World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:18, No:8, 2024

Unearthing Decisional Patterns of Air Traffic Control Officers from Simulator Data

Z. Zakaria, S. W. Lye, S. Endy

Open Science Index, Computer and Information Engineering Vol:18, No:8, 2024 publications.waset.org/10013775.pdf

***Abstract*—**Despite the continuous advancements in automated conflict resolution tools, there is still a low rate of adoption of automation from Air Traffic Control Officers (ATCOs). Trust or acceptance in these tools and conformance to the individual ATCO preferences in strategy execution for conflict resolution are two key factors that impact their use. This paper proposes a methodology to unearth and classify ATCO conflict resolution strategies from simulator data of trained and qualified ATCOs. The methodology involves the extraction of ATCO executive control actions and the establishment of a system of strategy resolution classification based on ATCO radar commands and prevailing flight parameters in deconflicting a pair of aircraft. Six main strategies used to handle various categories of conflict were identified and discussed. It was found that ATCOs were about twice more likely to choose only vertical maneuvers in conflict resolution compared to horizontal maneuvers or a combination of both vertical and horizontal maneuvers.

***Keywords*—**Air traffic control strategies, conflict resolution, simulator data, strategy classification system.

I. INTRODUCTION

THE development of automation in air traffic management (ATM) is contingent on understanding the intent of air traffic controllers (ATCOs) when dealing with conflict detection and resolution. Air traffic conflict detection and resolution are some of the most cognitive demanding functions for an ATCO. It consists of three subfunctions: Conflict situation assessment, action planning and control implementation [1]. Therefore, attempts have been made to implement automated conflict resolution to alleviate ATCOs workload and prevent overload of ATCOs in times of dense traffic flow [2]-[4]. Despite the continuous advancement in tools for automated conflict resolution, there is still a low adoption rate from ATCOs in the use of automation tools. Key issues of trust and acceptance by ATCOs and conformance to the individuals' preferences of strategic choice in resolving conflict remains unresolved [5], [6]. One approach that can ease and speed up the adoption of automation is to build more human-centric tools and solutions that can address conflicts at hand and yet conform to the existing culture and preferences of the ATCOs. This will involve understanding, identifying, and capturing the strategies used by ATCOs in conflict detection and resolution.

Research attempts were made to understand, identify, and establish mental models that an ATCO uses in conflict detection. One such study identified the strategies used by ATCOs in conflict detection and how such strategies were used to maintain their situational awareness [7]. Another concluded that ATCOs evaluate potential conflicts in a hierarchical manner, comparing altitude first for vertical separations, aircraft trajectories for horizontal separations and lastly comparing speeds to determine longitudinal separations [8]. In addition, studies were also carried out to understand and model ATCOs activities and strategies in conflict resolutions such as one proposed model of the cognitive activities in en-route control for both conflict detection and conflict resolution [9]. They noted that the mental processes of en-route controllers could not be reproduced accurately with a model using only rules or algorithms. In another study, it was found that ATCOs tend to deconflict using vertical maneuvers over horizontal maneuvers [10]. There is, however, still a lack of studies in deciphering detailed strategies of ATCOs and their related individual preferences or tendency in conflict resolution execution that takes place in upper air space, which is defined as airspace between FL290 to FL 410 for reduced vertical separation minima (RVSM) [11]. When ATCOs were interviewed or presented with a questionnaire, many struggled to substantiate their conflict resolution with strategy-based explanations. This is because such strategy-based reasoning of conflict resolution involves many dynamic factors is complex and difficult to conceptualize. ATCOs prefer to substantiate their actions in the context of the situations in the making of their decisions rather than in terms of their own strategies [9].

The ensuing study proposes a methodology to unearth strategies deployed by ATCOs in conflict resolutions using simulator data of trained and qualified ATCOs. A step-by-step guide on how to process simulator data to unearth ATCOs conflict resolution strategies will be presented along with a newly established classification system for ATCOs strategies. Finally, an evaluation of the choice of ATCO strategy of conflict resolution for certain conflict types would also be made.

II. METHODS

A. Data

Data were obtained and extracted from a study conducted in Nanyang Technological University using the Netherlands Aerospace Centre ATM Research Simulator (NARSIM) [12]. The dataset contained 231 conflicts that were managed by 11 trained and qualified ATCOs over a 60-minute simulator

Z. Zakaria and S.W. Lye are with the School of Mechanical and Aerospace Engineering, Nanyang Technological University (NTU), Singapore (e-mail: zain0004@ntu.edu.sg).

S. Endy is with the Air Traffic Management Research Institute (ATMRI), School of Mechanical and Aerospace Engineering, NTU.

session. All the 11 simulator sessions were based on the same scenario, which was realistically modelled after a Flight Information Region (FIR) in Singapore. The scenarios were designed so that a potential conflict between a pair of aircraft would occur at a particular waypoint in the upper airspace of sector six at a specific time. Therefore, the number of potential conflicts and the time and waypoint they occurred were known. These potential conflicts are referred to as convergences events in this study. To be specific, a convergence event is defined as an event where a pair of aircraft converged at a waypoint within 10 secs of the time of arrival of both aircraft. In this study, 231 convergence events were analyzed.

Each convergence is defined to begin at 17 minutes, that includes a buffer time of 5 minutes to allow for exceptions before the expected time of crossing between the two aircraft in the convergence events. This timing was chosen because another study had reported that most resolutions were realized 7 to 12 minutes before loss of separation occurred [9]. The expected crossing time can be retrieved from the aircraft's flight plan, which states the expected arrival time over the waypoint where the convergence point occurs. Additionally, four different categories were identified amongst all the convergence events.

The scope of this study was limited to analyzing convergence events that involve only two aircraft in each event as it is extremely rare to find convergence events that involve multiple aircraft [3]. In addition, data related to aircraft that were involved in multiple convergence events throughout each simulator session were not extracted for analysis. Furthermore, the speed of all aircraft remained unchanged in this study as it is not an area of interest in this study. It was assumed that ATCOs are unlikely to modify the speed of aircraft for deconflicting of aircraft. This assumption was supported by findings from literature that stated ATCOs avoided speed as a strategy for conflict resolution because of the higher mental workload required to predict and monitor possible conflict of aircraft as compared with using altitude or heading [13], [14].

B. Conflict Strategy Identification and Evaluation

This section proposes a five-phase methodology that seeks to unearth strategies from ATCO simulator data, as shown in Fig. 1. It is herein named as Conflict Strategy Identification and Evaluation (CSIE) methodology.

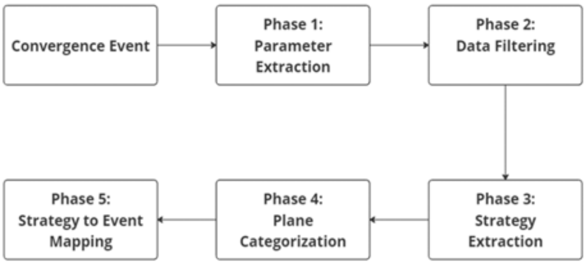
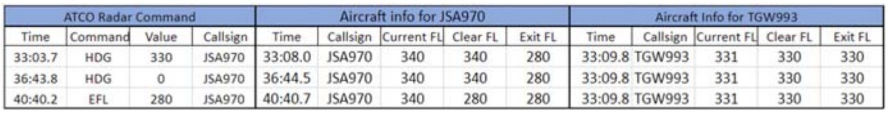


Fig. 1 Conflict Strategy Identification and Evaluation (CSIE)

In the first phase, parameters that were relevant to the analysis of the convergence events were extracted. The parameters are the timestamp of ATCOs radar command, type of maneuvers and altitude information of both aircraft. There are two categorical types of maneuvers, vertical or horizontal. Vertical maneuvers are executed by flight level change radar commands, while horizontal maneuvers are by heading change radar commands.

The extracted parameters are then combined to provide comprehensive background information for analysis on when the radar commands were issued. Firstly, ATCOs radar commands for either horizontal maneuvers or vertical maneuvers were noted along with their corresponding timestamps. Aircraft information closest to the timestamp of the radar commands are then extracted and combined. The timestamp of aircraft information would not match the timestamp of the radar command most of the time because aircraft information is updated every 9.8 seconds following the time it takes for one sweep of the radar. Fig. 2 shows how the relevant parameters from a convergence event involving JSA970 and TGW993 were combined with its relevant ATCO radar command to provide background information for analysis.



ATCO Radar Command				Aircraft info for JSA970					Aircraft Info for TGW993				
Time	Command	Value	Callsign	Time	Callsign	Current FL	Clear FL	Exit FL	Time	Callsign	Current FL	Clear FL	Exit FL
33:03.7	HDG	330	JSA970	33:08.0	JSA970	340	340	280	33:09.8	TGW993	331	330	330
36:43.8	HDG	0	JSA970	36:44.5	JSA970	340	340	280	33:09.8	TGW993	331	330	330
40:40.2	EFL	280	JSA970	40:40.7	JSA970	340	280	280	33:09.8	TGW993	331	330	330

Fig. 2 Combined radar command and aircraft position

In the second phase, convergence events that contained invalid data were removed from further analysis. The data are classified as invalid if the ATCOs actions in convergence events did not contribute to the deconflicting of a pair of aircraft in a particular convergence event or if there were no ATCO actions being recorded.

In the third phase, ATCO actions in the convergence events and the parameters extracted in Phase 1 are analyzed. An ATCO strategy classification system, represented by the flowchart in Fig. 3, was then applied to classify strategies that were used by ATCO. Yellow boxes represented the main ATCO strategies, while black boxes represented the sub-strategies.

The convergence events were initially sorted by the type of maneuvers chosen by ATCOs for deconflicting of aircraft. Based on the maneuvers issued by ATCO radar commands that were recorded in the simulator, it was observed that there were two different maneuvers. Hence, it was concluded that there were only three possible combinations. If only vertical maneuvers were used, the strategy used was labelled as LVL. On the other hand, if only horizontal maneuvers were used, it was labelled as HDG. If both horizontal and vertical maneuvers were used, it was labelled as HFL. Therefore, the three main strategies were LVL, HDG and HFL.

Out of the three main strategies, LVL and HFL strategies were further defined into sub-strategies according to the attributes observed in the actions of ATCOs in each convergence event. These attributes were represented by the magenta boxes in the flow chart, Fig. 3. HDG strategy was not broken down into sub-strategies due to the limited convergence events available in the data. For strategies that fall under LVL, there were three sub-strategies: LVL1, LVL2 and LVL3. Firstly, an ATCO strategy in deconflicting was classified as LVL1 if an ATCO issued the first radar command in a convergence event before the time of crossing of both aircraft, and the first clearance issued to either aircraft was a climb/descend clearance. Time of crossing is defined as the time both aircraft converge with one another at a specific waypoint in convergence events. Secondly, ATCO actions were classified as LVL2 if an ATCO issued the first radar command in a convergence event before the time of crossing of both aircraft, but the first clearance to either aircraft was not a climb/descend clearance to exit flight level. Thirdly, a strategy would be classified as LVL 3 if the first radar command issued by an ATCO in a convergence event took place after the time of crossing of both aircraft.

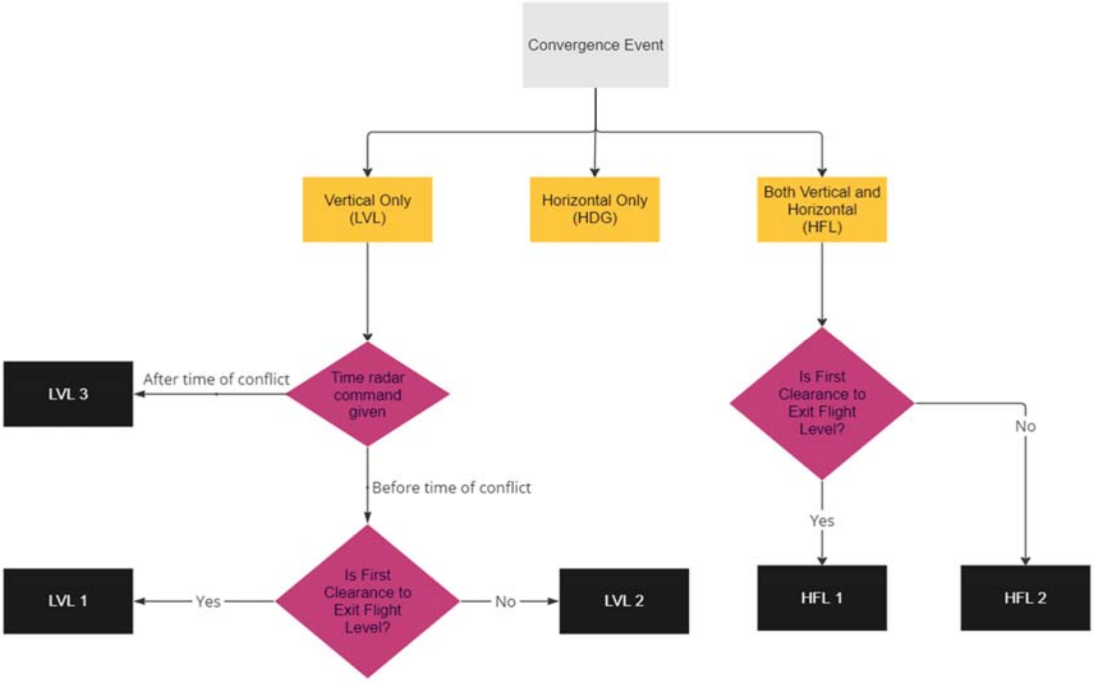


Fig. 3 Strategy classification system

The fourth phase consists of classifying each convergent event into a relevant category. Identified strategies can then be grouped according to the convergence events they were derived from. A classification system for the convergence events that categorizes them based on the way two aircraft's trajectories intersect along the horizontal and vertical planes was adopted. This system of classification was first proposed in [10]. In the horizontal plane, the convergence between two aircraft was classified using the definition created by US Federal Aviation Administration, which served as a guide for Air Traffic Controllers [15]. There were three categories defined by FAA in terms of convergence angle (CA), a convergence event was categorized as crossing if 45° ≤ CA ≤ 135°, opposite if 136° ≤ CA ≤ 180° and same if 0° ≤ CA < 45°.

CA could be calculated by first calculating the slopes of the straight proportions of the aircraft trajectories before a maneuver was commanded by an ATCO in convergence events as shown by (1). The x, y coordinates could be obtained from aircraft information in simulator data.

$$m = \frac{y_2 - y_1}{x_2 - x_1} \tag{1}$$

CA could then be computed by calculating the angle between the slopes of the two aircraft in convergence events by using (2):

$$CA = \arctan \left| \frac{m_1 - m_2}{l - m_1 m_2} \right| \tag{2}$$

As the slopes contained no directional information, the resulting angle from the equation must be visually checked against how the trajectory of both aircraft intersects with one another. The resulting CA from (2) had to be subtracted from 180 if CA was obtuse.

In the vertical plane, three different categories were defined. They were Parallel Climb/Descent, Level or Vertically Converging. Parallel Climb/Descent refers to scenarios when a pair of aircraft climbs or descent simultaneously. On the other hand, 'Level' refers to scenarios when both aircraft maintained their altitude throughout the convergence events, whilst Vertically Converging refers to scenarios when the altitude of both aircraft will converge at some point.

There were nine categories of convergence events formed from the classification rules mentioned above. However, in this study, a total of only four different categories of convergence events were found: crossing vertically converging, crossing parallel climb/descent, crossing level, and opposite vertically converging.

The naming convention of the convergence events was in the order of the horizontal category first followed by the vertical category. For example, the category of "Crossing vertically converging" meant that the horizontal category was "Crossing" and the vertical category was "Vertically Converging". As defined earlier, "Crossing" refers to convergence events where the convergence angle between aircraft was between 45 degrees and 135 degrees. Whereas for "Vertically Converging", it indicates that the altitude of both aircraft would converge at the same altitude at some point in time. It is essential to define the convergence events to understand ATCOs choice of strategies when subjected to different categories of convergence events.

In the last phase, the strategies identified were mapped to the convergence event categories. For each of the convergence event analyzed, its corresponding category and the strategy used were noted. The results were then tabulated by mapping the number of sub-strategies used against each of the four categories of convergence events.

The results from the CSIE methodology were then validated by applying them to a new data set. The new data set was derived from 15 randomly selected convergence events from another scenario. Results of the validation will be presented in the next section.

III. RESULTS

A. Maneuvers in Convergence Events

Table I summarizes the number of events that were resolved using the three main categories of LVL, HFL and HDG as well as the specific convergence events in which they were employed while Table II provides the breakdown within each main category. It can be seen from Table I that ATCOs were twice as likely to utilize LVL in an event as compared to HFL and HDG. It can also be observed that LVL was the most utilized maneuver that was deployed 49% of the time while HFL was the second most utilized maneuver, that was deployed 24% of the time. In 22% of all events, ATCOs preferred to wait until both aircraft passes each other at a crossing point before taking any actions. Lastly, ATCOs were least likely to utilize HDG as a strategy, deploying them in only 10 out of 231 or convergence events.

TABLE I
SUMMARY OF MANEUVER UTILIZATION

Maneuvers	Event Category						Total	% of all events
	Crossing Climb Descend	Crossing Climb Level	Crossing Climb Climb	Crossing Level Level	Crossing Level Descent	Opposite Level Descend		
LVL	6	63	6	1	30	0	106	49%
HFL	2	28	5	0	18	0	53	24%
HDG	0	2	0	2	6	0	10	5%
No action	2	11	0	5	19	11	48	22%

TABLE II
SUMMARY OF SUB-MANEUVER UTILIZATION

Maneuvers	Event Category						Total
	Crossing Climb Descend	Crossing Climb Level	Crossing Climb Climb	Crossing Level Level	Crossing Level Descent	Opposite Level Descend	
LVL1	5	48	3	1	24	0	81
LVL2	0	12	3	0	4	0	19
LVL3	1	3	0	0	2	0	6
HFL1	2	22	5	0	16	0	45
HFL2	0	6	0	0	2	0	8

TABLE III
SUMMARY OF VALIDATION DATASET

	Event Category					
Maneuvers	Crossing Climb Descend	Crossing Climb Level	Crossing Vertically Converging	Crossing Parallel Climb	Total	% of all events
LVL1	0	4	0	1	5	33%
LVL2	2	0	0	1	3	20%
LVL3	0	0	1	0	1	7%
HFL1	1	2	1	0	4	27%
HFL2	1	1	0	0	2	13%

B. Validation

The validation dataset comprised of simulator data of convergence events taken from five novices, five intermediates and five experts. Novices are defined as participants who are not trained ATCOs while intermediates are trained ATCOs who have less than three months of live operational experience, and experts are trained and qualified ATCOs with more than three months of live operational experience. The differing expertise levels was selected to showcase the ability of the methodology to accurately classify maneuvers and convergence events from a variety of participants. Table III illustrates the result of the validations, with the CSIE being able to identify and classify all maneuvers and convergence events found in the new set of data.

IV. DISCUSSION

ATCOs actions in tactical management of flights were successfully unearthed from raw simulator data through the proposed Conflict Strategy Identification and Evaluation (CSIE) methodology. The type of maneuvers commanded by ATCOs was chosen as the first common feature to define three main categories of strategies that were found in the convergence events as previous research showed that ATCOs deconflict aircraft based on vertical maneuvers, horizontal maneuvers, a combination of both vertical and horizontal maneuvers, and speed [16]. The main strategies were then broken down into sub-strategies using the flow chart in Fig. 3.

Through applying CSIE, trends emerged from analyzing ATCOs actions in convergence events. From Table I, it can be inferred that ATCOs were about twice more likely to choose LVL strategies over HFL or HDG. Consequently, this indicates an overwhelming trend for strategies that involve only vertical maneuvers. The observed trend is supported by observations made in other related literature where it was concluded that the use of strategies that involved vertical maneuvers only, which is referred to as LVL in this study, is less demanding on spatial working memory as opposed to strategies that require trajectory projection, which is referred to as HFL and HDG [7]. Similarly [10] also observed that ATCOs prefer vertical maneuvers over lateral maneuvers because it provides quicker resolution to conflicts than lateral turns. In addition, [8] found that strategies that involved only vertical maneuvers did not require as much attention and memory as maneuvers that involved a lateral change in the aircraft's trajectory. Whenever ATCOs instructs a lateral man oeuvre, ATCOs must spend extra mental capacity to monitor and maintain its horizontal separation from other aircraft and remember to reroute it back to its original course.

Table II shows the trend that LVL1 was the most deployed sub-strategy by ATCOs, followed by HFL1. Another trend can be seen for ATCOs strategies used in convergence events categorized as crossing in the horizontal plane. ATCOs were about two times more likely to deploy LVL strategies than HFL and HDG in convergence events that involved aircraft in crossing courses. This is congruent with findings that ATCOs tend to avoid lateral maneuvers for conflicts that involve aircraft on crossing course [10]. This is probably due to the larger lateral turns required to achieve adequate horizontal separations when aircraft are on the crossing course than on the same or opposite courses. Consequently, it would mean a more significant disruption to traffic flow and greater mental capacity would be required for monitoring and successful execution of HDG strategies compared to LVL or HFL in such a situation. In summary, ATCOs' tendency to use LVL strategies over HDG and HFL is evident as LVL is more efficient in deconflicting aircraft in convergence events due to it incurring less mental workload and disruption to traffic flow and planning.

The trends highlighted above are significant for use in the development of automated conflict resolution tools that can be designed or programmed with a bias for deploying only vertical maneuvers thereby allowing for a higher adoption rate from ATCOs.

It is acknowledged that there were limitations to the simulator data that were analyzed. First, speed was kept unchanged in this study. Even though ATCOs do not commonly modify aircraft speed in conflict resolution, it is still employed in specific scenarios. Therefore, the CSIE methodology can be expanded in further research to include speed as a variable. Other assumptions were made, such as no weather, constant wind, and aircraft performance. These are just some of the factors that could affect ATCOs decision in selecting a strategy. In reality, many factors may affect an ATCOs choice of strategy in a convergence event.

Overall, the CSIE proposed in this paper proved successful in unearthing ATCOs strategy from raw simulator data. CSIE presented in this paper will be helpful as a framework to analyze ATCOs conflict resolution in en-route convergence events that take place in the upper airspace. The results from this study might also improve machine learning and AI-based automated conflict resolution algorithm if the trend of LVL strategies highlighted in this study is incorporated in their algorithm. In addition, the six strategies identified in this study could serve as a foundation to investigate if further sub-strategies exist. There are also potential further research areas in unearthing ATCOs strategies using speed.

ACKNOWLEDGMENT

This project is supported by the Civil Aviation Authority of Singapore and Nanyang Technological University, Singapore, under their collaboration with the Air Traffic Management Research Institute and contribution from the Thales Group. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not reflect the views of the Civil Aviation Authority of Singapore.

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