DELEGATION OF CROSSING OPERATIONS TO THE FLIGHT CREW
FIRST QUANTITATIVE RESULTS

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Abstract
In the scope of assessing the impact of the delegation of crossing operations to the flight crew, an experiment with twelve controllers from different European countries has been carried out. The airspace simulated was a part of the Paris area, and consisted of two measured sectors with varied conflict situations. The controllers’ feedback is positive: delegation would allow solutions to be selected sooner, would induce less time-critical instructions and therefore would provide them with a higher availability. However, controllers questioned the usability in heavy traffic conditions, e.g. with more complex situations. The quantitative objective measurements match the subjective feedback from the controllers in suggesting potential benefits from delegation in en-route. A reduction of the number of manoeuvring instructions has been measured. The analysis of the distribution of manoeuvring instructions shows that the instructions are given earlier. No significant impact in terms of flight efficiency was observed, although for the crossing point considered trajectories become straighter. At this point, no significant impact on safety was observed.

1 Introduction
One of the options aiming at supporting air traffic controllers to cope with increasing traffic is to envisage a new distribution of tasks between all actors involved. This has been widely investigated between controllers and systems through the development of assistance tools or automation, e.g. for conflict detection or resolution. New distributions can also be envisaged between controllers and flight crews, and the delegation of some tasks related to separation assurance is one possible option. The delegation is expected to increase controller availability and enhance flight crew situation awareness. This increased availability is expected to provide safety improvements and, depending on traffic conditions and airspace constraints, to be converted into enhanced airspace capacity or flight efficiency. The delegation of separation assurance takes advantage of emerging CNS/ATM technologies in pre-operational state [4] along with additional avionics such as a Cockpit Display of Traffic Information [5] or an Airborne Separation Assurance System [6].

The delegation of separation assurance is envisaged for both en-route airspace and terminal areas. In en-route airspace, similarly to visual clearances, the delegation could consist in tasking the flight crew to report once the crossing with a designated traffic is completed, or even to alter his flight path to maintain separation to this traffic. This has been investigated under the form of an “ASAS crossing procedure” in [1]. The controller identifies a conflict, selects the manoeuvring aircraft and lets the flight crew decide which solution to use. The delegation is based upon controller initiative and uses a specific phraseology to communicate the instructions of delegation. Other applications have been proposed such as in-trail climb and descent [4] [8].

From a controller perspective, one of the main issues arising from the delegation is to identify the best “trade-off” in the level of tasks delegated. Indeed, on the one hand, delegating too low level tasks may induce additional communication with no gain in workload. On the other hand, delegating too high level tasks may induce a loss of predictability of aircraft trajectories (“mental picture”), resulting in a potential increase of workload. As an initial step to address this issue, the task distribution between controllers and flight crews has to be defined and the overall outcomes – benefits? – have to be evaluated.

Earlier in the course of this study [3], we have defined a form of delegation both for sequencing applications in terminal areas, and for crossing and passing applications in en-route. An experiment with human-
in-the-loop has been carried out to evaluate the expected benefits. The present paper aims at presenting the results for the crossing and passing applications. Results for the sequencing applications are presented in [7]. This paper is organised as follows: the next section outlines the principles of the delegation, while the following one presents the applications. The last two sections describe the context of the experiment and discuss the most significant results.

## 2 Principles of delegation

In the scope of defining a 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”.

The proposed task distribution was actually designed around the human actors involved – controllers and flight crews. Taking as its starting point existing human roles and activities, and more specifically the analogy with visual clearances, it is based upon the following key elements:

- Some separation assurance related tasks are delegated to flight crews, upon controller initiative who decides to delegate if appropriate and helpful.
- The delegation is limited since the controller can only delegate “low level” tasks (e.g. implementation and monitoring) as opposed to “high level” tasks (e.g. definition of strategy). In addition, only one flight parameter is delegated at a time.
- The delegation is flexible since the controller has the ability to select for each situation the level of task to be delegated from monitoring up to implementation.

This form of task distribution is expected to maintain unchanged core roles and working methods of controllers and flight crews. Typically, the delegation does not impact on controller’s decision-making: situation analysis, identification of problems (e.g. conflict detection), definition of solutions, and decision of delegation are part of controller's role and responsibility. Consequently, the controller keeps the initiative and overall authority on traffic management. In addition, the delegation does not impose any change of responsibility since it can be considered as a new instruction. Thus, the controller would be responsible for providing the appropriate instruction (i.e. which ensures the separation and is flyable for the flight crew) while the flight crew would be responsible for following this instruction, once they have accepted it. Indeed, flight crews can refuse delegation in case of inability to comply with the instructions. The controller should be able to anticipate pilot future actions and to predict future aircraft trajectories as today through: (1) the delegation of no more than implementation tasks; (2) the restriction to only one parameter delegated at a time; and (3) the use of appropriate pilot reports. The flexible aspect of the delegation would provide flexibility to use the delegation under different conditions such as traffic density, airspace constraints, and practice level. It would also enable a gradual confidence building in the delegation. Indeed, the levels of delegation reflect increased use in practice. Each controller should thus experience his/her own "trade-off". Major benefits are expected from controllers perspective, mainly in terms of increased availability. From a flight crew perspective, the delegation is expected to allow for more anticipation (less time-critical instructions to follow), to increase situational awareness, and to enable an optimisation of trajectories. It is also expected that safety would be improved (or at least maintained), through a better organisation of tasks and a redundant separation monitoring ensured by controllers and flight crews. The delegation may however induce modifications in activities. Compared to visual clearances, the delegation is expected to be used more often, over a longer time period, and also will impose larger path alterations (to ensure radar-based separation instead of staying visually apart).

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. Only the knowledge of a subset of the air traffic situation is needed on board aircraft along with appropriate display cues.

## 3 Crossing and passing applications

The delegation covers two classes of application: sequencing operations in terminal areas, and crossing and passing applications in en-route airspace. For crossing and passing applications, both lateral and vertical situations are considered and three levels of delegation are proposed (Table 1).
Table 1. Crossing and passing applications.

<table>
<thead>
<tr>
<th>Delegation level</th>
<th>Lateral</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Report separation</td>
<td>Report clear of target</td>
<td>Report clear of target</td>
</tr>
<tr>
<td>Maintain separation</td>
<td>Resume navigation</td>
<td>Resume climb</td>
</tr>
<tr>
<td>Create separation</td>
<td>Pass behind</td>
<td>Pass above / below</td>
</tr>
</tbody>
</table>

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 "Pass behind" procedure is given (Figure 1). In the example, DLH456 is the delegated aircraft, and AFR123 is the target aircraft with 1234 as SSR code. The two aircraft are in lateral crossing situation. The controller selects the type of manoeuvre that provides the separation, and asks the flight crew: ➊ to work out and activate the appropriate heading change to obtain the separation; ➋ to identify and report the clear of target, and ➌ to resume own navigation.

Once target is crossed:

Pilot: “DLH456, clear of target, resuming to WPT”

This report ends the delegation.

Similar dialogues are proposed for the other applications.

4 Context of the experiment

A first small-scale experiment took place in June '99. The main objective was to collect feedback from both controllers and pilots, in order to assess the operational feasibility and potential interest of the concept. Beyond, the objective was also to refine needs and identify other possible evolutions, as well as evaluation metrics for future experiments. The simulation environment consisted of one “measured” sector, two cockpit simulators equipped to receive delegations (CDTI with basic display cues), background traffic not equipped and low traffic sample. Five controllers (2 English, 2 French and 1 Spanish), 2 airline pilots and 2 pseudo-pilots (to handle background traffic) took part in the experiment. Due to the assumptions made – simple operational environment, small number of participants and limited occurrences of potential delegations – no quantitative measures were searched for. The results were qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses. The overall feeling on the concept was “promising with a great potential”. It could allow an increase of controller availability. The flexible use of delegation could provide opportunities to use the method under different conditions – traffic, airspace, practice level – however identifying the appropriate level of delegation did not seem easy. To ensure a safe and beneficial delegation, the procedures impose applicability conditions that shall be respected (e.g. no interfering traffic). It has been observed that the disregard of these conditions could result in an increase of workload, communication, and stress. This appeared as a potentially critical problem and was thus considered as an important aspect to be stressed on during the training in future experiments. This experiment allowed us to refine and restrict some of the applications, mainly the sequencing ones. The question of responsibility was raised as a major concern (this is however beyond the scope of the study).

The objective of the present experiment was to assess the concept of delegation and to evaluate its initial benefits in en-route and terminal areas. A subsidiary objective was to improve the procedures and the phraseology. The experiment consisted of two sessions, June and November for a total of four weeks of simulation. The November session also investigated flight deck issues through the connection...
of a cockpit simulator during the first week. Compared to the previous June 99 experiment, this experiment made use of a more realistic and comprehensive environment allowing quantitative measurements. The June and November sessions were split into two distinct sub-sessions of one week each: one for sequencing applications and one for crossing and passing applications. Two distinct organisations were thus simulated: an extended Terminal Manoeuvring Area (TMA) exhibiting sequencing situations from cruise to the Initial Approach Fix (IAF); and an en-route airspace exhibiting crossing and passing situations.

The simulated airspace was a part of Paris Southeast area (Figure 2), 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 12 controllers was familiar with the airspace). For the en-route organisation, four existing sectors were selected and combined into two measured sectors (denoted RO and TJ) of similar complexity with four crossing points. This grouping allowed a good anticipation (large sectors) and reduced need for co-ordination. Some existing altitude constraints were removed to create more conflict situations.

![Figure 2. Airspace dedicated to crossing and passing applications (snapshot of the replay tool – not of the actual controller display). The two measured sectors (RO and TJ) with their four crossing points (CHABY, OKRIX, BRY and TRO for RO; ATN, GERBI, LUSAR and DIJ for TJ).](image)

Each of the two measured sectors was manned with two controllers (executive and planning). The traffic samples were derived from two traffic recordings. For the en-route, some flows were considerably augmented to create numerous and varied conflict situations. The traffic also included some arrival flights. The resulting traffic was thus more complex than it is in reality. All the traffic was equipped to receive delegations, thus offering maximum opportunities to use delegation. It should be noted that in addition to crossing and passing applications, sequencing applications (the first week of each session) were also available.

For the June session, the working environment replicated the current one (paper strips, no advanced tool). Thus, controllers were able to get rapidly familiar with airspace and traffic flows, and were able to concentrate on the delegation concept. Six controllers (2 Italian, 2 Portuguese and 2 English) and 4 pseudo-pilots participated. During the measured exercises, controllers were familiar enough with the airspace, the traffic flows and the delegation.
For the November session, the working environment was stripless with delegation marking capabilities on the screen as a support for controllers. Six controllers (3 French, 2 Irish and 1 Italian), and 4 pseudo-pilots participated. Due to technical problems, the en-route session was considerably reduced (one training and one measured exercises per controller), and quantitative results are not considered as significant enough to be presented here.

5 Experiment results

To assess the concept of delegation and to evaluate its initial benefits, four specific objectives were considered:

1. Users acceptance of the concept
2. Impact on controller activity
3. Impact on flight efficiency
4. Impact on safety

In addition to questionnaires, system recordings were analysed, allowing for subjective and objective results. Three exercises were simulated in each session (denoted June 1 to 3 – Quantitative results from November exercises are not considered). To allow for a relevant comparison, each exercise was simulated twice: with and without delegation. Each exercise lasted two hours, and controllers swapped roles at mid-exercise.

5.1 Controller acceptance of the concept

The controllers’ feedback, provided in questionnaires is positive: delegation could increase capacity and efficiency through a reduction of workload and an optimisation of the airspace. Nine out of 12 controllers described the delegation as totally or generally useful, while 3 controllers (in November) described it as partially useful. Despite this perceived usefulness, controllers questioned the usability in heavy traffic conditions (e.g. with more complex situations) and beyond, they felt delegation will be less usable in en-route than in extended TMA. They generally admitted that different types and levels of delegation bring flexibility, allowing the use of delegation in multiple situations.

In terms of “objective” measurement, the controller acceptance could be reflected by the rate of use of delegation. Indeed, although controllers were invited to use delegation, they were not forced to. The rate of use can be represented by the number of aircraft delegated (Figure 3) and by the delegation duration (Figure 4).

* For more detail, please refer to the experiment report available at http://www.eurocontrol.fr/projects/freeer

The rate of use was quite low compared to extended TMA: less than 20% of the traffic was delegated, and the duration of delegation is less than 10% of the total flight time. (Extended TMA in June gave respectively 60% and 40%.) This might reflect the en-route specificity: (a) delegation is used for conflict situations and furthermore (b) these situations are time-limited (e.g. duration of a crossing). On the opposite, in extended TMA (a) potentially all aircraft may end up under delegation (e.g. at the initial approach fix), and (b) delegations can be (were) given early and lasted until transfer to next sector. Beyond, one question arises: is there potential for increased use?

5.2 Impact on controller activity

Controllers described delegation as compatible with their working method. They felt it allowed solutions to be selected sooner, it induced less time-critical instructions and therefore it provided them with a higher availability, e.g. time to deal with more complex situations. Answers to workload related item show that most of the controllers (all of them in June) perceived delegation in en-route as a factor of workload reduction. The most demanding tasks were respectively the identification of potential delegation,
the decision of delegation and the mental integration of delegations in the traffic. The monitoring of delegated situations was considered as mentally less demanding for all the June controllers. However, it is not clear whether the monitoring of delegation is different. Though they feel they still have to monitor, in case of heavy traffic, they admit they will probably monitor less the delegated aircraft. This monitoring is not considered stressful, as long as there is trust in the airborne side. The delegation seemed to require more co-ordination with previous/next sector but did not raise specific difficulties. An appropriate marking allowing a silent co-ordination could compensate this increase in co-ordination.

In terms of objective measurements, two aspects will be discussed: the overall reduction of manoeuvring instructions, and their geographical repartitions. These two points are thought to reflect a change in controller activity. It is clear nevertheless that this does not provide a complete picture of the overall activity and resulting mental workload, since for instance the monitoring task is not covered.

The two following figures show the number of manoeuvring instructions (Figure 5) and the breakdown of each type of instructions (Figure 6). Delegation led to a 19% reduction of the number of manoeuvring instructions, with 20% of aircraft delegated and 10% of duration of delegation. No significant difference appear between the two sectors. As a point of comparison, for the extended TMA, the manoeuvring instructions were reduced by 35% with 60% of aircraft delegated and 40% of duration of delegation.

Considering the breakdown of instructions, delegation led to a reduction of heading (mean RO-TJ 70%) and direct instructions (mean RO-TJ 27%). Level instructions were only reduced by 15%. In RO, speed instructions were reduced by 65%, while no speed instructions were given in TJ. These figures could be correlated to the respective usage of the type of applications: 64% for lateral (with 54% of “pass behind” applications), 17% for vertical, and 19% for sequencing.

To provide a picture on the number of messages exchanged, the target selection related messages (“select target”, “deselect target”) need to be added to the previous number of manoeuvring instructions. It is important to note here that controller requests for information was not recorded, as in the simulator such requests do not require any operator input to be fulfilled. However we expect a reduction of such requests with delegation. In both sectors the total number of messages is similar without and with delegation, i.e. the target selection messages counterbalanced the reduction of manoeuvring instructions. For comparison, for the extended TMA, the delegation provided a 20% reduction of the number of messages.

![Manoeuvring instructions](image1.png)

**Figure 5.** Number of manoeuvring instructions for both sessions, and for both sectors.

![Type of instructions](image2.png)

**Figure 6.** Breakdown of instruction type.

In addition to the number of instructions given, the important aspect considered here is their geographical distribution. To give a clearer picture, we focus on the distribution of manoeuvring instructions related to one crossing point (OKRIX). (In extended TMA, we considered the initial approach fix.) The two maps (Figure 7) suggest that with delegation fewer instructions were given, and occurred earlier. To provide a more synthetic view, we represent the distribution of instructions as a function of the distance to the crossing point where they were given (Figure 8). This also allows to easily differentiate the type of instruction given. However, due to the scale considered, some instructions related to other crossing points (DIJ and ATN) also appear.

The figure shows the overall reduction of the number of instructions, and the earlier occurrence of the remaining ones. The bulk of the instructions are given when aircraft are around 50-60NM before the crossing point while, without delegation, the instructions are distributed in a wider 20-70NM area.
range. Beyond, the histograms show the impact of delegation on two aspects (highlighted by magenta rectangles): first, initial headings (initial conflict solving) are replaced with delegation instructions, and second resuming instructions disappear (direct given around the crossing point). Indeed, the resuming instructions are included in the delegation instruction. This might contribute to alleviating the controllers in terms of time-critical instructions and active monitoring.

Figure 7. Geographical distribution of instructions for aircraft crossing over OKRIX without delegation (top) and with delegation (bottom). Flows consist of northbound and north-westbound traffic.
Although Figure 8 is related to a selected exercise, similar trends can be observed for all the exercises. Figure 9 shows the median value of distance to crossing point, even if this is a rough representation of the distributions. A slight increase can be observed: with delegation, instructions are given slightly further from the crossing point. The anticipation however is less visible in en-route than in extended TMA (about 30Nm). It is not clear if this reflects that anticipating is less easy, or if this results from the inclusion of instructions related to other crossing points “polluting” the results. It is still needed to find how to restrict the analysis to a specific point, in isolation from others.

5.3 Impact on flight efficiency

Even though trajectories become straighter with delegation (Figure 10), no significant impact have been observed in terms of time, distance and fuel consumption (Table 2).

<table>
<thead>
<tr>
<th>Time (hh:mm:ss)</th>
<th>Distance (NM)</th>
<th>Fuel (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>117:32:25</td>
<td>48883</td>
</tr>
<tr>
<td>With</td>
<td>117:03:20</td>
<td>48744</td>
</tr>
</tbody>
</table>

Table 2. Cumulative values of flight duration, flown distance and fuel consumption in the measured airspace.

5.4 Impact on safety

In June, controllers were more confident in delegation, as 3 out of 5 controllers thought delegation could generally or totally increase safety and the other two thought it could partially increase safety or have no detrimental impact. In November, 6/6 controllers thought delegation could partially increase safety or have no detrimental impact. The difference between June and November controllers could be explained by the significantly reduced duration of the November session.

In June, fewer losses of separation were observed with delegation. The very serious loss observed during the June 2 exercise (with delegation) did not concern an aircraft involved in delegation. Yet, we feel that these figures were not sufficient to understand and qualify the impact of delegation on safety.
Figure 10. Trajectories of aircraft crossing over ORKIX without delegation (top) and with delegation (bottom).
6 Conclusion

In the scope of assessing the impact of the delegation of crossing operations to the flight crew, an experiment with twelve controllers from different European countries has been carried out. The airspace simulated was a part of the Paris area, and consisted of two measured sectors with varied conflict situations. The controllers’ feedback is positive: delegation could increase capacity and efficiency through a reduction of workload and an optimisation of the airspace. They felt it allowed solutions to be selected sooner, it induced less time-critical instructions and therefore it provided them with a higher availability. However, controllers questioned the usability in heavy traffic conditions (e.g. with more complex situations) and beyond, they anticipated fewer benefits from delegation in en-route compared to terminal areas.

A reduction of the number of manoeuvring instructions around 20% with 20% of aircraft delegated and 10% of duration of delegation has been measured. The analysis of the distribution of manoeuvring instructions related to a given crossing point show that the instructions are given earlier. This suggests a positive impact on controller activity: initial headings (initial conflict solving) are replaced with delegation instructions, and resuming instructions disappear (direct given around the crossing point). No significant impact in terms of flight efficiency was measured, although for the crossing point considered, trajectories become straighter. At this point, no significant impact on safety was observed.

The quantitative objective measurements match the subjective feedback from the controllers in suggesting potential benefits from delegation in en-route. However, results are less optimistic compared to extended TMA. It is not clear at this point whether this is due specifically to the en-route context (lower applicability of delegation?) or to the experiment set-up (e.g. selected airspace and traffic flows?).

7 References