

IDENTIFYING CONTROLLER STRATEGIES THAT SUPPORT THE 'PICTURE'

Ashley Nunes¹ & Richard H. Mogford²

¹ Aviation Human Factors Division
University of Illinois at Urbana Champaign
Savoy, IL

² NASA Ames Research Center
Moffett Field, CA

Air traffic controllers build up a comprehensive mental representation of the current traffic scenario, which is known as the 'picture.' This picture helps them ensure that aircraft are safely separated as they travel from one point to another in the airspace system. The maintenance of the picture is related to various strategies that controllers use to determine if a conflict exists between two aircraft. However, studies that deal with identifying such strategies are lacking. Therefore, the goal of this paper is to cohesively bring together the empirical literature that identifies these strategies and the instances in which they are used, to provide the reader with a basic set of strategies controllers use in conflict detection situations, and to discuss the application of such strategies in relation to controller training.

INTRODUCTION

The primary goal of the air traffic control (ATC) service is to provide for the safe, orderly and expeditious movement of traffic through the National Airspace System (NAS). The safe separation of aircraft involves all three spatial dimensions and time (Hopkin, 1995), and this separation is assured through the enforcement of minimum vertical and horizontal separation standards, established by the Federal Aviation Administration (FAA). Air traffic controllers maintain separation between aircraft by using a variety of tools such as the radar display and flight progress strips (FPS). Controllers rely on important cognitive resources to maintain separation between aircraft and manage traffic flow through a sector. These are an accurate mental model and up-to-date 'picture' of the ATC system.

The Mental Model of the Controller

Mental models embody stored long-term knowledge that can be called upon to direct problem-solving and interaction with the relevant system when needed (Dubois & Gaussin, 1993; Endsley, 2000b). Within the ATC context, an accurate and up-to-date mental model of system functioning is critical because it "provides a mechanism for guiding attention to relevant aspects of the situation, integrating information perceived to form an understanding of its meaning, and projecting future states of the system based on its current state and an understanding of its dynamics" (Endsley, 2000a). The works of Redding, Ryder, Seamster, Purcell, & Cannon (1991) suggest that the mental model acts as storage space for various strategies that controllers rely on to form and maintain what is known as the 'picture.'

The Picture

Using information from both external (radar screen and FPS) and internal (mental model) sources, controllers build a comprehensive mental representation of the current traffic scenario. This representation is commonly referred to as the picture (Whitfield & Jackson, 1982). "The controller's picture consists of all that is perceived and is meaningful, interpreted in the context of recalled events preceding the current situation, anticipated events predicted from the current situation, and the professional knowledge and experience used to maintain control over the air traffic through sanctioned rules, practices, procedures and instructions" (Hopkin, 1995). A controller works to constantly and consistently ensure that the picture is accurate and up-to-date, thereby making maintenance of the picture an active and continuing process. Hopkin (1995) provides the most succinct yet precise explanation for why the picture is so important. He states:

It (the picture) provides the basic understanding of the traffic scenario as a whole on which planning, scheduling, predicting, solving problems and making decisions depend, and also provides the basis for checking that instructions are being obeyed, that decisions are correct, and that plans reach fruition (Hopkin, 1995, p. 312).

An accurate picture of the air traffic situation is highly dependent on the underlying mental model and the strategies stored within it. A controller relies on these strategies to detect conflicts while maintaining the efficient flow of traffic through a sector of airspace. Sperandio (1978) first drew attention to the notion of such strategies, postulating that they

are used to moderate the levels of workload experienced by the controller, thereby ensuring that the picture is not lost. Since then however, little attention has been paid to the subject. This paper seeks to expand on the topic by bringing together empirical evidence from numerous studies that focus on the strategies used by controllers while maintaining the picture. Only those strategies relevant to conflict detection (CD) will be discussed as will their significance for research and development, and the training of controllers.

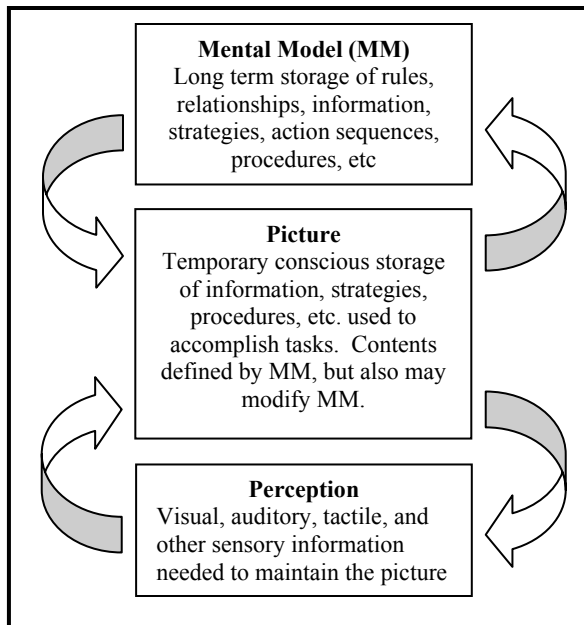


Figure 1

The following is a set of assumptions about strategies and their relationships to the mental model and picture (Figure 1):

1. Strategies are learned and stored in the mental model.
2. A controller retrieves a strategy by first recognizing a problem on the radar screen. This problem becomes a part of the current picture.
3. The correct strategy is accessed from the mental model. That is, the controller "recognizes" the problem, and the correct problem solving strategy is automatically accessed.
3. Once the strategy is in consciousness (the picture), it can direct perception and action to access specific sensory information. This, in turn, changes the picture.
4. Once the problem is solved, the strategy fades from the picture as other requirements emerge.

Strategies for Conflict Detection

CD can be initiated by one of two strategies: trajectory prediction (TP) or altitude comparison. The selection of a particular strategy to initiate CD (altitude comparison versus TP) depends we argue, on training, experience, preference, and the specific situation unfolding on the radar display. The controller either first checks whether two aircraft are on converging trajectories or if they are at similar or same altitudes. If either analysis indicates that a future loss of separation has occurred or will occur in the horizontal or

vertical dimension, a further strategy is applied to determine if separation will also be lost in the other dimension at roughly the same time. If this is the case, the controller concludes that a potential conflict exists (Figure 2). A critical component of making such an assessment is trajectory prediction.

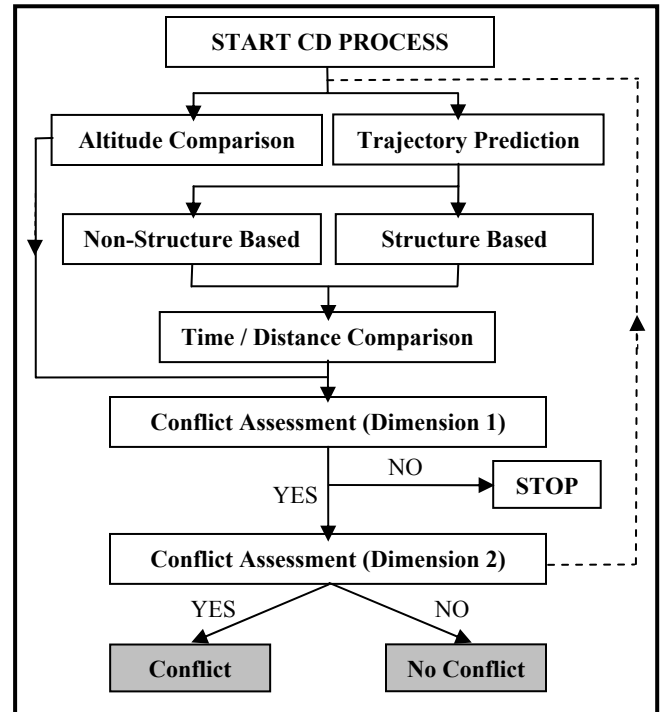


Figure 2

Trajectory Prediction. TP is an essential ATC task, given that a controller has to predict the future trajectory of one aircraft to determine if it is on a converging trajectory with another, which could result in a possible conflict. Indeed, prediction has been the focus of many studies in ATC (see e.g. Galster, Duley, Masalonis, & Parasuraman, 2001; Kimball, Hofmann, & Nossaman, 1973; Remington, Johnston, Ruthruff, Gold, & Romera, 2000) and loss of the picture has most commonly been associated with failure on the part of the controller to predict the future trajectory of an aircraft (Endsley, Mogford, Allendoerfer, & Stein, 1997). As the name implies, during this process, the current trajectory of an aircraft is mentally extrapolated to some future point on the basis of the present heading, speed, altitude, and location.

The ease of performing this task relies on whether the route structure in the NAS can be used to assist with the analysis. A controller watching a specific aircraft may determine where in space it will be by looking at the airways depicted on the radar screen. If the aircraft in question are following the airway structure, it simplifies the projection of the future state. Non-radar (or procedural) air traffic control assumes adherence to route structure in some environments to simplify TP. TP can however also be achieved, independent of this airway structure by ascertaining the relationships between the target aircraft and other traffic by projecting a trajectory vector ahead of the aircraft. Evidence of this was seen in a study by Nunes (2002) in which ATC trainees were

required to determine possible conflicts in a Free Flight (FF) environment. Subjects reported that rather than use TP (which was complicated by the absence of a fixed route structure and associated high working memory costs), they first determined which aircraft was of interest to them (for example, aircraft A in Step 1, Figure 3). Next they looked ahead on the radar screen to find another aircraft (aircraft B) that was traveling on relatively the same heading and ascertained the probability that the target aircraft would most likely occupy the same location at some point in the future. If the probability was high, the procedure could be repeated between aircraft B and an aircraft C (Step 2). By determining the spatial relationship between the target aircraft and other traffic, they were able to assess where the aircraft of interest (aircraft A) would most likely be in the future. The result (Step 3) is the ability to project the position of aircraft A well beyond its current location (to the star in Step 3). This is done mentally, or can be supported by tools on the radar display, but may be more workload intensive than if the aircraft are adhering to airways.

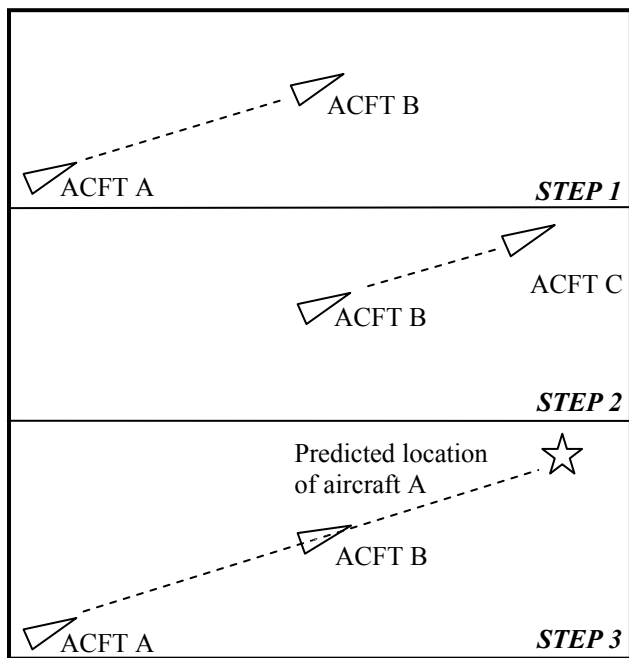


Figure 3

Regardless of the technique employed to achieve TP (i.e. with or without the use of airspace structure), if the controller concludes that the trajectories of the aircraft do overlap, he/she must then determine whether or not these aircraft will occupy the same region of airspace at the same time by either making time or distance comparisons.

Time Comparisons. Xu & Rantanen (2003) suggest that the process of CD may have a strong temporal component postulating that controllers make an initial determination whether two aircraft will reach an intersection point at different times. They called this process ‘relative judgment’ (RJ) (Law, Pelegrino, Mitchell, Fischer, McDonald & Hunt, 1993). If the aircraft are sufficiently separated in time, then no further prediction is required (assuming of course that the temporal separation conforms to the distance-based separation

standards established by the FAA). For example, if aircraft A and aircraft B in Figure 4 are separated by at least 10 minutes, then the probability of a conflict is zero. However, if the aircraft are predicted to arrive at the intersection point at the same time (or close to the same time), there may be a loss of horizontal separation. The presence and use of strategies that embody strong temporal components is also supported by Schaefer (2001) who postulates that controllers often use rules such as “the distance the aircraft will cover in one minute equals its ground speed divided by 60” or, less precise: an aircraft covers about five miles per minute” (Schaefer, 2001, p. 66). In such instances, the controller makes a TP by taking into account the aircraft’s speed (particularly when the aircraft in question are traveling at different speeds) to determine what time it will be there. It is important to note that the prediction of the time at which a single aircraft will be at a specified location is relatively effortless. However, when multiple aircraft move in three dimensions and vary in airspeed such that their predicted position at the future time uncertain, the controller’s processing capabilities may be stressed, thus limiting the accuracy with which the future states of traffic in the airspace can be visualized (Wickens, Mavor, & McGee, 1997).

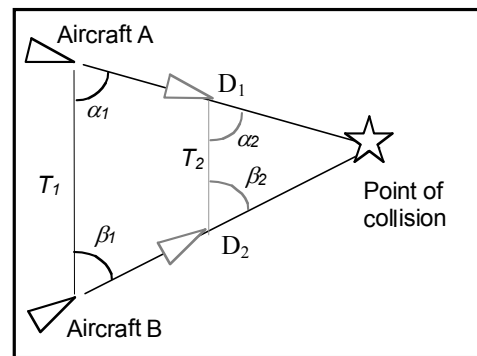


Figure 4

Distance Comparisons. The second form of the TP analysis assumes that both aircraft are traveling at the same speed towards the intersection point. In this case, the controller is not concerned with temporal considerations (given that the aircraft will travel the same distance in the same amount of time) but rather the absolute difference in distance of the two aircraft ($|D_1 - D_2|$) to this point. If this difference is greater than the separation minima, there is no conflict. If however, this difference is less than the separation minima, a conflict in the lateral dimension potentially exists. Therefore, the next logical step for the controller is to check the altitude of both aircraft to assess whether or not vertical separation exists (assuming of course that this was not already done at the onset of the CD process).

Altitude Comparison. Simple mental arithmetic can serve as the basis for initiating CD (or ascertaining vertical separation following TP that confirmed a conflict in the lateral dimension). The applicability of this technique would be particularly appropriate when a controller wishes to determine if two adjacent aircraft are vertically separated. Rather than use strategies that place greater demand on spatial working

memory (such as those listed above), a controller would determine the absolute difference in altitude between the two aircraft from data tag information. If the obtained result is greater than the prescribed separation minima, then safety is assured (assuming that the altitudes of both aircraft are constant). Use of this strategy first, however, could preclude the need for any further analysis or action by the controller and could be the initial step in CD, as opposed to starting with TP. Controllers from at least two previous studies alluded to using such a technique (Mogford, 1991; Nunes, 2002). The popularity of such a technique amongst controllers may also explain why recall of altitude in various studies is very good (Bierwagen, Eyferth, Helbing & Kolrep, 1994; Mogford, 1991; Nunes, 2002), the effect being attributed to the frequency of use of this information (Sperandio, 1978).

DISCUSSION

This goal of this paper is to provide the reader with some of the basic strategies, identified in previous studies, that controllers utilize during the CD task, which may not only be an aspect of the picture, but also a reason for the maintenance of the picture. The list of strategies provided here is by no means exhaustive and effort to isolate other strategies is an ongoing process and must continue. Such efforts however, must also be coupled with others aimed at classifying those specific situations in which such strategies are applicable and effective versus those situations in which they are not. The benefits of doing so can be best illustrated within the context of FF and environmental considerations (e.g. terminal operations).

FF proposes dissolution of the current route structure and some existing air traffic control procedures to increase efficiency in the NAS. It has been argued that doing so would reduce the ability of controllers to anticipate where the aircraft would most likely be in the future. However, the inability of controllers to anticipate potential conflicts in such a situation would be evident if the controller employed the use of a strategy that utilized route structure as a prerequisite for its basic functioning. Evidence of this has been seen in at least one previous study (Endsley et al, 1997). However, the use of a strategy for TP that does not rely on route structure as a prerequisite for its causal functioning would overcome this problem. For example, usage of the non-route structure based method would prove to be particularly effective under FF given that there is no reliance on predetermined airways but rather the number of aircraft that are present in the vicinity. It is worthwhile noting however that the cognitive costs of accomplishing TP in the absence of route structure may be high and only further studies of controller CD strategies will help define the best practices in a FF environment.

Another example of the benefits of strategy and situation classification is where aircraft operating within a region of space are required to make numerous speed changes. An example of this would be a terminal area where controllers have to make fine adjustments to aircraft speeds as they merge them into the final approach flow at the airport. In such

situations, the ability of the controller to ensure adequate separation is dependent on the execution of time comparisons, which require integration of the speed variable. However, it has been well documented that speed is the variable that is least well integrated into the controller's mental representation of the traffic situation (Sperandio, 1978), given the complex space-time calculations that are required and the high cognitive cost associated with such computations. These high cognitive costs could compromise a controller's ability to detect speed-based conflicts between aircraft in a timely manner. Moreover, by exhausting cognitive resources for speed-based CD, a controller may leave him/herself vulnerable to an unforeseeable set of circumstances that demand urgent action (Hopkin, 1995). A solution to this would be the execution of the altitude comparison strategy, which is based on comparing the absolute difference in altitude between pairs of aircraft. In such situations, the speed of the aircraft is secondary to whether or not their vertical profile is identical. Therefore by utilizing this strategy, a controller is able to arrive at a diagnosis of the current traffic situation at relatively low cognitive cost, enabling him/her to deal with other unexpected situations that may arise.

Therefore, through the two provided examples, we postulate that it is the appropriate application of a specified strategy to a particular situation that reduces the likelihood of overall task performance being compromised. Verifying this hypothesis is ultimately dependent on a) the comprehensive classification of the various types of strategies and situations and b) research on how and when controllers employ these strategies in various situations.

Strategy & Situation Classification

The information utilized in the execution of strategies pertaining to the safe and expeditious movement of traffic in the NAS has been well documented. For example, through in-depth interviews, researchers have found that controllers have subjectively reported using specific pieces of information as the basis for diagnosing the current traffic situation (Leplat & Bisseret, 1966; Bisseret, 1971; Sperandio, 1971). However, most of this work has fallen short of specifically asking the question: what are the various types of strategies used by controllers to employ this information and provide assistance in the CD process? In the present paper, we provide several strategies that have been reported by controllers, each of which has its own strengths and weaknesses. Also provided are specific situations in which the benefits and costs of using one strategy over another are clearly evident, in terms of both time and performance. We argue that efforts to classify controller strategies and the situations in which they are useful should continue, utilizing both subjective and objective means. This research holds many potential benefits for both air safety and increased throughput in the NAS.

Implications for Training

The identification and categorization of strategies and situations in which they are most applicable have clear

training implications and benefits. Unlike expert controllers that have the luxury of previous experience to assess strategy/situation compatibility, trainees must carefully formulate strategies to deal with the current traffic situation, thereby increasing their on-the-job training time. The incorporation of standardized strategies into the ATC training curricula may reduce the training time that novice controllers require, given that they have already been made aware of some of the strategies that have been used in the past to confront similar situations, strategies that have a high success rate and low cognitive cost. However, the strategies that work for one controller may clearly not work for another, highlighting the importance of considering individual differences amongst controllers (Hopkin, 1995). Therefore, it is important to ensure that curriculums aimed at making controllers aware of such strategies, also provide them with an adequate opportunity to assess which ones work best for them, through practice. The result of doing so will be a controller who is able to assess the traffic situation in a temporally and cognitively efficient manner.

CONCLUSION

The ability of the controller to ensure that aircraft are safely separated as they travel from one point to another is dependent on maintenance of the picture. Hopkin (1995) states that loss of the picture is worrisome given that the associated loss of meaning and understanding of what is perceived is usually accompanied by a strong subjective impression of temporary loss of control, a situation that is unacceptable. Therefore, every effort must be made to ensure that controllers are able to recognize situations and apply the appropriate CD strategy in those situations. It is only in doing so that the accuracy and integrity of the picture can be maintained.

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