Assessing Negative and Positive Dimensions of Safety.  
A Case Study of a New Air Traffic Controller-Flight crew Task Allocation.

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Abstract: The work reported in this paper is a preliminary investigation of the safety of a new controllers-flight crews task distribution. It proposes a vision of safety assessment as a dual process of ensuring that a situation is simultaneously “not error prone” and “error free”. It suggests that in addition to measuring the risk of error occurrence, it is essential to assess how the new situation provides means for error avoidance. Results issued from small-scale real time simulations conducted with air traffic controllers illustrate this approach. Typically, the new task distribution improves controllers availability, maintain them in an anticipative position and introduces redundancies that could contribute to the system dependability. 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 and to perform microscopic analyses of situations aiming to combine various indicators, such as aircraft parameters and control instructions in order to detect “soon to be unsafe” situations. Last of all, in addition to automated data analysis, the paper stresses the need for replay tools enabling operational experts to make sense of controllers activity.

Keywords: Air-traffic control, delegation, human-in-the-loop experiments, task distribution, safety indicators.

Introduction
Safety is generically defined as the “Freedom from unacceptable risk”. (ISO/IEC Guide 2, 1996)  
In air traffic control, it is transposed into:

“While providing an expeditious service, the principal safety objective is to minimise (…) the risk of an aircraft accident as far as reasonably practicable” (SMS Policy, 2000).

Safety assurance lies on the combination of four main means, which are error prevention, prediction, avoidance and tolerance (Laprie et al., 1993). This approach relies on the acceptance of errors as unavoidable events. Even though analyses provide solutions to eliminate as much errors as possible, they also define back-up solutions supporting the tolerance of errors through 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 Shorrock & Kirwan, retrospective, predictive and real-time based applications are complementary to conduct such investigation of safety. However, most of the existing approaches show three main limits.
First, 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 (Bressolle et al., 1996; Rognin et al., 2000) 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).
Second, 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.

Third, even though the objective of safety is the absence of failure (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 (FHA, PSSA and SSA) proposed by EUROCONTROL (Eurocontrol, 2001) 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 (Marti et al., 2001) 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” (Leveson et al., 2001). 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. Even though the nuance might sound subtle, there is a gap between avoiding errors and avoiding error-prone conditions. 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 (Endsley, 1994). 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 (Rognin et al., op. cited) also need to be secured.

This 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) will be illustrated in the present paper, through a case study in air traffic control domain. Human in the loop experiments have been conducted in order to assess the impact of a new task distribution on controllers and flight crews activity. After a brief description of the context, the new task distribution, known as “delegation of spacing tasks from the controller to the flight crew” is introduced. The experimental method set up to assess the concept of delegation is explained in the second section. In the third section, benefits and expected risks induced by delegation are presented. In the last section, initial indicators and measures of safety and unsafety issued from the case study are discussed.

Delegation of spacing tasks

Spacing tasks in approach: Air-traffic control is the service provided to airlines, ensuring that the separation standards between aircraft are maintained. Closely related to the temporal organisation of flights (air-traffic management), it is restricted to actions on aircraft aiming to avoid collisions and manage the daily traffic. Air traffic control is usually decomposed into three main activities: guidance (tower),

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1 For an extended discussion about the distinction between error and failure, see Laprie, 1993. 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.
flows integration (approach) and crossing (en-route). In approach control, controllers’ objective is a sequence of horizontally spaced aircraft exiting the sector. Controllers’ strategies are usually based on two main options: either act on the speed or on the heading parameter. The controller’s task consists in first identifying in which order to build a sequence (based on each aircraft speed, type, level, current position and heading), second choosing the appropriate strategy enabling space to be created and third ensuring that the obtained space is maintained down to the sector exit.

Rethinking the function allocation: Today’s challenge in the domain of air traffic control is the foreseen increase of traffic load. While the capacity of the system is expected to double within the next 10 years, its level of safety has to be maintained if not improved. One of the options aiming at supporting controllers to cope with increasing traffic is to envisage a new distribution of tasks. This was 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. In this context, most of the studies rely on the "free flight" paradigm in which the whole separation assurance lies to flight crews (e.g. Johnson et al, 1999). In terms of task distribution, this induces a swapping of roles: flight crew becomes the primary actor for separation assurance whereas the controller is supposed to supervise the traffic and intervene as a last resort in case of failure. The controller is thus in a position of acting by exception, which raises the key issue of human performance (Wickens, 1997; Billings, 1997; Corker, 1999; Dekker & Woods, 1999). On the opposite side of the spectrum, some studies have proposed a more conservative approach (Zeitlin et al., 1998; Pritchett et al., 1999; Casaux & Hasquenoph, 1997). Rather than following technical driven approaches, exploring how safety-critical tasks could be delegated to automated systems, we consider how function re-allocation (or tasks re-distribution) among the existing "components” could improve the current system.

Redefining the controller - flight crew task distribution: In the scope of redefining 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 “take into account 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” (Grimaud et al., 2000). Actually built around controllers and flight crews existing roles and activities, it is based upon the following elements: delegation remains upon controller’s initiative, who delegates only “low level” tasks (e.g. implementation and monitoring) as opposed to “high level” tasks (e.g. definition of strategy).

For illustration purposes, let us consider the following example: two aircraft (DLH456 and AFR123) are flying along merging trajectories in descent with compatible speeds. In order to sequence DLH456 behind AFR123, the initial spacing (4 nautical miles) needs to be increased to 8 and then maintained until the waypoint (WPT), despite speed reductions imposed to the leading aircraft in descent phase. The strategy consists in giving first a heading in order to increase spacing, and then adjusting speed to maintain the acquired spacing (Figure 1).

![Figure 1 - "Heading then merge behind" scenario.](image)
Without delegation, the controller gives a first heading instruction, which is executed by the flight crew. The controller monitors the aircraft until enough space is obtained. Then, the controller gives a new heading instruction, followed by heading change in the cockpit. The controller monitors the resulting spacing in order to assess if additional instruction is required to maintain it. If so, the controller gives a speed instruction, which leads to speed adjustment in the cockpit. With delegation, the controller still gives a heading instruction to initiate the spacing, and instructs the flight crew to "merge behind the target". This instruction encompasses: ➊ report when the predicted spacing at the merging point reaches the desired spacing; ➋ resume own navigation to the merging point, and ➌ adjust speed to maintain the desired spacing. The flight crew implements the task which now includes the understanding of the context, the identification of the resume point, the monitoring of the situation, the execution of the resume and the potential speed adjustments. The new task distribution is expected to contribute to safety in reducing controller workload, improving situation awareness on ground and in the air and enabling anticipation of actions in the flight deck. In addition, delegation should provide redundant monitoring and control, contributing to error detection and recovery.

**Expected impacts of delegation**

Human-in-the-loop experiments involving controllers and flight crews have been conducted in order to assess the possible benefits, limits and impact of delegation. An initial part task real time simulation, involving five controllers and two airline pilots, was conducted in 1999 in order to get initial feedback on the operational feasibility and potential interest of the concept (Grimaud et al., op. cited). Beyond, the objective was to identify user requirements, other possible applications and evolutions, as well as indexes of evaluation for future experiments. The results were qualitative indications gathered through questionnaires and debriefings, with an inherent subjective component in controller and pilot responses. The overall feeling was "promising" with a "great potential", and "could reduce workload". Later (in 2000 and 2001), three small-scale real time experiments over a total of seven weeks involved eighteen controllers from different European countries. The main objective was to validate the concept in a more realistic ground environment and get an initial quantitative evaluation of its impact on controllers’ activity (Grimaud et al., 2001). During the latest experiment, in addition to issues previously identified, new indicators of quality of control, safety (typically transfer conditions), controllers activity (typically monitoring tasks) and initial impact on airborne side were included. Controllers’ activity was decomposed between active control (derived from instruction given) and monitoring tasks. System recordings provided information about types of instructions, time of occurrence, duration and number of communications.

From the onset of the project, hypothesis related to the impact of delegation on safety emerged. Both advantages and limits of delegation were identified, in terms of impact on the following aspects, relevant for both controllers and pilots. However, only controllers’ perspectives are addressed in this paper.

**Availability:** With delegation, controllers should focus their attention on the building task (first part of the sector entry) in order to identify what can be delegated. Once spacing task is delegated, controllers are expected to be relieved of the speed instructions previously associated with maintaining spacing. However, in terms of monitoring, the situation should remain unchanged: controllers responsibility require them to "keep an eye" on the traffic, even when delegated. It is expected that the availability gained in terms of active control could be used for the monitoring task, and typically through readiness and ability to detect and recover drifting situations. Regarding the flight deck perspectives, despite a limited realism, we considered the number of instructions per aircraft as a possible indicator of overload in the cockpit.

**Task distribution:** Delegation induces a new task distribution, where the general task of "sequencing" is split between the sequence elaboration and the spacing achievement (acquisition and maintaining). We expect a better organisation of task, where actors’ expertise is appropriately used. Controllers should be in the best position to define strategy (thanks to their overall picture of the traffic and their knowledge of how to sequence traffic) while flight crews should be more appropriate to identify the accurate action enabling the spacing to be obtained. However, roles might potentially become confused. First, controllers might forget their responsibility and reduce their monitoring, expecting too much from flight crews’
ability to maintain the spacing despite the non-respect of applicability conditions. Second, because traffic is displayed in the cockpit, flight crews might be in a position to question controllers strategies.

**Situation awareness (mental picture):** With delegation, controllers should anticipate the traffic situation, in order to prepare delegations that are initially and remain ultimately feasible, despite flight variations and later flows integration. This requires controllers to build an overall mental picture (as opposed to a more local one used to define the strategy). In addition, the availability provided by the removal of speed instructions represent extra time possibly used by controllers to update their situation awareness. However, delegation induces strong dependencies between aircraft. Maintaining the global picture of chained aircraft and anticipating the propagation of constraints along the chain might become complex and cognitively demanding.

**Error management:** In addition to reducing controllers peaks of workload (and consequently risks of errors), flight crews are put in a position to contribute directly to error detection and recovery. Typically, when detecting an infeasible delegation or a violation of applicability conditions, flight crews might detect an erroneous strategy chosen by controllers, or an omission of updating the situation. Delegation provides redundant monitoring and loops of control. However, with the introduction of new tasks (target selection, monitoring), delegation also induces new types of errors that need to be identified and managed.

**Measuring the positive impact of delegation**

The results presented in this section correspond to the second week of measurements, in condition of high traffic load (31 arrivals per hour), without and with delegation.

During the experiment, neither the rate nor the duration of delegation was constant: it evolved from 35% of aircraft delegated during 25% of their flight time to 68% delegated over 60% of their flight time. Influencing factors were the level of traffic load (medium or 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 spacing versus obtain and then 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.

**Availability:** With delegation, the number of instructions (including delegation ones) was reduced by 28%. Speed instructions were reduced by 70% and heading instructions by 47%. In addition, we considered the geographical distribution of instructions and eye fixations (Figure 2). It appears clearly that with delegation sequences are built earlier, and the tasks of maintaining the spacing is no longer performed by controllers. This confirms that delegation provides availability, and enables controllers to focus on more complex problems. Because delegation relieves controllers from time-consuming and more importantly time-critical tasks (e.g. resume an aircraft at the appropriate moment), it should reduce the time pressure and consequently associated risks of errors. In terms of monitoring tasks, with delegation controllers are still focusing on the building area, whereas their monitoring is over the latest area without delegation. Without delegation, it looks like controllers are no longer anticipating the sequence building, but rather reacting and taking "last minute" decisions. Regarding pilots availability, we analysed the number of instructions given to each aircraft. We observed that in high traffic, with delegation, 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 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). It invalidated the hypothesis that the use of delegation could be detrimental to some aircraft. Even though delegation reduces the number of instructions given to pilots, the ground experiment does
not inform us about the number of speed adjustment performed in the cockpit. Such results are expected from the experiment run specifically on the airborne side.

**Task distribution:** The geographical distribution of instructions (Figure 2) shows that the controller no longer performs the task of maintaining the spacing (corresponding to the usage of speed instructions between 0 and 100 Nm from the IAF). In the reported experiment, the limited realism of the airborne side does not inform on the performance of these tasks by the flight crews\(^2\). The monitoring curves show that with delegation controllers spend most of their monitoring time focusing on building areas, supposedly getting aware of the situation and possibly defining the appropriate strategy. Whereas a large percentage of fixations is noted over the building areas, there is still some monitoring all over the sector. We assume that it reflects regular even if less frequent monitoring, assessing if everything works as expected. However, this raises an issue in terms of unsafety: some monitoring is still performed all along the sector, but what does the reduction of the monitoring curve once the aircraft are delegated mean? Are delegated aircraft less monitored? Are there risks that controllers over-trust flight crew and implicitly forget that they remain responsible for the safety of the traffic? In order to answer these questions, we performed a microscopic analysis of fixations per aircraft: first we analysed the number of fixations per aircraft and then the interval between two fixations on a same aircraft. The results provide three answers: no aircraft were forgotten, neither without nor with delegation. The frequency of monitoring was similar for aircraft delegated and not delegated.

Even though their investigation will be necessary, we did not investigate the task distribution between executive and planning controller at a same position. However, we did question possible impact of delegation on interaction between sectors, because the quality of transfer has an impact on the next sector activity (typically if recovery or correction of actions is necessary). We considered the distribution of aircraft as a function of their spacing value. Without delegation, 17% of the aircraft are transferred with a spacing between 7 and 9 Nm, whereas delegation enabled 52% of the aircraft to be transferred in similar conditions. From the perspective of the receiving controller, the traffic is more homogeneously spaced. Regarding the closure rate (speed difference between delegated and target aircraft), the impact of delegation is less impressive: with delegation 60% of the aircraft were sent in stable conditions (+/− 10 knots difference between the aircraft), against only 45% without delegation.

**Figure 2.** Geographical distribution of instructions and eye fixations without delegation (left) and with delegation (right).

\(^2\) However, initial observations 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.
Situation awareness: even though the eye-tracker analysis show that something happened in terms of visual information acquisition, we have no objective evaluation of the possible impact on 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 cockpit). 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. 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) could 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?

Measuring risks induced by delegation

Delegation-related errors: 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 (Rognin et al., 2001). In order to automatically detect some of them, we defined types and conditions of occurrence. The resulting structure is composed of four categories: non-respect of initial applicability conditions, non-maintaining of these applicability conditions, misuse of delegation (e.g. giving instructions not compatible with delegation) and use of superfluous instructions. Once these events were detected and documented (exercise and aircraft concerned), an operational expert analysed the conditions in order to understand motives behind the error (lack of training, misuse of delegation, simulation pilot error).

Losses of separation and spacing at exit point: Compared to standard task distribution, delegation did not induce more failures (i.e. losses of separation). With high traffic, 4 losses of separation were observed in both conditions (without and with delegation). 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 of the controller (and actually of the flight crew with delegation) is to obtain and maintain a given spacing between aircraft until their exit point. Therefore, in addition to losses of separation we looked at losses of spacing at the exit point (i.e. difference between requested and obtained spacing). We considered the number of aircraft transferred with less than 7 Nm (8 was the requested one). It showed that with delegation more aircraft had not acquired the desired spacing when transferred. This could be explained: with delegation, the desired spacing is supposed to be acquired over the exit point, and not when transferred to the next frequency (which occur about 40Nm 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.

Conditions of transfer and impact on next sector: Following the idea that even behind seemingly nominal situations (orange rectangle on Figure 3), 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 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. As evoked previously, spacing is not a discrete event, but rather an evolving situation. Due to aircraft respective speed variations, a “soon to be” unsafe situation was transferred to the next sector. In order to measure unsafe conditions of transfer, we combined spacing indicators with closure rate

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3 Separation and spacing do have a very different meaning in air traffic control. Separation refers to safety minima defined by air traffic management regulations, whereas spacing refers to a distance fixed by controllers in order to organise their flows of traffic.
indicators (basically speed differences between successive aircraft), in order to detect acceptable spacing possibly between delegated aircraft faster than its target (orange circle on Figure 3). 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 3), 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.

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Respect initial applicability conditions, then maintain them: Specific applicability conditions need to be respected in order to benefit from delegation. Ensuring the feasibility of delegated tasks is part of the controllers’ tasks. In addition to this initial assessment, controllers are in charge of maintaining the applicability conditions during the flight. 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

Figure 3. Microscopic analysis of transfer conditions.
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). These results are now questioned in terms of causes and potential means for their prevention or/and tolerance. Whereas some errors were knowledge-based (lack of expertise), other were simulation-related and should have been detected by the flight crews in a real environment. In addition to detecting errors, 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 and next steps

The work reported in this paper is a preliminary investigation of the safety of a new controllers-flight crews task distribution. It proposes a vision of safety assessment as a dual process of ensuring that a situation is simultaneously not error prone and error free. It suggests that in addition to measuring the risk of error occurrence, it is essential to assess how the new situation provides means for error avoidance. Results issued from small-scale real time simulations conducted with air traffic controllers illustrate this approach. The new task distribution improves controllers availability, maintain them in an anticipate position and introduces redundancies that could contribute to the system dependability. 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. 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. Last of all, in addition to automated data analysis, the paper stresses the need for replay tools enabling operational experts to make sense of controllers activity.

In terms of safety assessment, a further step could consist of investigating controllers and flight crews ability to detect and recover incidents. However, the main limitations of the current experimental setting is the limited realism of the simulation environment, and more specifically the airborne component. Typically, flight crew contribution to error detection (e.g. non respect of applicability conditions) could not be simulated. This limit should be overcome in the context of the next ground simulation, where the system will provide simulation pilots with information enabling them to assess the feasibility of delegation. A human in the loop experiment, focusing on the airborne side was also conducted in May 2002 with five flight crews. The data collected are currently analysed, using similar indicators. A new airborne experiment is planned next winter. For the time being, no fully integrated simulation (combining controllers and flight crews) is envisaged: indeed, such an experiment requires the concept to be at a more advanced stage.

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