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Modelling Human Reliability in Air Traffic Management

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Abstract

This paper outlines how the human information processing model of Wickens is combined with Hollnagel's cognitive control mode model and human error models for application within the context of conventional Air Traffic Management (ATM). The aim of this model-based approach is to enable the evaluation of both accident risk and aspects like cognitive workload and reliability of the human controller in managing air traffic situations safely. The combined model has been integrated with models for pilot, aircraft and other ATM elements and a comparison with available statistical data is made through running Monte Carlo simulations with the integrated model.

Keywords: Human reliability, Methodology, Aerospace Transportation

1. Introduction

Since air traffic is steadily growing, there are populated areas in the US and in Europe where the air traffic demand is higher than the capacity that can be realised with established operations. In order to resolve this situation, it is necessary to introduce new effective operations in Air Traffic Management (ATM). The high safety standards in civil aviation in combination with the complexity of ATM make it far from trivial to foresee the consequences of introducing new operations with respect to safety. By the very nature of civil aviation, the ATM architecture is highly distributed: there are human controllers in each aircraft, at each airport, and also in each node of the global network of ground based air traffic service centers. Statistical analysis is not very helpful here; it is not even sufficient to analyze safety of present operations in ATM, let alone to predict future operations. Since pilots and air traffic controllers currently play a key role in realising the high safety standards in civil aviation, special attention must be directed to the modelling of their cognitive performance in ATM operations and the relation with safe separation.

The aim of this paper is to outline how such modelling has been accomplished in [1] on the basis of the following three psychological models:

- Human error models that are in use for aviation incident and accident investigations (e.g. [2], [3]).
- Multiple resources theory [4] which is in use for human centered designs in aviation [5].
- Control modes of human cognition [6], which assumes that human controllers strategy and degree of control varies significantly over time.

The paper outlines how these approaches are combined into a single model for a tactical controller in a conventional en-route ATM context. First, a suitable decomposition into controller subtasks is outlined in Section 2. Next, Section 3 shows how this is combined with the cognitive control mode model. Section 4 compares some Monte Carlo simulation results obtained with the new model with realistic data. Section 5 draws conclusions.

2. Controller subtasks

The conventional ATM scenario considered is an en-route ATM sector containing 15 aircraft. The responsibility of the air traffic controller is to give timely instructions to the pilots on the basis of conventional surveillance, communication and automation systems. The tasks of the tactical air traffic controller are now subdivided along two dimensions: 1) generic cognitive activities and 2) scenario specific tasks. For the scenario specific task division we focus on safety critical actions in conventional en-route ATM. This leads to the identification of the following three scenario specific tasks:

A. Anticipate for aircraft deviating from intentions.

B. React to Automation alerts.

C. Perform other control activities.

For the division into generic cognitive activities we follow [7]. This leads to ten generic cognitive activities. We next identified the scenario relevant task overlap *across* the dimensions in the table below.

Table 1: Relevant subtask overlap for the en-route ATM scenario.

	Generic cognitive activity	Scenario specific subtask A. Anticipate	B. Alerts	C. Others
1	Sensing	A1		C1
2	Integration	A2		C2
3	Prediction	A3		C3
4	Communication			C4
5	Problem solving /planning	A5	B5	C5
6	Executive action	A6	B6	C6
7	Rule monitoring	A7	B7	C7
8	Coordination			C8
9	Overall performance			C9
10	Maintenance			

Next, a scheduling strategy for the relevant subtasks has been identified with support from available ATM expertise on the aspects of **pre-emption** between other subtasks and **concurrent execution** of two subtasks taking into account the principles of [4]. The resulting model allows a flexible approach: one can restrict to giving details relevant for the problem at hand along the scenario specific dimension, while the generic cognitive activities appropriately models the variety in cognitive requirements placed on the controller.

3. Opportunistic and tactical control modes

In [6] a human reliability modelling approach has been introduced that aims to bring into account that humans operate in various cognitive control strategies, while the variation in these strategies is largely governed by the amount of subjectively available time and the outcome of the previous action in terms of success and failure. To illustrate the possible range of control strategies [6] proposes four typical control modes:

- Scrambled control mode.
- Opportunistic control mode.
- Tactical control mode.
- Strategic control mode.

Since [6] describes this control mode model in general terms only, the specific details for the en-route ATM scenario considered had to be identified on the basis of domain expertise. In doing so it appeared that air traffic controllers easily recognized the switching control mode model to be a good representation of their performance, and that the context specific knowledge for the different control modes was readily available with human factors specialists in ATM. Based on this information, we specified the detailed influence of the tactical and opportunistic control modes on the performance. See the next table for subtasks A6 and A7. For the other subtasks similar specifications are obtained [1]. It also appeared that the strategic control mode was relevant only in non-critical situations, while the scrambled control mode would not occur due to the fact that traffic flow is regulated such that the maximal number of aircraft in each sector is kept below a certain upper bound.

Table 2: Control mode characteristics of subtasks A6 and A7.

Sub task	Control mode	Characterisation	Mean period
A6	*Tactical*	The controller gives a series of R/T instructions to the aircraft involved. He verifies whether the pilot(s) readback these instructions correctly.	5 s
	Opportunistic	The verification of correct readback may be omitted.	2.5 s
A7	*Tactical*	After the R/T communication the controller verifies whether the aircraft comply to his clearances.	30 s
	Opportunistic	This may be omitted or be performed less thoroughly.	15 s

Next we identified that ATCo related errors may occur at random during performance of subtask A6 where the frequency of occurrence depends on the control mode the controller is in. Furthermore, such errors may be detected and corrected during rule monitoring subtask A7, also depending on the control mode (e.g. [3]). Following this approach, the net clearance error frequency is assumed to be 10 times higher when the controller is in opportunistic control mode rather then in tactical control mode.

4. Example ATM application

We evaluated for an ATCo routine monitoring concept the period to detect severe deviations of aircraft from contoller expectation such that a comparison with available statistical data is possible [8]. To do so, the ATCo performance model has been integrated with appropriate models for the other relevant components in conventional ATM for the specific ATM example. For details on this integration we refer to [1]. Figure 1 compares the detection time results of the ATCo model (drawn line) with the statistical data results (dashed line). This comparison clearly contributes to gaining confidence in the model-based approach taken.

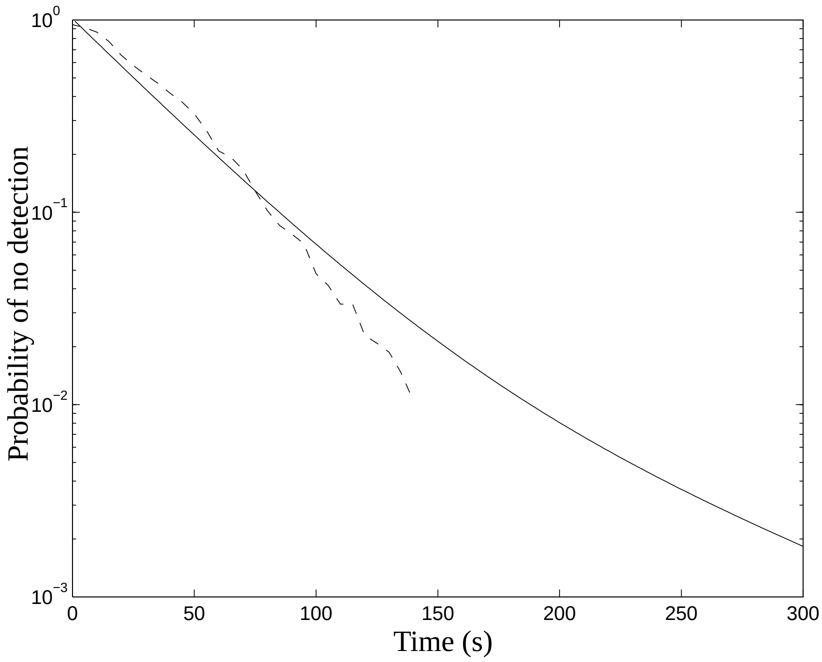

Figure 1: ATCo detection time of severe deviations of model (—) and data (---).

5. Concluding remarks

Within the context of a conventional ATM scenario, this paper described the development of a cognitive reliability model for a tactical en-route controller by combining Hollnagel's control mode model with Multiple Resources theory and human error models. In [1] this cognitive reliability model is integrated with all other elements in the ATM scenario considered and is subsequently used to perform accident risk assessment for ATM following the approach of [9].

During the collection of the scenario specific model details it appeared that air traffic controllers easily recognized the switching control mode model to form a good representation of their performance, and that the context specific knowledge for the different control modes was readily available with human factors specialists in ATM. Subsequently it has been shown that Monte Carlo simulation results of the model agree quite well with the statistical data in [8].

Follow-up work on Hollnagel's control mode based cognitive reliability modelling of human performance in ATM is directed to further model validation, to enhance the developed modelling approach with other psychological models, and further application to ATM safety assessment [10].

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