Controller-in-the-loop experiments were conducted in order to assess the impact on air traffic controller activity of the delegation of spacing task to the flight deck. Three experiments involving a total of 18 European controllers during 7 weeks took place over the past two years. In addition to standard data analysis, a geographical-based analysis was introduced. It consisted in analysing the distribution of manoeuvring instructions and eye fixations as a function of their distance to the sector exit. This analysis confirmed assumptions that delegation leads to anticipate the building of the sequences, and to relieve the controller of maintaining these sequences. Although these initial results suggest a positive impact on controller activity, they still need to be complemented, typically with contextual analysis of monitoring through microscopic analysis of eye fixations.

INTRODUCTION
In the past, diverse and sometimes opposite approaches, ranging from free flight to more conservative approaches aimed at rethinking the function allocation between air traffic controllers and flight crews (Johnson et al., 1999; Dekker & Woods, 1999; Corker, 1999, Zeitlin et al., 1998; Casaux & Hasquenoph, 1997). Following a conservative approach, from the onset of the project, we identified and adopted two key constraints. The first one is related to human aspects and can be summarised by “take into account current roles and working methods of controllers and flight crews”. This implies no drastic change of roles: decision-making shall remain to the controller. The second one is related to technology and can be expressed by “keep it as simple as possible”. The proposed task distribution was actually designed around the human actors involved – controllers and flight crews. Taking as a starting point existing roles and activities, and more specifically the analogy with visual separation, it is based upon the following principles: delegation is at controller's initiative who delegates only “low level” tasks (i.e. execution) as opposed to “high level” tasks (i.e. strategy). Two types of operations are envisaged: crossing for en-route airspace and sequencing for terminal areas.

Controller-in-the-loop experiments were conducted in 2000 to assess the impact of the delegation of spacing task to the flight deck. In addition to standard analyses, a geographical-based analysis was performed. It consisted in mapping the manoeuvring instructions over the considered area, and more specifically in analysing their distribution as a function of their distance to the exit point. A new controller-
Table 1. A typical controller pilot exchange without and with delegation. Communications are in italics; pilots readbacks are omitted.

<table>
<thead>
<tr>
<th>Sequencing of converging aircraft</th>
<th>Without delegation (conventional)</th>
<th>With delegation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The designation of the target aircraft is done by its transponder code (here 1234).</td>
<td>XYZ, select target 1234.</td>
<td>After selection and identification on the screen, the pilot replies: XYZ, target 1234 identified.</td>
</tr>
<tr>
<td>After checking the speed of leader aircraft, the controller asks to reduce speed:</td>
<td>XYZ, What is your Mach number? XYZ, Mach number .78. XYZ, reduce Mach number .75.</td>
<td>The controller can then issue the delegation instruction: XYZ, behind target, merge to WPT to be 8 miles behind. The pilot has to adjust his/her speed to maintain the spacing at the converging point and after the point.</td>
</tr>
<tr>
<td>Considering distance to the leader aircraft and its airspeed, the controller may need to issue a first airspeed restriction:</td>
<td>XYZ, speed 280 knots maximum. Similarly, one (or more) further speed reduction(s) may be needed: XYZ, reduce speed 260 knots.</td>
<td>The delegation will be ended by the controller when appropriate: XYZ, cancel delegation, reduce speed 220 knots.</td>
</tr>
<tr>
<td>When appropriate (e.g. in approach) another speed instruction is given:</td>
<td>XYZ, reduce speed 220 knots.</td>
<td></td>
</tr>
</tbody>
</table>

Past experiments

Human-in-the-loop experiments involving controllers and pilots have been conducted to assess the possible benefits, limits and impact of delegation. A small-scale simulation was conducted in 1999 to get initial feedback on the operational feasibility and potential interest of the concept. Beyond, the objective was to identify user requirements, other possible applications and evolutions, as well as indices 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" would enable the gradual growth of confidence and would also provide flexibility to use the method under different conditions (e.g. traffic, airspace, practice level). In 2000, a second large-scale experiment consisting of two sessions of two weeks each took place. Twelve 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 1999 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 sequencing operations of the landing traffic and in the resolution of lateral conflicts between cruising traffic. Regarding flight efficiency, delegation had a minor positive impact.

A three weeks session focusing on sequencing operations took place in 2001. In addition to pursue the analysis defined during previous experiments, the objective was to extend the scope towards more insight on the impact of delegation on controller activity (workload, monitoring, situation awareness) and overall safety (transfer and applicability conditions, tracing of potential delegation related errors). In addition, it was planned to carry out an initial assessment of the delegation in approach area (transfer and co-ordination, capability to integrate flows) and in non-nominal situations such as mixed equipage and unexpected events (detection and recovery).

METHOD

Participants and Experimental Set-up

Six European controllers with experience took part in the experiment. Six simulation pilots (each handling around ten aircraft at a time) were following controllers’ instructions to simulate aircraft behaviour. The 6 controllers were split in two teams of three, with respect to the sector configuration. The airspace comprised four sectors from Paris handling south-east arrivals to Orly (AO) and Charles-De-Gaulle (AR) airports and the two associated initial approach sectors (Figure 1). The traffic simulated was derived from a real traffic, and was increased up to maximal sector capacity for some exercises.

Terminal sectors were manned by an executive and a planning controller, initial approach sectors by a single controller. The working environment consisted of a “traditional” controller...
position, with paper strips and no advanced tool, but marking capabilities allowing to highlight aircraft under delegation.

![Figure 1. Map of the airspace, displaying terminal sectors (AR and AO), approach sectors (INI-O and INI-R) and converging points where sequences are built (●).](image)

Our study was a 2 (level of traffic) × 2 (sector) × 3 (controller position) × 2 (availability of delegation) design that contained 2 levels of traffic (medium and high), 2 sectors (AO and AR), 3 positions (executive, planning and approach) and 2 options (without and with delegation). An expert controller determined the level of traffic: medium traffic consisted of 27 arrival aircraft per hour and high traffic consisted of 31 arrival aircraft per hour (above maximal capacity). In addition over-flying traffic was introduced. Controllers were first trained on moderate traffic load and then controlled traffic on a given sector at medium and high levels. Each controller played each condition once (i.e. 24 runs per controller). In runs with delegation, the use of delegation was left to controllers’ choice, as they were invited to use it if they felt like it.

Each run lasted 75 minutes. Additional runs were planned to explore non nominal situations, such as the handling of mixed fleet (100% versus 75% equipped).

**Data Collected**

For measurement purposes, objective and subjective data were collected after each run. In accordance with standard simulation analysis, the objective data consisted of recordings instructions, radio communications, aircraft data. In order to investigate more specifically the monitoring tasks, we introduced in the experimental set-up two eye-tracking devices, worn by the AO and AR radar controllers. For the sake of consistency (limited duration of eye-tracker recordings), the analysed sample was restricted to 45 minutes.

Subjective data consisted of self assessment techniques, questionnaires and debriefing sessions. Typically, to address workload, we used the Instantaneous Self Assessment (ISA) device and NASA Task Load Index (NASA-TLX) questionnaires. In order to address more specifically situation awareness, we used blank maps of sectors. At the end of each run, controllers were asked to reproduce on blank maps “the traffic situation as it was before the switch off” (including as much detail as possible about aircraft features). Another feature introduced in the experiment was the use of replay tools in the context of debriefing sessions, following a double objective: support training (helping controllers understand what happened and why) and initiate collective discussions and comments on the use of delegation.

Dependent variables were grouped in four main categories (table 2). Variables discussed in this paper¹ are in bold font.

**Table 2. Indicators and dependent variables**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept acceptability</td>
<td>Acceptance Usability Subjective feedback Use of delegation</td>
</tr>
<tr>
<td>Flight deck perspective</td>
<td>Pilot activity Aircraft performances Instructions per aircraft Time and distance flown, fuel consumed</td>
</tr>
<tr>
<td>Controller performance</td>
<td>Individual workload Controller activity Radio occupancy Instructions (number, type, location) Monitoring (fixations, scanning patterns)</td>
</tr>
<tr>
<td></td>
<td>Collective activity Task distribution (between executive &amp; planning controllers) Co-ordination between sectors</td>
</tr>
<tr>
<td>Safety</td>
<td>Conflict analysis Losses of separation / Aircraft proximity index Conditions of transfer/Fluctuations in spacing Applicability conditions</td>
</tr>
</tbody>
</table>

**RESULTS**

**Concept acceptance**

Five out of the 6 controllers considered the concept as generally or totally useful. For all of them, it could significantly increase capacity. The main benefit of delegation is in terms of anticipation and improved solutions. As expressed by a controller, it provides “more time to think about traffic problems, and to find the best solutions”.

In medium load conditions, delegation concerned in AO, 48% of the traffic during 13% of the flight time and in AR, 55% of the traffic during 33% of the flight time. In high load conditions, it concerned in AO, 44% of the traffic during 24% of the flight time and in AR, 68% of the traffic during 31% of

¹ For exhaustive presentation of the results: Grimaud et al., 2002 or web site.
the flight time. The configuration of the AO sector (typically the late integration of converging flows) reduces the use of delegation, whereas the early converging in AR enables more delegations over longer periods.

**Flight deck perspective**

Instructions per aircraft. Despite a limited realism of the flight deck, it is nevertheless possible to have an initial insight into 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, the distributions of the number of instructions per aircraft without and with delegation were compared. It was observed in high traffic with delegation that the maximum number of instructions per aircraft was between 1 and 6 (only 3 aircraft received 7 or 8 instructions), while it went up to 11 without delegation (2 aircraft even receiving 12 or 13 instructions per flight). Focusing on speed instructions, we see that more than twice the number of aircraft with delegation get no instructions, and only 2 receive 2 speed instructions per flight (against 19 aircraft without delegation).

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

**Controller activity**

According to controllers, delegation enables earlier and better solutions (anticipated and more homogeneous spacing). In addition to this subjective feedback, we considered the impact of delegation on two dimensions of controller activity: active control and monitoring.

![Figure 2. Geographical distribution of instructions and eye fixations duration as a function of distance to IAF, in AR sector. Instructions without delegation (left) and with delegation (center), eye fixations (right). Medium traffic (top) and high traffic (bottom), without delegation (left) and with delegation (right), medium traffic.](image-url)
Impact on active control.

The “geographical based” analysis of instructions developed for experiments in the year 2000 (Grimaud et al., 2001) was applied on these latest results. It consisted in mapping the manoeuvring instructions over the considered area, and more specifically in analysing their distribution as a function of their distance to the exit point (Initial Approach Fix). We observed same trend: delegation leads to anticipate the building of the sequences (earlier use of heading instructions), and to relieve the controller of maintaining these sequences (reduction of speed instructions by 60%) (Figure 2). Once sequences are built (heading and delegation instructions), no further speed instructions are given. It can be noticed also an overall reduction of manoeuvring instructions (24% in AO and 26% in AR in high traffic situation).

Impact on monitoring. A similar geographical analysis was applied to eye fixations. In medium traffic, the global monitoring was similar without and with delegation: more fixations occurred around the converging point (located approximately at 120Nm from exit point). In high traffic, curves are opposite: with delegation, most of the fixations are concentrated over the converging point, while without delegation, they are concentrated after, near the exit point. This suggests that with delegation in high traffic, controllers can concentrate where the sequences need to be built, whereas without delegation, the building of sequences could not be anticipated. Controllers were thus more in a reactive position. To summarise, with delegation, the reduction of time spent actively monitoring delegated aircraft seems to increase controller availability. One question arises: is reduced monitoring not detrimental to safety? In other words, are the aircraft still monitored? As an attempt to answer this question, a “contextual” analysis of monitoring is ongoing. It consists, for each aircraft, depending on its status (delegated or not) in analysing the duration and frequency of fixations, i.e. the interval between two consecutive fixations.

Further investigation will focus on the scanning patterns: typically, we analyse if the order in which aircraft are monitored depends on their status and their location in the sector.

CONCLUSION

Controller-in-the-loop experiments were conducted in order to assess the impact on air traffic controller activity of the delegation of sequencing operations to the flight deck. In addition to standard data analysis, a geographical-based analysis was introduced. It consisted in mapping the manoeuvring instructions and the visual fixations duration over measured controlled sectors.

This analysis allowed confirmation of the following assumptions: delegation leads to anticipate the building of the sequences, and to relieve the controller of maintaining these sequences. Although these initial results suggest a positive impact on controller activity, they provide a partial view on monitoring tasks: whereas general fixations’ locations were identified, the issue of their content (e.g. objects monitored, frequency and patterns) is still pending. Beyond “measuring” monitoring per se, one of our objectives is to assess its impact on situation awareness and consequently on safety.

Similar method of analysis is currently applied to pilot-in-the-loop experiments carried out last Spring.

ACKNOWLEDGMENTS

The authors would like to thank controllers and pseudo-pilots for their participation in the experimentations and the technical team for their support. The eye tracker analysis has been performed with the support of Luc Rodet and Anne Pellegrin from Novadis, Grenoble, France.

REFERENCES


