Introduction

Today’s challenge in the domain of air traffic control is to maintain if not improved the level of safety considering the foreseen increase of traffic. Among the different options investigated, a new task allocation between air and ground to manage aircraft spacing is seen as part of a possible solution. Beyond assessing the impact of this new task allocation (denoted delegation) on controller and flight crew activities, it is essential to understand how the overall level of safety is impacted. In this paper, we suggest that safety assessment requires a dual approach, measuring not only the negative dimension of safety (error free) but also the positive one (error tolerant). In the first section, we introduce current safety approaches and describe our safety related hypothesis. In the second section, we describe our experimental method, in terms of experimental plan and set-up. After the discussion on the method in the third section, remaining questions and foreseen follow-up are listed in the conclusion.

Safety in air traffic control

Safety is generically defined as the “Freedom from unacceptable risk” [8] . In air traffic control, the principal safety objective is "while providing an expeditious service, (…) to minimise (…) the risk of an aircraft accident as far as reasonably practicable" [5] .

Safety assurance requires the combination of four main means: error prevention, prediction, avoidance and tolerance [9] . This approach accepts errors as unavoidable events. Providing solutions to eliminate as much errors as possible needs to be completed with back-up solutions supporting the tolerance of errors by preventing their propagation. The implementation of such means requires preliminary identification of risks, including the understanding of errors and of their context of occurrence. As illustrated by [14] , retrospective, predictive and real-time based applications are complementary to conduct such investigation of safety. However, most of the existing approaches, focusing on error analysis show three main limits.

Firstly, a failure is fortunately quite a rare event. Even though its analysis enables to identify the succession and combination of unsafe events, those are by nature accidental and might not, hopefully happen twice in the same exact conditions. Consequently, the "micro-incident" approach ([2] [13] is interesting. Microscopic analysis of what looks like nominal situations in air traffic control, highlight numerous mistakes and abnormal events detected and recovered before leading to failures. The studies show first how the system organisation (including redundant monitoring supports) enables implicit interactions and unexpected loops of control to emerge and second how these emerging mechanisms contribute to the early recovery of errors. What is suggested is to go beyond an overall safe-looking system, and question underlying and not so apparent tolerance means rather than failures. Such an approach provides insight on context of error occurrence ("unsafety" indicators) and on tolerance means introduced in the system, often under the form of recovery actions performed by the controllers themselves (safety indicators).

Secondly, a failure is a resulting event, which often materialises the combination of erroneous information processing, decision making and execution of actions. Error prevention and tolerance require risks of errors to be previously identified and understood so that safety means can be introduced in the system. It rests more on understanding the context of production, than on qualifying the production itself (number, frequency and criticality of the event for example).
Consequently, from safety perspective, understanding the context of production of initial errors is more essential than counting their materialisation under the form of failure (for an extended discussion about the distinction between error and failure, see Laprie, 1993).

Thirdly, even though the objective of safety is the absence of failure (typically, in air traffic control, the absence of loss of separation between aircraft), the main indicator used in safety assessment analysis is the probable number of failures. Safety is actually tackled through the assessment of risks of un-safety. Safety assessment methods often focus on the negative side of safety. Their main objective is to ensure that errors will be absent from the system. Typically, the three steps of the safety assessment analysis proposed by EUROCONTROL [6] focus on the identification and mitigation of potential risks. Functional Hazard Assessment (FHA) aims to identify potential hazards, evaluate their consequences and specify the maximum probability of occurrence of such hazards. Preliminary System Safety Assessment (PSSA) questions possible degradation of safety. System Safety Assessment (SSA) provides assurance that each system element (and ultimately the whole system) as implemented meets its safety requirements. Even more promising method, such as CRIA [11] focusing on interactions between components, investigates criticality of interactions. These methods tend to "prove the completed design is safe rather than construct[ing] a design that eliminates or mitigates hazards" [10]. Safety is more than the absence of error or failure. It should also include the definition of the context in which errors should not occur or could be tolerated. In air traffic control, this could be understood as the guarantee that despite the occurrence of local errors (which must be accepted as unavoidable events), the overall traffic handling (including safe separation between aircraft) is ensured. It relies on providing a "not unsafe" working environment. Typically, it requires ensuring that actors know the objectives of their tasks, are in a position to make the appropriate decisions and execute correctly the appropriate actions. This means that people are continuously aware of the situation, in terms of perceiving the information, making sense of it and anticipating correctly how it will evolve [3]. In air traffic control, it requires for example usable tools, acceptable workload and time pressure enabling actors to anticipate events (rather than react to them). In addition, interactions between the various components, information sharing, mutual understanding and control loops that have proven to contribute to systems safety [13] also need to be secured.

### Safety and unsafety of delegation

It needs to be clarified that the present study focuses on the (un)safety introduced with delegation as opposed to (un)safety of air traffic control in general.

#### What is delegation

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 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.

#### Expected impact

Because the concept of delegation is based upon current practices, we expect it to be accepted because easily understood and usable. However, although we expect delegation to reduce the risks of errors, new forms of errors might be induced by delegation. The main safety objective is to ensure
that such risks are mitigated and to do so a typology of delegation-related errors, including possible causes and mitigation means needs to be proposed.

We expect delegation to enable a better organisation of task, where actors’ expertise is appropriately used. Typically, 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. adjust speed 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 an instruction. No questioning of controllers strategy or decisions should be allowed. From the controllers’ perspectives, the message also needs to be clear. The expected gained availability is related to the active control part (instructions) rather than the monitoring: remaining responsible for separation controllers must continuously monitor separation between aircraft, be they delegated or not. 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 controllers peaks of unacceptable workload, 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 or erroneous applicability conditions.

We identify risks of overtrust between controllers and pilots. If delegation, within acceptable applicability conditions, enables pilots to successfully conform to controllers instructions, is there a risk, that with time controllers try to delegate more and more to the flight deck, including non feasible cases? If delegation works as expected most of the times, would controllers keep monitoring delegated aircraft? 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 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 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, studies on problem solving [1] 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, we expect such risks of expert destabilisation introduced initially with delegation.

**Experimental method**

The vision of safety as the provision of an environment that is both safe (i.e. error free) and not unsafe (i.e. prone to error prevention and tolerance) influenced the validation of the delegation concept.
We performed retrospective error analysis on human in the loop simulation data. The safety assessment actually consisted in measuring unsafety in terms of risks of errors and safety in terms of conditions for error avoidance and tolerance.

**Past experiments**

In the scope of assessing the acceptance from controllers and measuring the impact on their activity, four human-in-the-loop experiments were carried out (June 1999, June 2000, November 2000 and December 2001). A total of 23 controllers from different European countries participated over a total duration of 9 weeks. The feedback from the controllers was positive: the delegation is perceived as useful and potentially leading to more anticipation and to an overall workload reduction.

Three flight deck experiments were also conducted (June 1999, November 2000 and May 2002). A total of 15 airline and test pilots participated over a total duration of 10 days. Despite a new task in the flight deck which requires appropriate assistance to contain workload, pilots stress the positive aspects of getting in the loop, understanding their situation (through goal-oriented instructions), and gaining anticipation.

The present paper specifically covers results illustrating the impact of delegation on safety. An overview of results can be found in [7].

**Latest experimental set-up**

The airspace simulated consisted of two Paris South East arrival sectors, including extended terminal manoeuvring area (ETMA) sectors and approach sectors (INI position). We considered the Orly area (AO and INI-O) and the Charles de Gaulle area (AR and INI-R). Only sequencing applications were evaluated in the experiment. The working environment consisted of a “traditional” controller position, with paper strips and no advanced tool, but marking capabilities allowing to highlight aircraft involved in delegation. Six European controllers with experience in ETMA took part in the experiments. The team was composed of 2 French, 2 Italian and 2 Swedish controllers. Six pseudo pilots (each handling up to ten aircraft at a time) were following controllers' instructions to simulate aircraft behaviour. Two teams of three controllers (one of each nationality) manned the Orly and the Charles de Gaulle arrival sectors.

In addition to the availability of delegation, two independent variables were defined in the experimental plan: the sector manned and traffic level. An expert controller determined the level of traffic: high traffic consisted of 27 arrival aircraft per hour and very high traffic consisted of 31 arrival aircraft per hour (above maximal capacity). In addition over-flying traffic was introduced. Eye-trackers were included in the experimental set-up during the second week of measurements. For each scenario, controllers successively played the role of radar controller, planning controller and approach controller. Even though it was encouraged, the use of delegation was left to controllers' choice, as they were invited to use it if they felt like it.

We considered as dependent variables, indicators of safety such as the acceptability of delegation (e.g. rate of use), its outcomes (i.e. quality of control, e.g. conditions of transfer), its impact on controller activity (e.g. distribution of instructions and eye fixations) and indicators of unsafety such as values of spacing and numbers of delegation-related errors.

Preliminary analysis of the first week of simulation supports the feeling that controllers were still learning how to use delegation. For the sake of consistency between dependent variables, we focused our analysis on the second week of measurements, when both simulator and eye trackers logs could be jointly considered.

**Results**

In order to qualify how the delegation positively contributes to safety in modifying the work context, we considered its acceptability and its impact on the controller activity and on the outcome (quality of control).
Acceptability and usability of delegation

During the experiment, neither the rate nor the duration of delegation was constant: it evolved from 30% of aircraft delegated during 25% of their flight time (AO sector, high traffic) to 80% delegated over 70% of their flight time (AR sector, very high load). Influencing factors were the level of traffic load (high or very high), the sector configuration (requiring more or less anticipation in integrating the flows) and also the controllers confidence in the new instructions. The progressive use and the adaptation to the situation constraints highlight an understanding of the concept both in its benefits and limitations. In addition, the type of instruction delegated ("maintain" versus "obtain and maintain") differs according to the situations: 82% versus 18%. According to us, it reflects that providing different levels of delegation enables controllers to handle predictability issues. Typically, controllers pay attention before delegating the most complex type (obtain then maintain) in which they lose part of their control on the situation. Indeed, the resume phase (and consequently the trajectory up to the resume) is under flight crews decision.

Organisation of controller tasks

Active control

With delegation, the number of instructions (including delegation ones) was reduced by 25%. Typically, speed instructions were reduced by 70% and heading instructions by 47%. Traffic load was not an influencing factor, whereas sector configuration did influence the reduction of heading instructions. In order to understand the impact of delegation on the task of building and maintaining the sequences, we analysed the geographical distribution of speed, heading and delegation instructions. Typically, in sequencing activity, heading instructions are used to build the sequences, whereas speed instructions are used to maintain the spacing between sequenced aircraft. When comparing situations without and with delegation, in high and very high load (Figure 1), we notice that with delegation heading instructions are used far from IAF to build sequences, while speed instructions are no longer given in the second part of the sector.

Monitoring

The impact of delegation is most noticeable in very high load. With delegation, controllers are focusing on the building area, and maintain a reduced monitoring over the second part of sector. Without delegation, the monitoring is concentrated over this second part. It looks like controllers are reacting and taking "last minute" decisions rather than anticipating the sequence building. We assume that without delegation in very high traffic load, controllers are no longer able to build an early picture of the traffic situations. Most of their monitoring is focused near the transfer area. In order to understand the reduction of monitoring in the second part of the sector with delegation, we analysed the number of fixations per aircraft and then the interval between two fixations on a same aircraft. The results showed that first no aircraft were forgotten, neither without nor with delegation and second the frequency of monitoring was similar for aircraft delegated and not delegated.

Organisation of tasks between controller and flight crew

The geographical distribution of instructions (Figure 1) shows that controllers no longer perform the maintaining of spacing (corresponding to the usage of speed instructions between 0 and 100 Nm from the IAF). Such tasks are delegated to the flight crews. In order to ensure that delegation is not detrimental to some aircraft, we analysed the number of instructions per aircraft with and without delegation. In very high traffic, with delegation, the maximum number of instructions per aircraft was between 1 and 6, while it went up to 11 without delegation. Regarding speed instructions, with delegation more than twice the number of aircraft get no instructions, and only 2 aircraft received 2 speed instructions per flight (against 19 without delegation). Even though delegation reduces the number of instructions given to flight crew, the ground experiment does not inform us about the number of speed adjustments performed in the flight deck. Such results are expected from the experiment run specifically on the airborne side. Note that initial analysis of the latest airborne experiment show that not only pilots did perform the speed adjustments, but they also succeeded in remaining within less than 1 Nm from the required spacing.
Controller situation awareness

Situation awareness is essential to ensure appropriate decision making and actions [4]. 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. 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. 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.

It is envisaged in the future to analyse controllers’ ability to detect abnormal events, either
announced or not by flight crews (e.g. technical problem on board or erroneous action in the flight deck). The use of degraded scenarios and consequently the management of failures can be interesting in terms of duration of failure, in the sense that they could inform about controllers’ situation awareness. Typically, indicators such as 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) will be analysed. In terms of unsafety, these observations stress risks that could be defined in terms of controllers tendency to delegate too much, expecting flight crews to do more than what is really delegated (including maintaining spacing even outside feasible conditions). A complementary indicator to consider here could be the transfer moment. It appeared that with delegation, some aircraft were transferred later. The underlying question here is: were the aircraft forgotten and possibly removed from controllers’ mental picture?

Assessing unsafety

In the paper, we consider error as an initial local event (e.g. wrong instruction given) which might lead, under certain circumstances to a failure (loss of separation) that is visible at the system level [9]. Our method of analysis followed three steps (Figure 2): we first defined indicators (Table 1), then indexed and counted cases and finally used replay tools to understand the contexts of error occurrence.

Failures

Loss of separation and of spacing

Following traditional analysis in air traffic control experiments, we first looked at the number of losses of separation between aircraft at same flight level. Delegation does not have a significant impact: with very high traffic, 1 minor loss was detected with delegation, against 2 without. Initial discussion about the limitations of such an indicator must be completed here, in the specific context of the spacing tasks in approach. The objectives being to maintain a given spacing between aircraft, losses of spacing need to be looked at. However, some types of delegation (e.g. merge application) require spacing to be obtained at a given geographical point. Therefore, spacing value in the sector might be above or below the requested one, as long as it is exact at the exit point. We considered, depending on their status (delegated or not) the number of aircraft transferred with less than 8 Nm (expected spacing). In both cases, 8% of aircraft were transferred below the expected spacing. However, with delegation, the desired spacing should be obtained over the exit point, and not when transferred to the next frequency (which occur between 20 and 40 Nm before the exit point). The reason why we did not consider the exact spacing when the aircraft are over the exit point is related to the experimental set-up: indeed, once transferred, the aircraft might be given new instructions by the next sector. Therefore, when geographically over the next sector, they might no longer reflect the results of initial instructions. Additional analysis need to investigate if these detected losses were actually supposed to have the exact spacing at the exit point.

Unstable situations

Following the idea that even behind seemingly nominal situations (orange rectangle on Figure 2), abnormal events or process could be taking place, we considered cautiously the conditions of transfer. In addition to building sequences and maintaining safe spacing between aircraft, it is expected that controllers transfer safe and stable situations. Whereas the spacing value at transfer reflects a discrete event, it does not inform about dynamic aspects. We did observe without and with delegation, situations where correctly spaced aircraft were transferred in a catching up situation.

In order to measure conditions of transfer, we combined spacing indicators with closure rate indicators (basically speed differences between successive aircraft). 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 2). Depending on closure rates, we qualified the situations as either endangering safety (spacing soon to reach 5 NM, 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). In AO sector, we noticed 1 unsafe situation without delegation and 1 with delegation. None was observed in AR. Regarding reduced impaired quality, we noticed 12 cases without delegation against 9 with delegation.
Table 1. Indicators of unsafety considered

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

In addition to analysing the detail of identified problem (exercise, time, aircraft involved, speed difference, current spacing, delegation status, as listed in the table on Figure 2), we used replay tools to go back in time and investigate the whole process that led to the loss of spacing. Indeed, analysing in details context of losses, including their recovery, was essential. It enabled the understanding of the initial conditions, the reasons for losing separation (controllers or flight crews’ error, slip or mistake) the status of aircraft concerned (delegated or not), the time needed to detect and recover the problem, the complexity and the quality of the solution implemented (including the number of aircraft impacted). Beyond unsafety per se, unstable transfers may lead to an unacceptable workload increase in the receiving sector. In the current working practices, the receiving sector is in charge of integrating various flows of aircraft (typically Paris Orly approach is composed of two main and one marginal flows). Spacing and stabilising incoming aircraft might then represent an additional task. In addition to assess the possibility of integrating an aircraft within an existing flow, approach controllers are then in charge of ensuring spacing within this existing flow.

**Errors**

**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.

Deeper analysis are now needed to define criteria to evaluate the omission of other instructions such as heading or speed instructions.

**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 [12]. In order to automatically detect some of them, we defined indicators (see Table 1). 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 trajectories (e.g. ensure an aircraft is not asked to merge behind an aircraft following a diverging path) and compatible flight levels. One of the difficulties induced by delegation is the mutual dependencies between delegated aircraft, and consequently the cognitive cost of maintaining appropriate situation awareness in case of long chains. Whereas it is quite easy for a controller to understand that an aircraft is reducing speed because its target is descending, the task becomes harder when the speed reduction is suddenly observed for an aircraft ending a long chain (e.g. number 6) and actually reacting to the descent of the aircraft number 1. The resulting speed reduction might be amplified all along the chain and therefore result in inability to respect the delegation any longer. 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 sometimes combined) to each cases. The third step consisted in analysing 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 (non compatible speeds and target not direct to a waypoint).

Next step

The identification of failures causes (errors) need to be completed. We plan to use the cognitive framework defined in [14] to classify errors in terms of:

- Perception (visual or auditory): e.g. misreading;
- Memory: e.g. forgetting to give an instruction;
- Judgement, planning and decision-making: e.g. not giving the correct instruction;
- Action execution: e.g. not giving the intended instruction (slip).

Additional analysis will question errors (and more specifically judgmental errors) in terms of role confusion, trust, expertise, situation awareness (and beyond time pressure, information overload). In addition, the analysis of applicability conditions...
will guide the definition of algorithms for an error detection function (possibly introduced as a ground or an airborne support). Last of all, analysing monitoring patterns could help assessing the cost of checking and respecting applicability conditions. Whereas we expect delegation to induce a change in the data monitored (aircraft flight level instead of respective positions), it is necessary to evaluate first if the modified pattern is efficient and second if it is more or less complex. This is directly related to the issue of predictability. How do controllers anticipate aircraft behaviour, are they continuously aware of the current situation and do appropriately envisage how the situation should evolve. For the time being, monitoring efficiency could be investigated using degraded scenarios might indicate controllers ability to detect drifting situations. However, it will be necessary to distinguish two underlying assumptions: soon detection would reflect an appropriate monitoring, based on correct expectations and focused on relevant information. For the time being, comparing the complexity of monitoring is only envisaged through controllers subjective feedback.

Conclusion

The work reported in this paper is a first step in investigating the impact of a new controllers-flight crews task allocation on the air traffic system safety. It proposes a vision of safety assessment as a dual process of measuring safety (improved conditions and mitigation means) and unsafety (risks of errors). Results issued from human in the loop experiments conducted with air traffic controllers illustrate this approach. The new task allocation improves controllers availability, maintain them in an anticipative position and enable critical area to be still monitored, even under high pressure. It suggests that controllers are in a position to build and regularly update a traffic situation awareness enabling them to make efficient decisions. Even though redundancies are introduced by delegation, the current experimental set-up did not permit their evaluation. In terms of risks identified, it points out risks not only in terms of facts (e.g. loss of separation, violation of applicability conditions), but also in terms of process. It suggests to go beyond the counting of abnormal events. Typically it proposes a microscopic analysis of the situation, in which various indicators, such as aircraft speed, distance, altitude are combined in order to detect "soon to be unsafe" situations.

In order to complement preliminary analysis of safety, three tasks are identified. First a similar retrospective analysis of error is currently performed on data recorded during a pilot-in-the-loop experiment conducted in May 2002. Second, a predictive error analysis based on delegation task analysis is envisaged. Last of all, the introduction of degraded scenarios in the next ground experiment will investigate controllers and flight crews ability to detect and recover incidents.

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