Introduction

The delegation of separation is envisaged as one possible option to increase controller availability, and beyond, to increase safety and/or capacity [2]. For aircraft within an arrival stream, the delegation could consist in tasking the flight crew to determine and perform the necessary speed adjustments so as to maintain a given separation to a lead aircraft.

Mathematical simulations were carried out in order to capture the essence of in-trail following in terminal areas from a system dynamics perspective [3][5]. Model-based simulations were conducted to evaluate the impact of different control strategies on the inter-aircraft time dispersion at the runway threshold, or in another study the impact of traffic complexity on the applicability of delegation in en-route airspace [1]. A number of human-in-the-loop simulations investigated pilot perspective [4][6] and controller perspectives [7]. More specifically, in a latter case, there is a need to assess the impact on controller activity. For the sequencing applications, one of the main assumptions is that delegation could provide an increase of controller availability, through an anticipation in building aircraft sequences and the relief of maintaining these sequences.

This paper aims at showing how the use of a geographical mapping of instructions could provide additional insight on controller activity, specifically regarding the previous assumption, compared to standard analysis. A real-time experiment was carried out, involving twelve controllers from different European countries. The airspace simulated was a part of the Paris terminal area, and consisted of two measured sectors with arrival flights from cruise level to initial approach fix. Though the same analysis was applied to the en-route applications, this paper will focus only on sequencing applications.

The paper is organised in three main sections: the next one will outline the principles of delegation; the following one will present the experiment setup. The last one will introduce the method of analysis consisting of standard analysis (e.g. workload, radio occupancy) and geographical-based analysis of instructions.

Principles of delegation

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”.

The proposed task distribution was actually designed around the human actors involved – controllers and flight crews. Taking as 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 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.

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 will be considered in this paper, in-trail and merging situations are proposed along with three levels of delegation (Table 1).

<table>
<thead>
<tr>
<th>Delegation level</th>
<th>In-trail separation</th>
<th>Merging separation</th>
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</thead>
<tbody>
<tr>
<td>Report distance</td>
<td>Report in-trail distance</td>
<td>Report merging distance</td>
</tr>
<tr>
<td>Maintain separation</td>
<td>Remain behind</td>
<td>Merge behind</td>
</tr>
<tr>
<td>Resume then maintain separation</td>
<td>Heading then remain behind</td>
<td>Heading then merge behind</td>
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Table 1. Sequencing applications.

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 (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 separation, and instructs the flight crew: ➊ to report when the predicted separation at the merging point reaches the desired separation; ➋ to resume own navigation to the merging point, and ➌ to adjust speed to maintain the desired separation.

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 autopilot 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 required task information includes the display of relevant target aircraft information.

**Experiment set-up**

The objective of the experiment was to assess the concept of delegation and to evaluate its initial benefits in en-route and terminal areas. The experiment consisted of two sessions, June and November for a total of four weeks of simulation. 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, and was thought to be representative of a dense area and generic enough to allow an easy assimilation by the controllers. For the terminal area applications, four existing sectors were selected and combined into two measured sectors (denoted AO and AR), the grouping allowed for a handling of a majority of flights from cruise to IAF by the same sector. Thus, the delegations 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.

Each of the two measured sectors was manned with two controllers (executive and planning). The traffic samples were derived from two traffic recordings. The traffic was slightly increased and represented a real high-density traffic. All the aircraft were equipped to receive delegations, thus offering maximum opportunities to use delegation.

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), 5 pilots (2 test pilots, 3 airline pilots), and 4 pseudo-pilots participated. Though we introduced a new interface, no specific training was planned. Indeed, we thought that either controllers were familiar enough with stripless environment, or they could easily get familiar with it. In addition, due to technical problems, they had to cope with interface trouble-shooting. Some of the controllers were not familiar with the type of flows and work (sequencing in extended terminal area). Consequently, during the measured exercises, controllers did not manage to get familiar enough with the delegation procedures and this impacted the results.

Analysis of results

As stated in the introduction, one of the main expected benefits from controllers perspective is an 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 controller 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).

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

1. Controller 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 measured in each session (denoted June 1 to 3, and Nov 1 to 3). 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.

Controller acceptance of the concept

The controllers’ feedback, provided in questionnaires is positive. Indeed, June and November controllers understood the concept and found it satisfying. They stressed benefits in terms of workload, anticipation and quality of control.

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 and by the delegation duration. Between 60% (June) and 45% (November) of the traffic was delegated, for a duration of 40% of the total arrival flight time. Whereas the use of delegation was constant in June, it was more progressive in November (from 30% to 55%).

1 For more detail, please refer to the experiment report available at http://www.eurocontrol.fr/projects/freer
Delegation was used more often and over longer periods in AR than in AO sector.

The lower rate of use observed in November might be related on the one hand to the required familiarisation with not only the delegation, but also with a new HMI (stripless working environment) and for some, with the type of traffic, and on the other hand to HMI troubleshooting.

**Impact on controller activity**

In terms of feedback, 10 out of the 12 controllers (and 6 out of 6 for June) describe delegation as a workload reduction. They feel that delegation enables earlier sequences, earlier solutions, reduced communications, reduced vectoring and reduced monitoring (less speed control). Therefore it helps reducing the workload during highly demanding phases of sequencing. For most of the controllers, the mental effort required to monitor delegations is lower or much lower, only one feels the effort is similar. They felt that usually once delegated, an aircraft would not require anymore instructions from the controllers. For 11 out of 11 controllers, the resulting mental workload is lower or much lower, because delegation enables a reduced monitoring of aircraft and an early organisation of the sequences. However, workload could increase in degraded situations, when sequences of delegated aircraft suddenly need to be cancelled, each aircraft requiring an individual end of delegation.

In terms of objective measurements, two aspects were considered: the overall reduction of manoeuvring instructions\(^1\), 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\(^3\).

The following figures show the number of manoeuvring instructions\(^4\) (Figure 2) and the breakdown of each type of instructions (Figure 3). In June, the manoeuvring instructions were reduced by 35%, with a 40% rate of use (delegation duration). The reduction is even higher for AR than for AO sector. In November, there is no significant reduction while the rate of use was 27%. Considering the breakdown of instructions, the main reduction results from the reduction of speed instructions.

**Figure 2.** Number of manoeuvring instructions for both sessions, and for both sectors.

**Figure 3.** Breakdown of instruction type.

\(^2\) A manoeuvring instruction refers to a standard manoeuvring instruction (speed, heading, and climb/descent) or a delegation instruction (“remain behind”, “merge behind”, “heading then...”).

\(^3\) For the November session, workload issues were also addressed through self-assessment and physiological measurements. However, due to the problems encountered, they did not provide a clear view of the impact of the delegation, and are thus omitted.

\(^4\) Controller instructions were collected through pseudo-pilot inputs automatically recorded.
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 were 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 June, even despite the additional messages, the delegation still provided a 20% reduction of the number of controllers’ messages. The November results show however a 13% increase.

Although the overall reduction of instructions suggests an overall increased availability, it does not provide any insight in terms of anticipation in building aircraft sequences and the relief of maintaining these sequences. For that purpose, we considered the geographical distribution of instructions (Figure 4). Beyond the clear reduction of instructions, these two maps suggest that without delegation, a lot of instructions are given in the second half of the sectors.

In order to provide a more synthetic view, we focussed on the distribution of the instructions as a function of distance to IAF (exit point). Figure 5 shows on two curves the cumulative number of instructions (level instructions are not integrated since they are located in a same area reflecting the top of descent). Once again, one can notice the reduction of instructions with delegation (blue versus red curves). Two points have to be stressed here: the gathering of instructions reflected by steep slopes (highlighted with rectangles) and the location of latest instructions (e.g. in AR, around 40NM without delegation versus 100 NM with delegation).

An alternate presentation is shown on Figure 6. It uses density lines as an indicator of distribution of instructions. Gathering of instructions is reflected by high density of lines, while empty areas between lines highlight quiet periods, when no instruction is given.

In order to distinguish the building of sequences from the maintaining sequences, a more detailed picture is required. Thus, we used an histogram-based presentation, where various types of manoeuvring instructions can be displayed: heading, speed and delegation instructions if applicable (Figure 7). Three points can be observed.

**Building vs. maintaining sequences:** Without delegation in the two sectors, it is interesting to see that following sector entry, most of the instructions are heading instructions, while they become speed instructions when approaching the IAF. This is evident in sector AR with the transition from heading to speed instructions showing up 100Nm from IAF. This reflects the two successive steps in conventional control strategy with arrival streams: building sequences (with heading) then maintaining sequences (with speed).

**AO sector vs. AR sector:** Without delegation, while AR (with one converging point at the sector entry) allows for an early building of sequences, AO (with two converging points, one at 50Nm from IAF, i.e. rather close to the IAF) constrains a late building of some of the sequences.

**With vs. without delegation:** Similar peaks can be observed when controllers build sequences (typically around 120Nm from IAF for AR), whereas the delegation allows for a reduction of the instructions given after, i.e. when controllers maintain sequences.

Although the Figure 7 is related to selected exercises, similar trends could be observed for all the June exercises. The Figure 8 shows the median value of distance to IAF, even if this is a rough representation. Increase of the median value can be observed for June exercises and specifically for AR sector (about 30Nm) suggesting that instructions were generally given earlier. For the November exercises however, no significant trend emerges.

**Impact on flight efficiency**

An initial estimation of the efficiency variation was made through the record of time, distance and fuel consumption. A minor gain of delegation emerges (around 3% in June). Even though the benefits are very light, it is at least important to stress that delegation has no negative impact on the flight efficiency.
**Figure 4.** Geographical distribution of instructions without delegation (left) and with delegation (right).

**Figure 5.** Cumulative curves of manoeuvring instructions relative to IAF, without and with delegation in AR (left) and AO (right).

**Figure 6.** Density lines of manoeuvring instructions relative to IAF, without and with delegation in AR (left) and AO (right).
Impact on safety

Globally, the controllers have a positive feeling about the impact of delegation on safety. Moreover, they feel delegation could increase pilots’ situation awareness and therefore enhance their contribution to the safety of the overall system. Their concerns are rather related to doubts regarding the pilots’ performances, combined with pre-existing ideas about pilots’ attitudes which may worsen if responsibility is inappropriately assigned. Despite observed benefits in terms of stability of transfer with delegation, the analysis of objective data (loss of separation, Aircraft Proximity Index) shows cases when the safety of the system is endangered not only with delegation but also surprisingly without. With delegation, the main problem faced by controllers was the maintaining of applicability conditions over time.

The observation of simulations as well as the analysis of debriefing items stresses potential sources of errors. Based on existing error taxonomy, describing errors in terms of slips (erroneous execution) and mistakes (errors in planning actions), we developed our own classification of errors associated to possible means for their prevention and or tolerance.
Conclusion

To assess the impact of delegation of sequencing operations on controller activity, in addition to a standard analysis, 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 (IAF). From this geographical-based analysis, we could infer strategies controllers used to build and maintain sequences. It allowed to confirm our assumptions: delegation leads to anticipate the building of the sequences, and to relieve the controller of maintaining these sequences. This might alleviate the controllers in terms of active monitoring and time-critical instructions.

Although these results suggest a positive impact on controller activity, this analysis provides only a partial view. Indeed, delegation is expected to reduce the amount of time spent actively monitoring and thus to contribute to an overall reduction of workload. This will be investigated in next experiments, typically in analysing controllers’ scanning patterns. In addition, though the reduced monitoring can be seen as a benefit in terms of workload, it raises the issue of controllers’ awareness of delegated situations, and thus their ability to identify and take back degraded situations. Even though the impact on safety can hardly be measured in real-time experiment, evaluation of impact on situation awareness is a first step.

References