maintain spacing

To acquire the spacing, the AFR2105 initially increased its speed (+50knots).

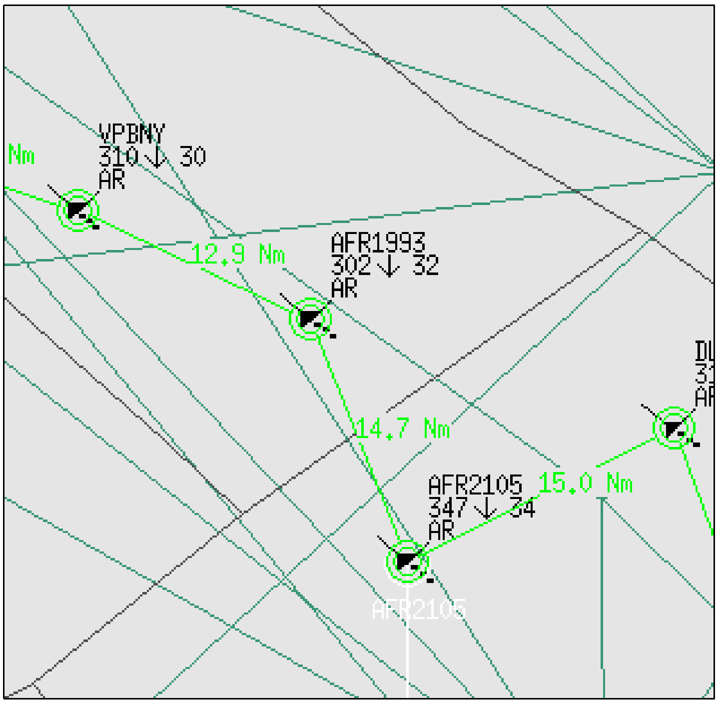


Figure 53: Exactly versus at least. Decreasing speed to maintain spacing when target is reducing speed

When the AFR1993 started to reduce speed to maintain the spacing towards the VPBNY, the AFR2105 had to reduce its speed again.

To avoid unnecessary speed changes the controller should have used "at least" instead of "exactly". There would still have been a benefit for the controller in terms of reduced monitoring: the controller should be relieved of assessing that the distance is maintained once the AFR1993 starts its descent or reduces its speed to maintain spacing with VPBNY. However because controllers remain responsible for separation, they need to regularly monitor the situation.

7.5.2.8. Remain behind when not on same trajectory

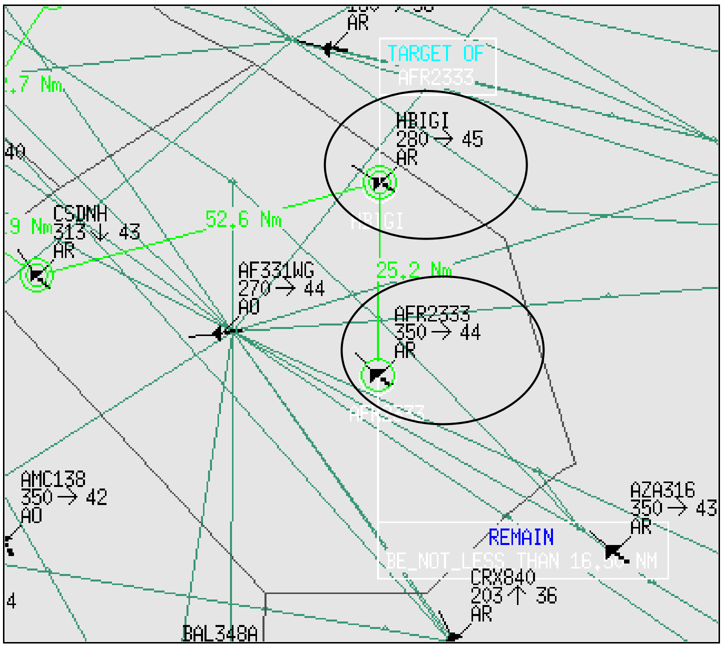


Figure 54: Remain behind on converging trajectories

The HBIGI and AFR2333 are on converging trajectories. Asking the AFR to remain behind will result in his increasing speed to establish a current distance of 8NM.

7.5.2.9. Speed variations following delegation instructions

For every delegated aircraft we measured the speed variations a certain time after the execution of the delegation instruction (see example on Figure 55). We identified the 40 seconds delay as the most appropriate one: it includes reactions to erroneous initial conditions, and should exclude normal speed reductions. Results show peak around 0knot. However the extreme values indicate erroneous applicability conditions, leading flight crews to drastically increase or reduce their speed. Following the detection of abnormal cases, we did investigate their details.

For high traffic, we had similar number of important speed variations in both sectors. Speed variations above 30knots represented between 17% (AO) and 21% (AR) of the delegation. For very high traffic, we did notice an effect of the sector. Important speed variations represented 23% of the delegation in AO and only 3% in AR.

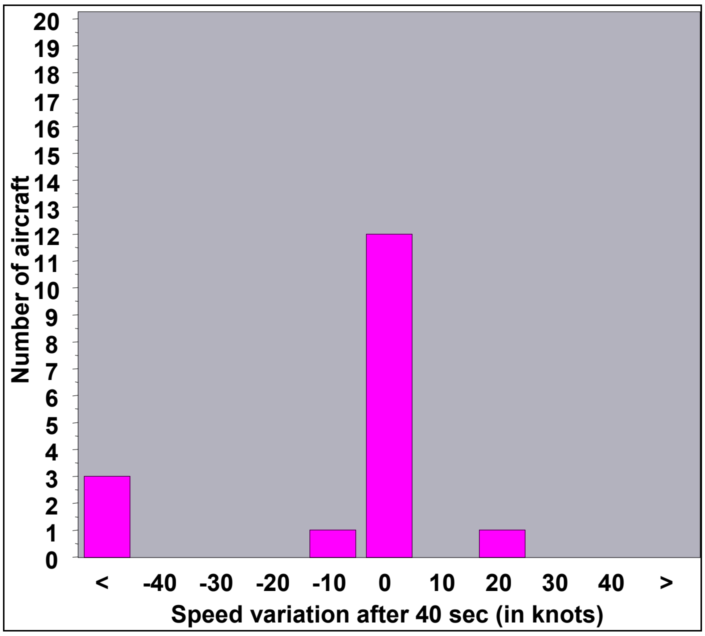


Figure 55: Speed variations following first delegation instruction (40 seconds after the instruction). Example for 1 run

7.5.3. Synthesis on safety

The safety assessment consisted in analysing in detail traffic management activity. The definition of unacceptable events enabled their systematic detection. Expert analysis using replay tools helped identifying the initial conditions and possibly causes leading to such unacceptable events.

Compared to current situation, delegation does not induce more losses of separation. Delegation induced errors are mainly related to the set up of initial applicability conditions. It is envisaged to insist on such errors during training. The possible contribution of flight crews as mitigation means could not be assessed in the experiment.

8. CONCLUSION

8.1. DESIGN AND FEASIBILITY

The respective utility and usability of each application could be identified. Whereas "merge" application is the easiest and the most beneficial, the other ones show limits. "Remain" requires aircraft to be on same trajectories, while "heading then…" introduces some perceived uncertainty. In this latest case, controllers need to check the surrounding aircraft and then feel they might lose control on the aircraft trajectories. This requires them to keep monitoring closely until the aircraft resume their navigation.

The experiment confirmed the impact of the sector structure on the use and on the benefits of delegation. The existence of a flow to be integrated later in the sector reduces the opportunity to build early sequences. In such a configuration, early delegation might be cancelled, whereas late delegations have limited benefits.

Delegation benefits are the most noticeable in very high traffic.

8.2. HUMAN INVOLVEMENT

Despite the same strategies and the similarity with existing procedures, the acceptance and proper use of delegation will require an extensive training.

Delegation reduces controller workload and more specifically their active control load: once sequences are built, no more instructions are given to aircraft. The sequence maintaining is transferred to the flight deck. For high traffic, without and with delegation, the monitoring is reduced in the second part of the sector, reflecting the focus on the sequence building area. For very high traffic, without delegation, the monitoring is focused on the second part of the sector (sequence maintaining area), whereas with delegation, it is still focused on the first part of the sector. This suggests that delegation enables controllers to remain ahead of their traffic and to anticipate the sequence building. In other words, with delegation E-TMA controllers can focus on the more strategic part of their activity.

8.3. EFFICIENCY

Delegation enabled more homogeneous spacing between transfer aircraft, as well as more stable transfers. From the flight deck perspectives, delegation does not improve nor decrease the fuel consumption. However, distance based spacing induces an overall reduced speed profile, that might impair the flight economics.

8.4. SAFETY

Delegation does not induce an increase in the number of safety critical events. Compared to current control, delegation reduces the number of unstable transfers, or even the number of aircraft sent in cluster, vertically separated. Such transfers increase the approach sector workload, and possibly the subsequent risks of error occurrence.

Delegation induced errors are mainly related to applicability conditions. Two aspects need to be covered: first the quality and relevance of training, second the role of flight crews in the detection and possibly recovery of errors.

Controllers' ability to detect and recover degraded situations with delegation could not be investigated in the experiment. Our only data issued from the monitoring analysis show that delegated and not delegated aircraft, in situation without and with delegation are monitored similarly. However, even though periods are similar, the content of the monitoring and typically the perceived information need to be assessed.

8.5. CAPACITY

The impact of delegation on capacity can not be directly validated. However, the experiment showed that even with a very high traffic delegation show benefits. In addition, the improvement of transfer conditions might benefit to the rate of arrival.

9. NEXT STEPS

9.1. IMPROVING EXPERIMENTAL MEASURES

Monitoring issue

An initial assessment of the impact of delegation on monitoring has been obtained. In term of global monitoring, the positive trend (capability, with delegation and very high traffic, to stay ahead of the traffic) needs to be confirmed on a larger scale.

In terms of contextual monitoring, can we associate a fixation located in the middle of a configuration of aircraft to each of the aircraft? This issue was previously raised for instance in the context of chess games (Charness et al., 2001): in this typical spatial oriented activity, expert player fixations occur more frequently between objects rather than on them. Their strategy aims at recognising patterns rather than analysing each object. Similar pattern recognition strategy might be used in air traffic control. Consequently, are patterns comparable without and with delegation? Do controllers apprehend them similarly? This will be investigated in the next controller in the loop experiments.

Situation awareness

To assess situation awareness, the blank maps were useful in some cases. However, their subjective nature did not enable us to perform systematic analysis. In addition to refining the usage of blank maps, it is envisaged to use degraded scenarios to analyse controllers' ability to detect abnormal events. Relevant indicators could be time to detect a problem, time to recover it and quality of the solution implemented (e.g. number of manoeuvre per aircraft, number of aircraft impacted).

Safety

We developed a three step method of safety analysis, consisting in first defining indicators and associated measures, second indexing and counting occurrences and third using replay tool to understand their context. Delegation enables more stable and regular transfers, without inducing more losses of separation. However, some errors, related to setting up delegation were observed.

In order to complement this preliminary analysis of safety, the following tasks are identified. First, a predictive error analysis based on delegation task analysis is envisaged. Second, the introduction of degraded scenarios in the next ground experiment could be used to investigate controllers and flight crews ability to detect and recover incidents. Last of all, a similar method of analysis needs to be performed on flight deck.

9.2. IMPROVED EXPERIMENTAL APPARATUS

Pseudo pilot feedback

One of the limits of the experiment was the simulation pilots inability to inform controllers when delegation was not feasible. Warning messages should be provided on pseudo-pilot positions.

Training

The training should take a more important place, in order to gradually get familiar with the very high level of traffic and with delegation. Indeed, despite its apparent simplicity, delegation requires to be used appropriately, in particular applicability conditions shall be respected such as the compatibility between aircraft speeds. Experience shows that controllers tend to expect more from delegation.

For that purpose, we will use replay facilities during (de)briefing to highlight good examples of use, and to discuss misuses as well. This is expected to enable avoiding classical delegation errors and “optimising” the use of delegation.

9.3. EXTENDING SCOPE OF EXPERIMENTS

Usability in TMA

Now that usability of delegation has been assessed in E-TMA, it becomes essential to assess it usability in TMA, in particular regarding integration of flows of (delegated) aircraft, transfer from and co-ordination with E-TMA. This should be addressed in a more realistic manner though the involvement of approach controllers.

Time-based versus distance-based spacing

As pointed out before, time-based spacing may be more efficient than distance-based. The impact of time-based versus distance-based should be addressed, not only in terms of flight profile but also of controller acceptability.

TRADUCTION EN LANGUE FRANÇAISE

RESUME

Ce rapport présente l'analyse de l'expérimentation EACAC de Décembre'01. L'objectif de ces trois semaines d'expérimentation était d'obtenir une meilleure compréhension de l'impact de la délégation sur l'activité des contrôleurs d'E-TMA (charge de travail, monitoring et compréhension de la situation). En outre, cette expérimentation visait une étude exploratoire de la délégation en approche (transfert et coordination, intégration de flux). Six contrôleurs européens y ont participé. L'espace utilisé était la partie Sud-Est de l'ACC Paris: quatre secteurs étaient simulés (deux E-TMA et deux approches simplifiées). Le sentiment des contrôleurs est positif, la délégation est perçue comme satisfaisante, et pourrait permettre une réduction de leur charge de travail. Le taux significatif d'utilisation reflète également l'acceptation du concept. L'analyse subjective de la charge de travail (ISA et NASA-TLX) semble montrer que la délégation réduit la charge de travail des contrôleurs. Les résultats de la simulation précédente ont été confirmés: la délégation permet de réduire significativement le nombre d'instructions de manœuvre et d'anticiper la construction des séquences. La configuration du secteur influence l'utilisation de la délégation. La tâche de monitoring a été analysée grâce à l'enregistrement des mouvements oculaires. Les résultats semblent montrer qu'en situation de très fort trafic, la délégation permet au contrôleur de rester en avance sur le trafic et de continuer à anticiper la construction des séquences. En d'autres mots, avec la délégation, en E-TMA, les contrôleurs peuvent se concentrer sur la partie la plus stratégique de leur activité. La délégation ne modifie pas la fréquence des fixations sur chaque avion. La méthode utilisée pour évaluer la situation awareness doit être améliorée. En termes de sécurité, la délégation n'entraîne pas plus de perte de séparation, mais une meilleure stabilité des transferts et un espacement plus régulier. Les erreurs induites par la délégation sont principalement liées aux conditions d'applicabilité.

1. INTRODUCTION

L'objet de ce document est l'analyse de l'expérimentation EACAC'01, qui s'est déroulée en Novembre et Décembre 2001. Cette expérimentation avait pour but d'évaluer la délégation limitée, du contrôleur à l'équipage, du maintien de séparation en région terminale, faisant usage des applications de séquencement. Ce document est organisé comme suit :

- Section 2 expose les principes de la délégation.
- Section 3 présente les objectifs de la simulation et la méthode d'analyse.
- Section 4 décrit l'environnement expérimental.
- Section 5 discute des résultats de l'expérimentation.
- Section 6 résume ses principaux résultats.
- Section 7 énonce quelques recommandations.

2. CONCEPT DE DELEGATION

La délégation des tâches d'espacement du contrôleur à l'équipage est envisagée comme une option possible pour augmenter la disponibilité du contrôleur, et au-delà, augmenter la sécurité et/ou la capacité.

Partant de l'analogie avec les séparations à vue, la distribution des tâches proposée repose sur la délégation des tâches d'espacement dans laquelle l'équipage est chargé d'implémenter une solution définie par le contrôleur. Réduire la délégation à une tâche d'implémentation (par opposition aux tâches de décision) doit permettre au contrôleur de préserver son autorité et sa compréhension de la situation (sa « mental picture »). La délégation d'espacement est toujours à l'initiative du contrôleur, qui peut décider de l'interrompre à tout moment. Le pilote ne peut la refuser ou l'interrompre qu'en cas de problème à bord, tel qu'une panne technique. La délégation s'applique à des paires d'avions : l'un est le « délégué », l'autre la « cible ».

La délégation s'appuie sur les technologies CNS/ATM actuellement à l'état pré-opérationnel et sur le développement de nouveaux systèmes bord tels que le Cockpit Display of Traffic Information ou l'Airborne Separation Assistance System.

3. OBJECTIFS DE L'EXPERIMENTATION

Les principaux objectifs de cette expérimentation étaient d'évaluer :

- L'acceptation du concept par les contrôleurs.
- L'impact de la délégation sur :
- L'activité du contrôleur : charge de travail, contrôle actif, monitoring, image mentale.
- La gestion du trafic : qualité de contrôle, conditions de transfert, activité des pseudo équipages, efficacité des vols.
- La sécurité : analyse des conflits, conditions de transfert, précision de l'espacement, pertes de séparation et recherche des erreurs potentielles liées à la délégation.

En outre, cette expérimentation visait une étude qualitative préliminaire de la délégation en approche.

4. CONCLUSION

4.1. CONCEPTION ET FAISABILITE

L'utilité et l'utilisabilité de chaque application ont pu être identifiées. Alors que le « merge » est l'application la plus facile et la plus « rentable » à utiliser, les autres applications présentent des limites. Ainsi, « remain » sous-entend que les avions sont sur la même trajectoire et « heading then merge » provoque une incertitude sur la trajectoire de l'avion délégué. Cette dernière application demande une surveillance accrue du trafic environnant et donne aux contrôleurs le sentiment de perdre le contrôle sur la trajectoire de l'avion délégué. Il leur faut donc suivre la situation de plus près jusqu'à ce que l'avion mette le cap sur le point de merging.

L'expérimentation confirme l'influence de la configuration du secteur sur l'utilisation et les bénéfices de la délégation. Un flux à intégrer tardivement réduit les possibilités d'anticiper la construction des séquences. En effet une délégation faite trop tôt risque d'être cassée pour intégrer un autre avion. De plus, déléguer près du point de sortie présente un intérêt limité.

Les bénéfices induits par la délégation sont plus importants par fort trafic.

4.2. FACTEURS HUMAINS

Bien que les stratégies utilisées soient les mêmes et que les procédures soient similaires à celles en vigueur aujourd'hui, l'acceptation et la bonne utilisation de la délégation demandent un entraînement intensif.

La délégation réduit la charge de travail du contrôleur et plus spécifiquement la charge de contrôle actif. Le maintien des séquences est transféré aux équipages. En situation de fort trafic, avec ou sans la délégation, le monitoring est réduit dans la deuxième partie du secteur, la majorité des fixations se situant dans la zone de construction des séquences. En situation de très fort trafic, sans la délégation, le monitoring se concentre sur la deuxième partie du secteur (zone de maintien des séquences), alors qu'avec la délégation, il se concentre encore sur la première partie du secteur. Ceci semble montrer que la délégation permet au contrôleur de rester en avance sur le trafic et d'anticiper la construction des séquences. En d'autres mots, avec la délégation, en E-TMA, les contrôleurs peuvent se concentrer sur la partie la plus stratégique de leur activité.

4.3. EFFICACITE

La délégation permet un espacement plus homogène entre les avions au moment du transfert à l'approche, ainsi que des conditions de transfert plus stables. D'un point de vue bord, la délégation ne modifie pas la consommation de carburant. Cependant la délégation d'espacement en distance provoque une réduction globale du profil de vitesse, ce qui pourrait éventuellement être pénalisant en termes de coût.

4.4. SECURITE

La délégation n'induit pas une augmentation des situations mettant en péril la sécurité. Comparée au contrôle conventionnel, la délégation réduit le nombre de transferts instables et aussi le nombre d'avions envoyés en paquets, espacés verticalement. De tels transferts augmentent la charge de travail du contrôleur d'approche et donc les risques d'erreur.

Les erreurs induites par la délégation sont liées principalement aux conditions d'applicabilité. Deux aspects sont à considérer : d'une part, la qualité et l'adéquation de la formation, d'autre part, le rôle de l'équipage dans la détection et la correction des erreurs.

L'aptitude des contrôleurs à détecter et récupérer les situations dégradées avec la délégation n'a pas pu être étudiée au cours de cette expérimentation. L'analyse du monitoring montre que, avec la délégation, les périodes de fixation des avions, délégués ou non, sont similaires à celles observées dans les exercices sans délégation. Cependant, bien que ces périodes soient comparables, le contenu du monitoring, c'est à dire l'information perçue, reste encore à évaluer.

4.5. CAPACITE

L'impact de la délégation sur la capacité ne peut pas être directement évalué. Cependant, l'expérimentation a montré que même avec un niveau de trafic très élevé la délégation apporte un bénéfice. De plus, l'amélioration des conditions de transfert pourrait permettre un meilleur taux horaire d'arrivée.

5. OBJET DES FUTURES EXPERIMENTATIONS

5.1. AMELIORATION DES MESURES EXPERIMENTALES

5.1.1. Monitoring

Une première évaluation de l'impact de la délégation sur le monitoring a pu être obtenue. En termes de monitoring global, la tendance positive (la possibilité, avec la délégation et en situation de très fort trafic, de rester en avance sur le trafic) doit être confirmée à plus grande échelle.

En termes de monitoring contextuel, peut-on associer une fixation localisée au milieu d'un paquet d'avions, à tous les avions de ce paquet ? Cette question a été soulevée dans le contexte du jeu d'échecs (Charness et al., 2001) : dans cette activité à forte composante spatiale, les fixations des joueurs experts se situent plus souvent entre les objets que sur eux. Leur stratégie vise à reconnaître des configurations plutôt qu'à analyser la situation objet par objet. Cette stratégie de « reconnaissance de configurations » devrait s'appliquer au control aérien. Ces configurations sont-elles les mêmes avec ou sans délégation ? Ceci sera étudié dans la prochaine simulation en temps réel.

5.1.2. Image mentale

Pour évaluer l'image mentale, l'utilisation des cartes du secteur a parfois donné des résultats. Cependant, la nature subjective de la méthode n'a pas permis de faire une analyse systématique. En plus de l'amélioration de la technique des cartes, il est envisagé d'introduire des scénarios dégradés pour analyser l'aptitude des contrôleurs à détecter les situations anormales. Le temps mis à détecter un problème, celui mis à recouvrer la situation ainsi que la qualité de la solution implémentée (nombre d'instructions de manœuvre par avion, nombre d'avions impactés) pourraient être des indicateurs significatifs.

5.1.3. Sécurité

Nous avons développé une méthode d'analyse en trois phases : définition des indicateurs et des mesures associées, classification et comptage des occurrences, et enfin utilisation d'un outil de rejeu pour comprendre leur contexte. La délégation permet des transferts plus stables et plus réguliers, sans provoquer plus de pertes de séparation. Cependant, quelques erreurs liées à la mise en œuvre de la délégation ont été observées.

Pour compléter cette analyse préliminaire, les tâches suivantes ont été identifiées. Premièrement, une analyse des erreurs potentielles basée sur l'analyse de la tâche de délégation est envisagée. Deuxièmement, l'introduction de scénarios dégradés dans la prochaine expérimentation devrait nous permettre d'étudier l'aptitude des contrôleurs et des équipages à détecter et corriger les erreurs. Enfin, une méthode d'analyse similaire doit être appliquée côté bord.

5.2. AMELIORER L'ENVIRONNEMENT EXPERIMENTAL

5.2.1. Feedback des pseudos pilotes

Une des limites de l'expérimentation était l'impossibilité pour les pseudo pilotes de signaler au contrôleur qu'une délégation n'était pas faisable. Des messages d'impossibilité devraient être développés pour les prochaines simulations.

5.2.2. Formation

La formation doit prendre une place importante pour permettre au contrôleur de s'habituer d'une part à un niveau de trafic très élevé et d'autre part à l'utilisation de la délégation. En effet, en dépit d'une apparente simplicité, pour que la délégation soit bien utilisée, il est essentiel que les conditions d'applicabilité soient respectées. L'expérience nous a montré que les contrôleurs attendent trop de la délégation. Pour essayer d'éviter les erreurs classiques liées à la délégation et optimiser son utilisation, nous utiliserons un outil de rejeu pendant les débriefings pour mettre en évidence les bons exemples d'utilisation et aussi pour discuter des mauvais cas d'utilisation.

5.3. ELARGIR LE DOMAINE D'INVESTIGATION

5.3.1. Utilisabilité en TMA

Maintenant que nous avons évalué l'utilisabilité de la délégation en E-TMA, il devient essentiel d'évaluer son utilisabilité en TMA, en particulier en ce qui concerne l'intégration de flux d'avions (délégués), les transferts et les co-ordinations avec l'E-TMA. Ceci devrait être réalisé dans un environnement plus réaliste notamment en invitant des contrôleurs d'approche à participer à la simulation.

5.3.2. Espacement en temps / espacement en distance

Comme nous l'avons souligné plus haut, l'espacement en temps pourrait être plus efficace que l'espacement en distance. L'impact de l'utilisation du temps par opposition à l'utilisation de la distance devrait être analysé, non seulement en termes de profil de vol mais aussi en termes d'acceptation par les contrôleurs.