ICAS-96-3.9.1

INFORMATION PROCESSING STRATEGIES IN AIR TRAFFIC CONTROLLERS

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Abstract

The objective of this paper is twofold: a) identify knowledge and processes leading expert operators to divide their attention and focalize on the relevant information in a dynamic and informationally rich environment and b) observe this knowledge at work in an operational setting. We have investigated these questions in the domain of Air Traffic Control through the design of two studies. For the first study, operators were asked to verbalize their knowledge, and in the second they were asked to perform a memory task. Results show the presence of general heuristics that are used to simplify the search space and suggest that, for expert operators the unit of representation is a network of inter-related airplanes, rather than individual aircraft. Finally both studies emphasize the use of environmental information to develop time management strategies.

Introduction

We are interested in investigating the nature of the information filtering processes in the domain of Air Traffic Control. A central task faced by controllers is to select the data leading to the detection of potential future conflicts (i.e., lack of standard separation) and to the choice of the most effective solution. By "effective" we mean that the selected plan of actions has to simultaneously satisfy several, sometimes conflicting, constraints.

We shall present some elements concerning a model for selected attention in process control environments. It will follow a presentation of the two studies along with the obtained results and discussion.

The Taking and Filtering of information

The human perceptual system is of limited capacity, meaning that, at any given time, only a subset of the available information cross the perceptual threshold to be then possibly processed by higher level cognitive functions. This limitation known as the "bottleneck" implies that people have to develop filtering strategies to select what is relevant among the set of available information.

Variations of the visual search paradigm have been used to investigate the efficiency of selection or the conditions affecting the control of the filter. Typically, in these studies, subjects had to decide whether a target is present in a multi-element array (9) (17) (18) . Results showed that search time and accuracy depended on the similarity between the target and non-target elements. As the degree of similarity increased, performance accuracy decreased thus making it more difficult for the filter to focus only on the relevant information. An interpretation of these findings suggests that visual search, at its early stage, is guided by a match between the input element and some specified description of the information currently required. Such a description has been referred to as "attentional template" and its content is task-specific; the template specifies the features distinguishing targets from non-targets, allowing targets to receive the highest weights. Thus, the highest the match between the non-targets and the template, the hardest would be for the filter to reject them.

In the domain of dynamic process control like nuclear power plant, aviation, anesthesiology, such a model provides an account for how expert operators succeed in directing their attention at the relevant data. For example, in the domain of Air Traffic Control, often characterized by high time pressure, the observed reliable and timing detection of aircraft conflicts could be explained by the activation of templates specifying the characteristics that an airplane or a group of airplanes must possess to become interfering with a given reference aircraft. Two airplanes will be conflicting (or interfering) if any time during their trajectories, they are expected to loose their standard separations. The model would predict then that the difficulty in selecting the interfering aircraft is not so much linked to the number of airplanes present in the radar scope, but rather to the number of features shared by target (i.e. conflicting) and non-target aircraft. It follows that the degree of similarity between target and non-target would be a better predictor of workload or task difficulty than the absolute number of airplanes present on the radar scope.

Across different applied domains, a number of pervious works highlited the existence of a selected attention mechanism oriented towards some specified sources of information. Not all of the available data are processed by the operators. The filtering activity reflects the meaning assigned by the operator to the information selected at a given time (13)

De Keyser (8) claims that the perception and recognition of the useful data are accomplished by a cognitive filter allowing one to focus on the problem space relevant to the currently active operators' objectives. Two components defining such a filter are introduced: a statistical-inferential filter, oriented by probabilistic knowledge about the occurrence of future events, and a semantic filter related to the operator's objectives.

The fact that the search for relevant information is carried out in a dynamic environment should also be taken into account. To our knowledge, the temporal horizon characterizing the development of the activity has never been learned explicitly. The major difficulties to anticipate a system evolution in a near future as well as in a distant future, has been however emphasized by Mariné et al.(16) , and Boudes et al. (5). Their findings showed that the accuracy of estimation degraded as a function of the delay of the estimation interval.

On the other hand, some studies showed a variation of the temporal horizon learned by subjects under some specified conditions. Levels of expertise is positively correlated with the ability to stretch the spatio-temporal field, the experts being more successful than the novices (16) . The effects of expertise are also shown by Helbing (10) , in a longitudinal study involving air traffic control students. The tasks (prediction and recognition) concerned the estimation of future positions of aircraft at differing time horizons. Results showed a decrease rate of errors correlated to a higher level of learning.

Hollnagel (12) underlines an intra-individual variability in the representation of future and past time horizon as a function of control mode of the activity. The four control modes identified vary according to the whether past or future events are taken into account and as a function of the time horizon considered.

In another domain, Amalberti and Deblon (1) showed that high-tempo situations, such as flying combat aircraft, would affect the time horizon considered as it was reflected in the planning strategies adopted. In the case of an incident, the first objective would be to set the aircraft in a stable position. This being a short term objective, it would allow the pilot to gain some time for reasoning about long term goals. According to the authors, the choice to postpone a demanding activity constitutes an evidence to the pilot's ability to manage his/her cognitive resources, given the available time.

The objective of this paper is twofold: identify knowledge and processes leading expert operators to divide their attention and focalize on the relevant information in a dynamic and informationally rich environment; observe this knowledge at work in an operational environment. We have investigated these questions in the domain of Air Traffic Control which is characterized by data sets changing at a fast rate, thus requiring controllers to know where and what to look next.

Within the frame of an extensive project concerning the design of a decision support system for air traffic controllers (14), two studies have been carried out. The first aims at eliciting expert knowledge about strategies developed to identify interfering aircraft, and in the second study controllers were asked to carry out a (memory) recall task that would reveal the effect of focalizing attention only on a portion of the available data sets. The results of the first study provided a set of working hypothesis to explain controllers' performance in the second study.

Study 1: Eliciting expert knowledge

Methodology

Forty-four expert controllers from the five French Air Traffic Control Centers came to our laboratory. They were individually interviewed. They were presented with a simulated air traffic scenario that was different from Center to Center and representative of the type of traffic most commonly encountered in each Center. The simulation was already being played. Thus controllers were not involved in any control activity. The scenario was stopped at pre-determined times and for each time the interviewer had a list of aircraft designated as the "reference" aircraft. Each time the scenario was stopped (about 5 times), the controller was asked one by one, to focus on a reference aircraft and identify the conflicting airplanes, those that needed to be monitored and those that were to be taken into account for the choice of a solution to a conflict.

Each aircraft denoted by the controllers was filed by the system and later retrieved for analysis purposes. In addition, all of the interviews have been taped and transcribed.

Results and discussion

The analysis of the results is still underway and only some of the results will be discussed here. The obtained verbal protocols have been extensively analyzed to identify knowledge, such as heuristics and resources management strategies that would account for controllers' skills to effectively focus their attention on the relevant information.

Identification of general heuristics. The first observation is that controllers in the vast majority of cases, identified those conflicts occurring in the portion of the airspace (called "sector") under their control and sometimes those occurring in the adjacent sectors. The search for the conflicting airplanes was guided by the use of heuristics that directed controllers' attention to relevant portions of the airspace. In order to appreciate the nature of the elicited heuristics, it should be specified that, although different sources of information are available to controllers, two of them are the most frequently monitored and consulted, the radar scope and "paper strips" .

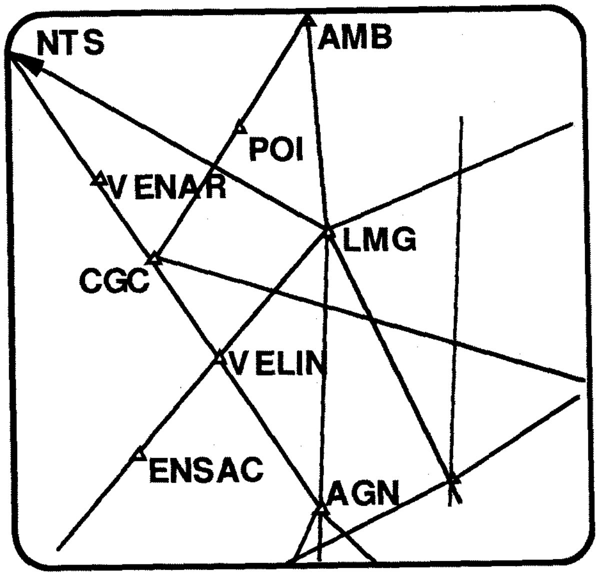

FIGURE 1 - Schematic map of a sector

Figure 1 shows a schematic map of a selected portion of the airspace on the radar scope, it size being determined by the scale chosen by the operator. Air routes are marked by lines that indicate the aircraft's standard trajectories. A range of possible flight levels and a sense (for example north-south) is assigned to each route. Routes do intersect and the locations of radio assistance throughout are used as spatio-temporal landmarks, for example an aircraft is supposed to turn 10 miles after crossing a given radio assistance. The other source of information, the "paper strip ", is a thin strip of paper containing the basic information about a single flight trajectory. Among other things, the cruising level and the time at which major beacons will be crossed is noted. In our simulated setting, people chose most of the time to obtain the required information through observing mostly the radar scope. Had they chosen to consult primarily the paper strips, we would have probably observed some slightly different organizing principles.

Controllers perceptually organize the traffic image into flow of traffic along the main axes represented by the air routes. These flows of traffic interfere with each other at some specified intersecting points where conflicts are then expected to occur. A given aircraft is then perceived as part of a flow of traffic, in which airplanes come from a common direction and continue on the same path for some time. With respect to an (or a group of) aircraft, a initial search of conflict means to look for airplanes coming from the interfering axes of traffic. An example of the use of such a "flow of traffic" heuristic is given by the following verbal protocol excerpt:

Example 1:
"[...] il sera à surveiller éventuellement par rapport aux avions qui vont descendre de LMG et de NTS. Pour le moment il n'y en pas (pas d'avions dans le flux Limoge-Nantes) [...]."
["It (the reference aircraft) has to be monitored possibly in relation to those airplanes coming from LMG et NTS. At the moment, there isn't any aircraft (in the axis Limoge-Nantes)"]

The role of such heuristic is to direct controllers' attention to specified portions of the entire search space (the radar image), i.e., to those areas where conflicts are most likely to be detected. However such heuristic alone would not suffice to establish the occurrence of a conflict, controllers have to judge whether two (groups of) aircraft coming from two intersecting airways will eventually flight in the same time range and the same flight level over the same crossing region. Thus another characteristics of the search for conflicts is that it is an iterative process. Specific contextual parameters, such as speed, destination, kind of engine, are verified after establishing that the aircraft is a likely candidate for becoming conflicting with the airplane of reference.

Another example of a general heuristic relied on the distinction between descending/climbing type of traffic versus stable en route traffic. This is not surprising as a climbing/descending aircraft is not as predictable as a "stable" en route airplane and it might intersect several flight levels and more than one axis of traffic. Due to a higher degree of uncertainty, a climbing/descending aircraft would imply controllers' attention on all of the airplanes that were either climbing or descending, sometimes irrespectively of other contextual flight parameters as shown by the following example:

Example 2:

"Je veux voir tout ce qui est évolutif [.....] non, celui-là ne gênera pas, parce que normalement il devrait être plus haut, mais il est en évolution dans le secteur [.....] "
["I want to see all the climbing/descending traffic, afterwards it might be said: no, that one won't be interfering, because usually, that one should be higher, although but it is climbing up while in the sector [...]"]

In this example, the controller was looking for airplanes conflicting with a reference climbing aircraft. He stated that initially all of the climbing/descending traffic should checked over ("I want to see all the climbing/descending traffic"). This first checking would establish that a given climbing aircraft normally will have reached a higher flight level when intersecting the route of the reference airplane ("usually, that one should be higher"). However, as it is a good "rule of the thumb" to monitor all of the climbing/descending traffic, one should not take for granted its usual rate of climbing ("but it is climbing up while in the sector").

The distinction between climbing/descending vs. en route type of traffic is what justify the formulation of the above rule. In the approach sector, where virtually all of the airplanes are descending, such a rule would be inapplicable.

The second example shows that controllers make use of regularities in the environment to anticipate future traffic developments. In this case, controller knew from previous experience what was the rate of climbing of the aircraft and used that knowledge to infer its flight level at a given time ("Usually, that one should be higher [...]"). This would correspond to the statistical-inferential filter hypothesis introduced by De Keyser(8) Our data showed, however, that people differed in the degree of reliability attributed to the likelihood of occurrence of events. Some controllers used this information to filter out certain aircraft as non-conflicting, while others kept open alternative less likely developments, thus focusing their attention on a larger number of aircraft. These findings can be accounted by the hypothesis that the process of assessing uncertainty is linked to subjective risk perception and cognitive resources management strategies. However these will not be further developed in this paper (for an initial elaboration of this hypotheses, see Amaldi (2) , Amaldi and Leroux(3)).

Examples 1 and 2 show that when looking at the radar scope, the controller has available heuristics about how to structure the radar image of the traffic and general rules about some characteristics of the traffic likely to be relevant for conflict detection. Note also that these heuristics have been shown to be in use both in light and heavy traffic situations, indicating that conflict detection is a principled search. These heuristics could be the content of "attentional templates" introduced in the previous paragraph. All of the airplanes that partly satisfy the description of an attentional template would receive some weight and then be likely to be checked over. Thus the hypothesis that conflict detection is a "principled search" has a twofold implication: first, the entire radar image is not exhaustively examined even when traffic is light, and secondly those airplanes that at a given time do not satisfy any of the activated attentional templates will not be considered and might go completely unnoticed.

Our data provide support to the first implication: even when faced with a light traffic scenario controllers never mentioned all of the present airplanes when asked to identify current conflicts. The claims of a principled search should not, however, be confused with the activity of continuously monitoring the overall traffic situation to verify that aircraft parameters are within the expected range. The second implication about neglecting certain airplanes need empirical support.

To summarize, conflict detection is a "principled search" guided by heuristics that direct controllers' attention to easily detectable features (i.e., climbing/descending) of the traffic and those portions of the space where conflicts are most likely to be detected. The process is iterative as the application of these heuristics generates a space that needs to be further refined through the use of contextual flight parameters and inferential knowledge about likelihood of future development. The treatment of uncertainty yields individual differences linked to how much people are willing to commit to a single development of the traffic or rather to consider a wider range of parameter values (resource management strategies).

Temporal information processing. Conflict detection is also subject to time pressure, some conflicts being more urgent than others. As resources are limited, an important aspect of filtering the relevant information is to decide when to direct one's attention to what(11) . Our data provide some evidence to the presence of time management strategies(6) .

When aircraft are still far from entering the sector, the number of uncertainties increase and anticipation will either be too unreliable or several alternative developments would have to be considered at the same time. To avoid a waste of memory space, controllers sometime refused to initiate a search detection simply because they felt that it was too early to try to predict the aircraft behavior. In an operational setting one would expect that some aircraft at a certain point in time even though visible on the radar image, would not be processed and thus would be unavailable for later recall.

When faced with a heavy traffic situation, controllers sometimes refused to focalize their attention on those conflicts that were going to concern the adjacent sector. In these cases our data show a fair agreement on the nature of the conflict, indicating that controllers were able to find the necessary information to solve the conflict, but they disagreed when they had to decide if they wanted to treat the problem or let other people do the job. The reason for the disagreement was basically linked to an assessment of the current workload: if controllers felt they were overloaded, they used time as a resource and postponed the solution of the conflict. Social knowledge is also involved concerning what people are expected to do in a cooperative environment. This aspect will not be further developed here.

To summarize, the analysis of the data carried out so far, indicate that controllers developed strategies to direct their attention where they were most likely to detect conflicts, and they used time as a resource to manage traffic overload. Given that people have limited attentional resources and time in dynamic situation is also limited, it is not surprising that expert operators have learned how to share their resources in the most cost-effective way. Our findings allow us to hypothesize three reasons to explain why controllers do not pay attention at anyone time to all of the airplanes visible on the radar image: 1) when aircraft does not satisfy any of the active attentional templates, 2) when it is still far from the sector and too many uncertainties surround its flight, and 3) when a currently diagnosed conflict is estimated to occur in a time range that allow the controller to chose whether to deal with it right away or to postpone its solution.

In the next study, we used a memory task to investigate how controllers applied their filtering strategies.

Study 2: Memory recall task

Methodology

The data analyzed come from a study concerning how people anticipate traffic development (for further information, see Boudes (4), and Boudes et al (5)). Sixteen expert operators managed a heavy simulated air traffic scenario. The simulation was unexpectedly stopped to allow people to carry out a number of tasks. One of them asked controllers to estimate future aircraft positions at different time horizons using a paper map of the sector and with no access to any traffic data. Operators were given a list of eight aircraft whose future position they had to project on the map. They could, if they wished, position additional airplanes. The presentation order of the aircraft changed to avoid presentation biases.

The call signs of the presented aircraft were the following: DIBAL, ITBY, MON1789, CYP455, DLH514, ACF5111, FBJMG, GBJMA.

We have identified the positioned aircraft and those who have been omitted as a function of two characteristics which are relevant to issues concerning how people select the airplanes to be focused on.

The first feature concerns the existing conflicting links. The first two aircraft of the list were involved in an on-going conflict at the time the simulation was stopped. The MON1789 is a constraining aircraft in the choice of a solution. CYP455, DLH514, ACF5111 are involved in future conflicts, and FBJMG, GBJMA are not conflicting with the rest of the traffic.

The second characteristic concerns the controller-pilot radio contact which is usually established shortly before the aircraft enter the sector, although the aircraft is visible on the radar image beforehand. When the simulation was interrupted the CYP455, DLH514 and the GBJMA were not yet in the frequency.

The current analysis focus on those aircraft that have been omitted and those that have been added (i.e., the "intrusive"), in order to highlight the outcome of the application of information filtering strategies. Roughly, the recall of conflicting aircraft means that during the management of the air traffic they fully satisfied the description of the currently active attentional templates, thus receiving full attention. We would expect that they would be accessible for recall right after the interruption. On the other hand, the omission of those aircraft that, at the time of the interruption, were not in the frequency or were involved in future conflicts, would be explained by the use of one of the time management strategies hypothesized : either the controllers felt they could not obtain the necessary information or they decided to postpone the solution of the conflict, given the high density traffic of the simulation.

Results

Results showed that some aircraft have not been positioned and 60% of those who have been were "intrusive" i.e., were not part of the original list.

Descriptive Analysis . The frequency of recalled aircraft varied. Concerning the aircraft from the original list, three of them were cited less than 30% of the cases. Those were the airplanes that were not yet in the radio frequency at the time of the interruption (CYP455, DLH514, GBJMA). Apparently, these aircraft are not accessible for recall, even though they were visible on the radar image. For the remaining aircraft from the original list the frequency of recall was over 60% and it got to 100% for the ACF5111.

Eleven aircraft have been spontaneously recalled by the controllers. Three of them had a very low frequency (less than 5%) due to a priming effect. This effect would cause the recall of aircraft whose call sign was similar to those from the original list. Three other aircraft have an even lower frequency (less than 2%). Thus, we do not consider the recall of these two groups of airplanes as the result of an application of any information filtering strategies. We will analyze the remaining 5 aircraft whose frequency of occurrence is higher than 7%. They are shown in figure 2 along with their rates of frequency.

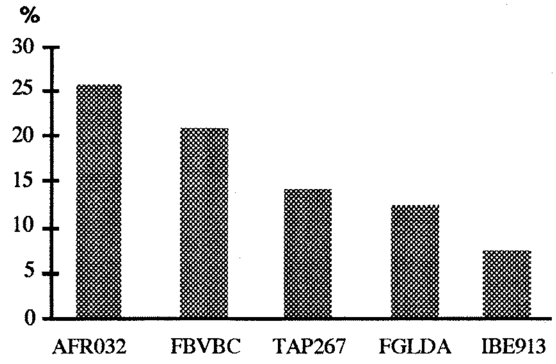

FIGURE 2 - Distribution of frequency of occurrence for the 5 most significant "intrusive" aircraft.

The differing frequency rates suggest that controllers distributed their attention over the aircraft according to different criteria. In the following we present some hypothesis concerning types of filtering that would produced the obtained results.

The types of filtering. A second analysis concerned the verbal protocols generated by the controllers while carrying out the task.

We have looked for reasons that would justify the positioning of the "intrusive" aircraft in order to emphasize the establishment of a link among certain airplanes. We were particularly interested to those links that relate the aircraft from the original list to the aircraft spontaneously recalled. Actually, controllers mentioned the existence of conflicting links between these two groups of aircraft. These links are clearly expressed in figure 3.

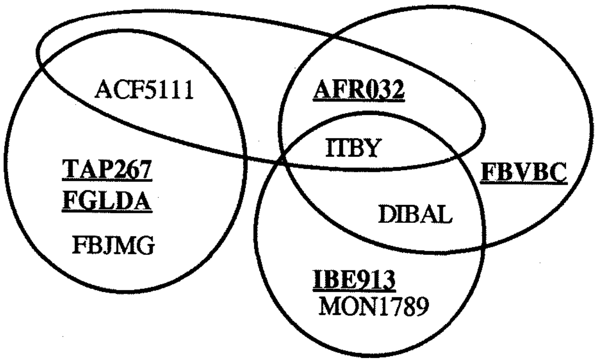

FIGURE 3 - Graphical representation of related groups of aircraft. Aircraft in bold and underlined are the 5 most frequently recalled "intrusive" and the remaining are from the original list.

Controllers expressed the existence of a link among two, three or four airplanes contained in the identified sets. Note that the aircraft from the original list represented in figure 3, are the most frequently recalled and were in the frequency at the time the simulation was interrupted.

This representation shows that the information has been clustered in terms of groups of aircraft. It appears that aircraft belonging to the same group cannot be separated to anticipate future traffic development. For example, the controller cannot consider the development of ITBY and DIBAL without taking into account the AFR032 and the FBVBC because of several potential interferences between these four aircraft. Grouping, however does not simply reflect the presence of a conflict but also the choice of a solution as it is the case for the spontaneous recall of the MON1789.

These results show that aircraft were not represented as individual points: rather the patterns of meaningful interactions among the airplanes were used by controllers to recall the positions. These results suggest that the "natural" unit of analysis for the controller seems to be an associative network where the entry points would be the aircraft and the links are ways in which airplanes interact with each other. The interaction considered are the outcome of strategies developed to focus on the relevant information. These conclusions confirm findings coming from studies investigating the organization of information in expert chess players, where memory was shown to organized around chess patterns rather than individual pieces positions (7) .

The identified links need to be integrated with the notion of time management strategies. In fact some aircraft involved in future conflicts or in conflicts that were almost over, were not recalled. As we discussed early on, these results show that in demanding situations, controllers decided to postpone the resolution of those conflicts that were not urgent. It is not surprising then that those airplanes were not accessible for later recall, even though available on the radar image. The findings that on-going conflicts were not recalled suggest the presence of a dynamic updating strategy which eliminates the information that is not longer relevant. Although this hypothesis needs further evidence, analysis of controllers' projections of future aircraft position provide additional support (4) (5).

Conclusion

The results coming from the two studies show that operators have learned how to use cues in the environment to develop strategies that would guide them to focalize on the relevant traffic data. In particular, findings from Study 2 showed that controllers in heavy traffic situation, did not recall those aircraft belonging to "tasks which can wait". Such is the case for the monitoring of those aircraft which are not yet in the sector, or for solving future conflicts. Postponing task accomplishment reflect the adoption by the operators of dynamic cognitive resource management. Postponing tasks allow operators to focalize their attention on a subset of the available data, neglecting everything else. Within this framework, accurate judging of the delay available is crucial as much as adjusting their cognitive resources to time management.

The nature of dynamic resource management strategies is also discussed by Leroux (15) in the domain of air traffic control. He claims that the choice of a solution to a conflict relies on an assessment of the situation, the working context, and the resources available. As a result of this complex evaluation process, controllers sometimes choose a plan that satisfy the safety of the aircraft but sacrifices other secondary objectives. Given the many criteria intervening in the decision of when and which problem to attend, the design of a decision support system (14) include a function that assist controllers in focusing on the relevant information at any chosen time.

In terms of designing concepts related to this function, our studies on cognitive strategies for filtering the information appear to be rather relevant in as much as they showed the need to assist the operators to simplify and reduce the problem space. This simplification implies that the entire air traffic situation is decomposed into sub-problems which can be dealt in a rather independent fashion. Within each sub-problems a filtering process that takes into account all of the discussed dimensions, should assist the operators to define the optimal solutions. Finally, the links existing among the sub problems, require a smooth transition from one sub problem to another one, and from each sub-problem to the entire traffic situation.

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