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Conflict Detection in Air Traffic Conrol: Distuinguishing Between Judgments of Conflict Risk and Intervention Decisions

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CONFLICT DETECTION IN AIR TRAFFIC CONROL: DISTUINGUISHING BETWEEN JUDGMENTS OF CONFLICT RISK AND INTERVENTION DECISIONS

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This paper seeks to make a distinction between cognitive processes involved in conflict risk judgment and those involved in conflict avoidance decisions (controllers' interventions for separation assurance). First, we conducted a systematic review of the conflict detection literature to identify studies that focused on conflict risk assessments and studies that focused on conflict avoidance (intervention). We then report empirical data pertaining to controller intervention judgments. Studies on conflict avoidance have rarely described the intervention decision making process and its interaction with the conflict risk assessment process, whereas our data indicated differences in terms of information processing between judgments of conflict risk and intervention judgments. We provide recommendation for future studies on conflict detection and conflict avoidance. These findings also have implications for the development of automated conflict detection tools.

Air traffic controllers (ATCos) assure the safe, orderly, and expeditious flow of controlled aircraft between a departure point and a destination. Detecting and resolving potential conflicts between aircraft are the most important tasks that ATCos perform. To do so, ATCos have to systematically scan the display (radar screen) and check the trajectories of the aircraft to assess whether a minimum separation is maintained between pairs of aircraft, and if not, develop and implement a solution that will assure sufficient separation. Conflict detection, which is the first tasks to achieve to keep the air traffic safe, is a complex and dynamic task that is cognitively very demanding. This task has been the topic of several studies in the field (for example, Bisseret, 1981; Remington, Johnston, Ruthruff, Gold, & Romera, 2000; Rantanen & Nunes, 2005; Boag, Neal, Loft, & Halford, 2006; Stankovic, Raufaste, & Averty, 2008; Loft, Bolland, Humphreys, & Neal, 2009). Several models of conflict detection have also been proposed (among the most recent are Rantanen & Nunes, 2005; Stankovic et al., 2008; Loft et al., 2009). More general models of separation assurance which describe both conflict detection and conflict resolution processes have also been developed but they are less numerous than conflict detection models (see for example Niessen, Eyferth, & Bierwagen, 1999). We argue in this paper that there are two distinct processes that come to play after initial conflict detection, one that pertains to judgments of conflict risk and another regarding conflict avoidance (intervention) decisions, and that great care should be taken not to confound them in experimental tasks or in models of conflict detection and avoidance.

Conflict Detection

The focus of current theoretical models of conflict detection concerns how controllers determine whether specific aircraft pairs that have been selectively attended will be in conflict or not. We define conflict as the potential loss of separation between two aircraft, or a situation where two aircraft would lose separation at some time in the future should they continue on their present trajectories. Consider two aircraft flying at the same altitude on converging courses. Determining whether these aircraft will violate lateral separation requires the integration of speed and distance information to predict the distance or time between the aircraft at the point of intersection of their trajectories (Law et al., 1993; Loft, Neal, & Humphreys, 2007; Neal & Kwantes, 2009). When aircraft are also changing altitude (especially in approach control), the prediction of loss of separation in the future also requires the integration of the vertical speeds and altitudes of aircraft, and the subsequent computation of whether the difference between aircraft altitudes at the time of the position overlap on the lateral plane are below a minimum separation (Stankovic, Loft, Rantanen, & Ponomarenko, in press; Xu & Rantanen, 2003). Several theoretical accounts of how controllers detect conflicts have been published (Loft, Bolland, Humphreys & Neal, 2009; Rantanen & Nunes, 2005; Stankovic, Raufaste, & Averty, 2008).

In empirical studies of conflict detection, researchers have typically either asked controllers to assess the risk of conflict between aircraft or to estimate the likelihood that they would intervene on a given aircraft pair to assure separation, but there has been little consideration of whether these two types of judgment are tapping into the similar decision process or not.Bisseret (1981) made a distinction between those two cognitive processes thirty years ago. In his study on decision making made by ATCos, he reported several studies that investigated conflict detection made by expert ATCos and trainees. In this study, Bisseret distinguished the information processing (risk of loss of separation) from the decision (intervention) process. Bisseret showed that trainees made more accurate separation estimations than expert controllers. This particular result has been explained by the safety margins that experienced controllers apply. Bisseret further hypothesized that experienced controllers are more concerned about succeeding in their overall control task (which also includes orderly and expeditious flow of traffic) than in the accuracy of their conflict risk assessments. On the basis of this hypothesis, Bisseret suggested that experienced controllers' operating decision process should not be entirely based upon their diagnosis of the air traffic situation. In an earlier study Bouju (1978) had asked experienced controllers to make a diagnosis (conflict or not) for twelve (six conflict and six non-conflit) air traffic situations, and to express their intention for intervention (action or not) for the same situations. Results showed that controllers decided to take actions in nine situations diagnosed as non-conflict, lending support to Bisseret's hypothesis that conflict risk judgments and decisions to intervene are separable.

Stankovic, Neal and Hasenbosch (2010) proposed in a recent study a model of separation assurance that described five, instead of three, main cognitive processes: (1) information gathering (selection of information), (2) trajectory anticipation (risk judgments of loss of separation), (3) intervention (decision making about future intervention), (4) solution choice (selection of conflict solution strategy), and (5) planning (resolution course of actions). These separation assurance processes are influenced by changes in ATCos' environment and their strategies. This study showed the importance of consider all separation assurance processes and their interactions when studying conflict detection, and in doing so makes a distinction between the *conflict risk process* (which corresponds to trajectories anticipation in their model) and the *intervention process.* Conflict risk consists of a judgment ATCos make about the loss of separation between aircraft, whereas intervention requires ATCos to decide whether to intervene or not on a particular pair of aircraft. Recent studies have reported quite different results using the two questioning methods (risk versus intervention).

Judgment of Conflict Risk

Several experimental studies have asked the participants to judge the risk of conflict between two or more aircraft. Bisseret (1981) did so when he investigated controllers' diagnosis process. More recently, Stankovic et al. (2008) used this method and three specific variables to predict controller judgment of conflict risk, (1) the distance between the crossing point of the aircraft pair trajectories and the closest aircraft to that point, (2) the distance between the two aircraft when they are laterally closest, and (3) the lateral distance between the two aircraft when their growing vertical distance reached 1,000 feet. These variables accounted for up to 50% of the variance in conflict judgments made by expert controllers. Stankovic et al. asked expert ATCos to judge the risk of conflict between two aircraft using an 8-pt scale (from "assured airprox" to "no conflict"). Large individual differences in controllers' judgments were evident. One group of controllers seemed to be more influenced by a distance that takes into account vertical separation between aircraft (the lateral distance between the two aircraft when their growing vertical distance reaches 1,000 feet) when judging the risk of conflict between aircraft than the other group of controllers.

In a recent study, Stankovic, Loft, Rantanen and Ponomarenko (in press) also reported individual differences in the effect of vertical separation on conflict risk judgments. In this study, we asked fourteen expert controllers to judge the risk of conflict between aircraft for situation were four variables (environmental cues) were manipulated, (1) lateral conflict geometry, (2) vertical separation between aircraft, (3), time to lateral separation threshold (3 nm), and (4) groundspeed difference between the aircraft. The question used to collect conflict risk judgment was the same used in the Stankovic, et al. (2008) study, but the scale was different (a 12-pt scale, from "no risk of conflict" to "extreme risk of conflict"). Results showed that an important effect of vertical separation between aircraft on controllers' judgments of conflict risk. Overall, the conflict risk judgments increased as the vertical separation decreased. Most importantly, we found individual differences in the effect of the vertical separation on conflict risk judgments. One group of controllers (group 1, $N = 7$) made lower conflict risk ratings than the other group of controllers (group 2, $N = 7$), and the effect of vertical separation on conflict risk judgment was greater for controllers in group 1 than for the controllers of group 2. Controllers in group1were more experienced (i.e., total experience, sector specific experience, older) than controllers in group 2, indicating that experienced controllers were less conservative and took vertical separation more into consideration than their less experienced counterparts.

Decisions of Intervention

Another experimental task consists in asking participant about their intention to intervene in a situation to assure separation between aircraft. This was one of the methods used by Bouju (1978). More recently, Loft et al. (2009) used this method for their study on conflict detection. Like Bisseret (1981), Loft et al. proposed that controllers use 'safety margins' to assure separation between aircraft. These safety margins reflect expectations regarding likely variation in aircraft trajectory, and also the degree to which controllers are biased to favor safety over accuracy. Depending on the magnitude of safety margins, controller predictions of aircraft position at specific points in the future will be some distance closer or further (or higher or lower in the vertical plane) than the positions predicted by aircraft state values. To test their the theory, Loft et al. (2009) presented to their participants pairs of aircraft and asked them to provide intervention judgments on a four point scale. A two-parameter computational model that emulated how controllers approximate aircraft trajectory closely predicted the conflict risk judgments made by controllers. A key finding reported by Loft et al. (2009) was that there was no variability in risk judgment as a function of the vertical separation between aircraft. Instead, risk judgment only varied with changes in aircraft lateral separation. To account for these data, the Loft et al. (2009) model was simplified to assume that controllers always consider aircraft pairs to be in vertical conflict when aircraft are descending or climbing through the levels of other aircraft. Loft et al. argued that controllers prefer to intervene to assure aircraft separation when aircraft are climbing through the levels of other aircraft in order to manage their own workload (Loft, Sanderson, Neal & Mooij, 2007), and thus that their computational model should indeed be able to predict risk judgments without the setting of a vertical separation safety margin parameter. This result contradicts the effect of vertical separation on conflict detection reported by Stankovic et al. (in press).

Once ATCos have detected a conflict risk between two aircraft, then they will intervene by instructing one of the aircraft to maneuver to avoid the conflict (Stankovic, Neal & Hasenbosch, 2010). This risk-intervention process has been rarely investigated as a unified process except by Bisseret (1981). Researchers have used risk judgment to examine conflict detection or conflict resolution, but to our knowledge only Bisseret's study examined cognitive processes involved in intervention decision. Despite the close relationship between judgment about the risk of conflict and intervention decision, it is worthwhile to specify the cognitive processes involved in each operation. This question is particularly urgent as new conflict detection tools that automate the conflict detection process are to be implemented in the air traffic management (ATM) systems worldwide (for a review see:Neal, Flach, Mooij, Lehman, Stankovic et al., 2011). Moreover, as showed by Bisseret (1981) intervention actions may occur even if a situation is diagnosed as non-conflict (cf. Loft et al., 2009).

Some studies on conflict resolution, however, have focused on the type of intervention actions that are applied by ATCos, once they have decided to intervene on a particular aircraft. For instance, Leroux (1999) defined three different policies that controllers apply when resolving conflicts according to task load level: (1) "be elegant first", (2) "be efficient first", and (3) "be safe and nothing more". A good description of how ATCos adapt their control strategies to anticipated workload and task demands is also provided in Loft et al. (2007).

Recent studies have reported quite different results using the different experimental tasks (judging the risk of conflict or the likelihood of intervention). For example, Loft, et al. (2009) claimed that there was no variability in risk judgment as a function of the vertical separation between aircraft, whereas Stankovic et al. (in press) reported an effect of vertical separation on conflict risk judgments made by expert controllers. The latter showed that controllers' judgments of conflict risk increased as vertical separation decreased for the half of the participants. In the same study and in addition to the risk of conflict judgments, Stankovic et al. asked fourteen licensed air traffic controllers (12 men and 2 women) to judge the likelihood by which they will intervene to assure separation between aircraft. Three questions were asked about three other judgments relating to strategies used to ensure separation, (1) will you intervene by assigning a new level to the descending aircraft? (2) will you intervene by assigning a new route to the descending aircraft, or (3) will you intervene by assigning both a new level and a new route to the descending aircraft. These data on intervention judgments have not been reported before.

First, we compared the three types of intervention (level, heading or both level and heading) to each other and we found a preference for the level solution compared to the heading solution ($t(1,13) = 3.11$, $p = .002$) and to the both level and heading solution ($t(1,13) = 3.23$, $p = .001$). This result is not surprising since in approach control controllers sequence aircraft for landing and takeoff by using mainly level solution. For this reason we decided to put together all intervention judgments (level, heading and both level and heading) by keeping the higher scores among all intervention judgments. We obtained thus just one intervention judgment variable. We used the *Tukey* for Post hoc tests and the values for small, medium and large effect sizes of.10, .25 and .40 respectively (Cohen, 1988). One important result was the significant difference between judgments of conflict risk and intervention judgments, $t(1,13) = 2.85$, $p = .004$. Post hoc tests showed that controllers made higher intervention judgments ($M = 9.27$, $SD = .68$) than conflict of risk judgments ($M = 7.30$, $SD = .53$). This result confirmed Bisseret (1981) hypothesis, expert controllers intervene on pair of aircraft that have been diagnosed not to be in conflict. We also found an effect of vertical separation on intervention judgments for the Same heading scenarios, $F(2, 26) = 5.41$, $p = .011$, $\eta_p^2 = 0.29$; for Opposite heading scenarios, $F(2, 26) = 5.54$, $p = .010$, $\eta_p^2 = 0.30$; and for the Cross Heading scenarios, $F(2, 26) = 2.94$, $p = .071$, $\eta_p^2 = 0.18$. These patterns are similar to those found for risk of conflict judgments; however this effect of vertical separation on intervention judgments was less than the effect found for conflict risk judgments. Only four controllers were sensitive to vertical separation in making intervention assessments. This result showed that the effect of vertical separation is less important on intervention judgments than on conflict risk judgments. This is consistent with Loft et al. (2009) findings and may attest to the difficulty of vertical speed calculations or estimations in conflict situations.

Discussion

There are empirical results that support the need for distinguishing between judgments of conflict risk and intervention decisions. First, we reported at least two recent studies on conflict detection that presented results in contradiction but that also confirm our hypothesis about of two sub-processes in ATC conflict detection and avoidance. Loft et al. (2009) showed that conflict detection (intervention decisions) was not affected by variation in vertical separation between aircraft. Hence, Loft et al. concluded that the controllers' made no calculations about vertical distance between aircraft but rather applied safety margins for detecting conflicts. On the other hand, Stankovic et al. (in press) showed that experienced controllers made calculations of vertical separation for judging the risk of conflict between aircraft. These two different results are, however, in line with Bisseret's (1981) conclusions. Conflict detection implies a conflict risk process which consists of assessment of the future separation between aircraft mainly based on calculations, or at least more than the intervention decision process which is mainly based on the conflict risk assessment.

Moreover, the comparison of results reported on conflict risk judgments reported in Stankovic et al. (in press) with the results on intervention decisions reported above also confirm the existence of two conflict detection sub-processes. Hence, results on conflict risk judgments showed that controllers took into account vertical separation between aircraft to judge the risk of conflict between aircraft. Results on intervention judgments showed also an effect of vertical separation on controller's intervention ratings; however this effect was reported for only 4 controllers. Controllers also made higher intervention judgments than conflict risk judgments for the same situation. Latter result shows that controllers made their intervention decision based on conflict risk assessment, but it also shows that controllers are more cautious when deciding to intervene than when assessing the risk of conflict between aircraft.

In conclusion, the empirical results reported above confirm Bisseret's conclusions that controllers are more interested in overall control task than in accuracy of individual conflict risk judgments, and that experienced controllers' operative decision process are not be entirely based upon his diagnosis (conflict risk judgment) of the situation but it is also include the application of safety margins such as Loft et al. (2009) showed. Conflict detection process implies two sub-processes: (1) a conflict risk judgment process and, (2) an intervention decision process.

Conclusion

This research highlighted the differences between cognitive processes involved in intervention and those involved in conflict detection. Controllers make more calculations in estimating the risk of conflict between aircraft than for deciding to intervene in a given situation. As for conflict detection, it seems that intervention operation is affected by vertical separation between aircraft, thus conflict detection tools which displays pair of aircraft in conflict and which suggest intervention solution should integrate such differences. This particular result on differences between conflict detection and intervention processes should be considered for the account of the reason why ATCos very often do not trust conflict detection tools when completing conflict resolution task.

It may also be argued that conflict avoidance, that is, decisions to intervene in potential conflicts early on, without careful assessment of the actual conflict risk is part of strategic ATC and an effective means to manage workload and maintain an accurate picture of the traffic situation. Accurate conflict risk assessment requires considerable amounts of cognitive (especially attentional) resources that ATCos working busy traffic can ill afford to trade off against strategic advantages. That experienced controllers exhibit such traits supports this hypothesis.

The aim of this paper was to clarify the conflict detection process rather than claiming that one method (conflict risk versus intervention question) is better than another. On the contrary, what it is claimed here is that both conflict risk judgments and intervention decisions should be considered when studying the conflict detection processes. For the design of future experimental protocols, distinguishing conflict risk judgments and intervention decisions is crucial since this clarification should guide researchers for choosing an appropriate method (question about the risk of conflict or about intervention) for the particular research questions they investigate. Understanding how expert controllers make conflict detection decisions in air traffic control is also crucial for the design and the evaluation of the future Air Traffic Management (ATM) systems (Stankovic, Neal & Hasenbosch, 2010). In particular, when conflict detection tools envisaged in the future ATM systems allocate conflict risk assessments to an automated system and as a consequence separate conflict risk judgments from intervention decision.

References

Bisseret, A. (1981). Application of Signal Detection Theory to Decision Making in Supervisory Control: the effect of the Operator's Experience. *Ergonomics, 24*, 81-94.

Boag, C., Neal, A., Loft, S., & Halford, G. (2006). An analysis of relational complexity in an air traffic control conflict detection task. *Ergonomics,* 14, 1508-1526.

Bouju, F. (1978). Analyse *de la prévision de séparation entre deux avions évolutifs convergents* [Analysis of the separation forecast between two converging aircraft] (No. C.O.7802-R54). Toulouse, France: Centre d'Etudes de la Navigation Aérienne.

Leroux, M. (2000). *Cognitive aspects and automation.* In N. B. Sarter & R. Amalberti (Eds.), Cognitive engineering in the aviation domain. (pp. 99-130). Mahwah, NJ: Lawrence Erlbaum Associates.

Loft, S., Bolland, S., Humphreys, M. S., & Neal, A. (2009). A theory and model of conflict detection in air traffic control: Incorporating environmental constraints. *Journal of Experimental Psychology: Applied, 15,* 106-124.

Loft, S., Neal., A., & Humphreys, M. S. (2007). The development of a general associative learning account of skill acquisition in a relative arrival-time judgment task. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 938-959.

Nunes, A., & Mogford, R. H. (2003). Indentifying controller strategies that support the 'picture'. Paper presented at the *47th Annual Meeting of the Human Factors and Ergonomics Society*, santa Monica, CA.

Neal, A & Kwantes, P. (2009). A random walk model of conflict detection performance in a simulated air traffic control task. *Human Factors, 51*, 164-180.

Niessen, C., Eyferth, K. and Bierwagen, T. (1999). Modelling cognitive processes of experienced air traffic controllers. Ergonomics, 42, 1507-1520.

Rantanen, E. M., & Nunes, A. (2005). Hierarchical conflict detection in air traffic control. *International Journal of Aviation Psychology, 15*, 339-362. doi: 10.1207/s15327108ijap1504_3.

Remington, R. W., Johnston, J. C., Ruthruff, E., Gold, M., & Romera, M. (2000). Visual search in complex displays: Factors affecting conflict detection by air traffic controllers. *Human Factors*, 42, 349-366.

Stankovic, S., Loft, S., Rantanen., E. M., & Ponomarenko, N., (in press). Individual differences in the effect of vertical separation on conflict detection in air traffic control. *International Journal of Aviation Psychology.*

Stankovic, S., Neal, A., & Hasenbosch (2010). A separation assurance model for automation design and evaluation. Paper presented at *HCI-Aero 2010*, 3-5 november, Cape Canaveral, FL.

Stankovic, S., Raufaste, E., & Averty, P. (2008). Determinants of Conflict Detection: A Model of risk judgments in air traffic control. *Human Factors*, 50, 121-134.

StatSoft (2005). *Statistica (Version 7.1)*. Maisons-Alfort, France: Author. (www.statsoft.fr)