# Unearthing Air Traffic Control Officer Strategies from Simulated Air Traffic Data

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**Abstract.** With the growth in air traffic volume, automation tools are being developed to increase the capabilities of Air Traffic Control Officers (ATCOs). In this paper, a novel approach to unearth Air Traffic Control (ATC) strategies from raw simulator data is described by utilizing executed radar commands obtained via mouse click data. Five sets of air traffic simulation exercise data were used to identify potential conflicts and unearth likely strategies undertaken using a proposed strategy identification model. The preliminary results demonstrate the success of the model in its ability to identify four distinct strategies adopted by the controllers to safely navigate air traffic conflicts that occurred during the simulation and the conflict type in which they occurred. Strategies identified were also verified by an expert panel to be effective in solving the targeted conflict type. The proposed model can be used to objectively identify ATC strategies for use in automation development.

**Keywords:** Human factors · Human-systems integration · Systems engineering · Strategy · Automation development

## 1 Introduction

With an expected increase in global air traffic volume over the long term, the future of Air Traffic Management (ATM) will be heavily influenced by new technological boundaries that will aid in accommodating this growth without compromising traffic safety. Advanced traffic modelling, such as the Four-Dimensional Trajectory Based Operations (4D-TBO), will provide more accurate and consistent predictions of flight trajectories [1]. This would then enhance sector capacity [2] while artificial intelligence (AI) in ATM will be essential in increasing our capabilities to handle both the higher volume of traffic and increasingly complex flows.

The introduction of automation into ATM operations is however not a simple process. Air Traffic Control Officers' (ATCOs) acceptance is one of the key inhibitors towards automation implementation [3] as they are hesitant to accept automation generated solutions without fully understanding the underlying processes that lead to the solution. To improve the controller's acceptance of automated aided decision tools, it was proposed that the automation's problem-solving strategies should match that of human ATCOs

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[4]. However, current strategies available in the literature are generic and do not describe the detailed actions required to be taken when handling specific repetitive traffic patterns attributed to a sector's characteristics. Furthermore, these strategies that are often derived from in-depth interviews and questionnaires with controllers [5] are limited as controllers often struggle to substantiate their decisions of the strategy being adopted using strategy-based explanations [6]. To fill this gap and aid in future ATM development, detailed knowledge of ATCO strategies and the traffic situation in which they are effective is essential. As illustrated in Fig. 1, the dotted box area and the strategy identification module in particular, will be the focus of this paper. The identified strategies is fed into the strategy generation module which the AI Decision Maker then uses to select from the best solution to resolve the traffic at hand. For the development and training of automated assisted tools in human-machine teams, knowledge of specific ACTO strategies is necessary to be able to train the automation aids to not only provide accurate solutions to the problem faced, but also solutions that are in line with those of their human ATCO partners.

This paper describes a proposed method used to unearth ATCOs traffic management strategies from raw simulator data and its embedded components. This strategy identification model focuses on deciphering ATCOs strategies for en-route flight clearances as it forms the largest segment of controlled airspace. Failure to manage and adopt the right strategies would lead to traffic accidents/incidents, overloading in the en-route sectors and other parts of the airspace [7]. Flight clearance in this airspace segment is essential to maintain safety separations, achieve optimal climb profile and maximize fuel economy [8]. Utilizing ATCOs radar command executions obtained via mouse click data and radar plots extracted from simulated air traffic exercises, ATCOs patterns of actions and the specific traffic scenario in which it is executed, can be identified. Identified ATCOs pattern of actions were grouped as part of a broader strategy and subsequently analyzed and validated by an expert panel of ATCOs with experience in daily ATM operations. Through this method, four ATCO strategies and the conflict type in which it was utilized in were accurately identified.

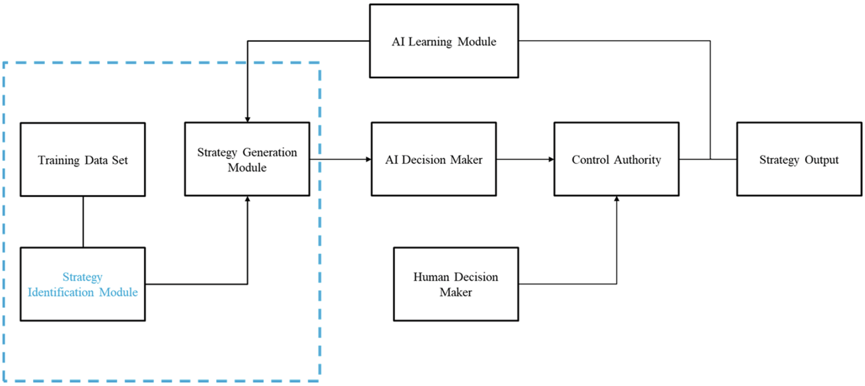

**Fig. 1.** Illustration of human-machine teams development model

## 2 Materials Used

### 2.1 Data Samples

Data sets used in this paper were retrieved from the database of the Air Traffic Management Research Institute in Nanyang Technological University, Singapore. Five sets of data were chosen to be used in this study with each containing ten instances of conflict. As a large majority of the data is obtained from the university student population who do not possess any prior experience with air traffic control (ATC), participants in these experiments are usually given guidance and training before the start of the simulation. Participants are also required to have normal or corrected to normal vision, basic comprehension skills and the ability to communicate in English.

### 2.2 Experimental Setup

A real-time ATC simulator, Netherlands Aerospace Centre ATM Research SIMulator (NARSIM) Interface, was used in this study. NARSIM is a human in the loop simulator for ATC tower and radar simulations that was developed by the Netherlands Aerospace Centre. The simulator data containing information about the aircraft movement throughout the simulation updates every 9.8 s which matches the amount of time required for one radar revolution in the en-route ATC environment. The simulator data also captures all executive radar commands issued by participants during the length of the simulation via their mouse click activity.

### 2.3 Experimental Design

The study was designed to unearth flight clearance strategies from data of simulated air traffic conflicts. The simulated traffic data selected thus consisted of ten conflict scenarios belonging to two main conflict types; sequenced climbs, and convergent climbs. Sequenced climbs refer to two or more aircraft climbing one after another along the same airway while convergent climbs refer to two aircraft climbing along adjacent airways that are expected to meet at an angle at a particular waypoint, resulting in an aircraft crossing or an intersection of pathways of the aircraft in question. Conflicts occurred between two to four aircraft at any one point in time. Each dataset contained a 30-min session segment where such conflict types are expected to take place.

### 2.4 Method

A method to unearth traffic controller's strategies from the simulator data collected will be described below. This method consists of four main stages namely; extraction, event log generation, strategy discovery and strategy verification as illustrated in Fig. 2.

**Fig. 2.** Illustration of strategy identification model

### 2.5 Extraction Stage

In this stage, log files were extracted from the NARSIM database in order to study the actions taken by controller participants during the simulation. This raw data consists of various log files broadly organized into information regarding aircraft flight plans, pseudo pilot commands, simulation recordings, aircraft track updates and participant command executions. For the purpose of this study, only the log file containing aircraft track updates and participant command executions was used as it contained all the relevant information regarding the strategies participants used in the simulation.

### 2.6 Event Log Generation Stage

At this stage, the relevant information is extracted from the raw data file to generate an event log. The event log should contain all relevant information necessary for the subsequent analysis. Python code was written to facilitate the creation of an event log file. The event log file included information on the radar commands executed by participants, together with the associated aircraft callsign, timestamp, speed, and altitude as well as track updates of all aircraft throughout the length of the simulation. The radar commands could range from heading changes, flight level changes and also other commands such as taking/handing over control of aircraft. An example of the event log can be seen in Table 1.

**Table 1.** Example of event log generated for analysis

| Time/Min | Callsign | Latitude | Longitude | Speed (knots) | Altitude | EFL |
|---|---|---|---|---|---|---|
| 0:09 | S001N892 | 3.895717 | 105.7343 | 170.73509 | 201.1822 | 0 |
| 0:09 | C006N884 | 2.826538 | 105.0113 | 162.32226 | 300.847 | 0 |
| 0:09 | C006N884 | 2.826538 | 105.0113 | 162.32226 | 300.847 | 0 |
| 0:19 | S001N892 | 3.886096 | 105.7222 | 176.83274 | 202.856 | 220 |
| 0:19 | C006N884 | 2.831739 | 105.025 | 166.25097 | 301.9201 | 0 |

### 2.7 Strategy Discovery Stage

During this stage, possible strategies used by participants to resolve air traffic conflict were identified. To better understand why a particular command was executed by participants during the stimulation, a snapshot of the environment in which the command was issued can be recreated using the timestamp at which the command was given. From the track updates in the event log file, the latitude (x-axis), longitude (y-axis) and altitude (z-axis) of all aircraft at the time of the executed command, as well as their associated speed and bearing, can be extracted and plotted out. In this way, not only can the corresponding aircraft in the conflict be easily identified but the exact conflict type can also be accurately determined. Furthermore, details regarding other aircraft in the immediate vicinity or even any aircraft that was present at that moment in time can also be included as part of the later analysis if required as the data is readily available in the event log file.

As reported by Rantanen and Wickens [9], conflict type can easily be categorized by the geometries in which they occur in, be it horizontal, vertical or both. Horizontal geometries can be broken into three categories, same, crossing, or opposite, depending on the conflict angle being less than 45°, within 45 to 135° or more than 135°. The conflict angle can be calculated using Eq. 1 as the angle between the slopes of the two aircraft in conflict.

$$AOC = \arctan\left|\frac{m_1 - m_2}{I - m_1 m_2}\right| \tag{1}$$

Vertical geometries can similarly be classified into parallel climb/descents, vertically converging or when both aircraft are at the same level. This classification can be done manually or automatically with a use of a conflict detection tool. Such tools can aid to efficiently identify and classify the conflict type. In this study, all simulated conflict falls within two categories, crossing-parallel and same-parallel as all aircraft are executing parallel climbs prior to any intervention from the participants.

Once the conflict pair and type has been established, the subsequent executed radar commands issued between the two aircraft up till the point at which both aircraft have safely reached their desired altitude can then be extracted. These are then grouped together as part of a broader strategy adopted by the participant. To better understand how each executed radar command is related to the other, details of the conflicting pair and even other aircraft in the vicinity can be continuously extracted and plotted out according to the timestamp at which the command was issued. In this study, the control strategy was limited to flight level changes, however, for future studies, strategy for adopting the preferred heading or speed changes can also be extracted and analyzed.

### 2.8 Strategy Analysis and Verification Stage

In this stage, the identified strategies are analyzed with reference to a set of performance indicators such as efficiency, robustness, fairness, safety, or equity [10] and are subsequently validated by an expert panel of ATCOs with experience in daily ATM operations.

## 3 Results and Discussion

From the data sample, 30 of the 50 conflict pairs were safely managed. As mentioned above, safe management of the conflict is determined by successfully climbing the aircraft pairs to their desired altitude without any safety infringements which in this case, is a loss of separation between aircraft. The remaining 20 conflict pairs were excluded from analysis as they were either not able to climb aircraft to their desired altitude or failed to do so safely. The conflict types in which the 30 conflict pairs occurred were also identified and classified into two categories, crossing-parallel and same-parallel based on the geometries of the conflict. From the 30 conflict pairs that were successfully managed and their associated strategy, four distinct sets of strategies were identified and grouped according to conflict type. Two strategies were identified each for the crossing-parallel and same-parallel conflict types as tabulated in Table 2.

Comparing between strategies utilized in the same-parallel conflict type, S1 represents a more efficient strategy as both aircraft reach their desired flight level the fastest and the succeeding aircraft, which is required to climb to a higher altitude can climb unimpeded, thereby reducing any fuel costs due to a staggered climb profile. However, compared to S2, S1 loses out in terms of equity as the preceding aircraft, which should be given priority by virtue of being first, had to maintain a lower and less fuel-efficient altitude for a longer period of time to allow for the succeeding aircraft to outclimb it.

Strategies identified in the crossing-parallel conflict type on the other hand were both equally equitable as the higher aircraft was always given priority and allowed to climb unimpeded. They did however differ in terms of efficiency. C2 allowed for the lower aircraft to continually climb for longer as compared to C1 which resulted in a more fuel-efficient climb profile. The lower aircraft in C1 however was allowed to climb to the next flight level only after the higher aircraft had cleared that level or otherwise known as a stepped climb. This resulted in a less optimal climb profile. It is worth noting that C2 required more monitoring from the controller to stop the climb of the lower aircraft at an appropriate time. This strategy would understandably run a higher risk of errors during situations of higher traffic intensity or complexity as the controller could very easily lapse in their monitoring, resulting in a loss of separation.

While similar strategies have been reported by Erzberger [11], the identified strategies were also validated in terms of relevance and accuracy by an expert panel of ATCOs with a combined experience of over more than 15 years of ATC experience in en-route operations. The panel was able to identify the four strategies from a list of eight that contained an additional four dummy strategies, thereby verifying that the individual steps when put together do form a broader strategy that can be used to resolve conflict. Furthermore, when given all four strategies and tasked to match them to either of the two conflict types, the panel was also able to correctly match them with the conflict type in which they could be used to resolve.

**Table 2.** Summary of identified strategies classified by conflict type

| Conflict type | Breakdown of strategy |
|---|---|
| Same-Parallel | S1a: Stop climb preceding aircraft while succeeding aircraft continues climb<br>S1b: Once succeeding aircraft is higher, step climb preceding aircraft till desired altitude |

(*continued*)

**Table 2.** (*continued*)

| Conflict type | Breakdown of strategy |
|---|---|
| | S2a: Stop climb succeeding aircraft while preceding aircraft continues climb<br>S2b: Once sufficient lateral separation is achieved, climb succeeding aircraft to desired altitude |
| Crossing-Parallel | C1a: Step climb aircraft at lower altitude<br>C1b: Once clear of intersection point, climb aircraft to desired altitude |
| | C2a: Climb aircraft at lower altitude to intermediate altitude<br>C2b: Stop climb lower aircraft at safe altitude when nearing the intersection point<br>C2c: Once clear of intersection point, climb aircraft to desired altitude |

Overall, the proposed strategy identification model presents a new method to identify strategy used in ATC. Strategies identified can then be analyzed and compared against one another to determine the most effective strategy for every situation. This overcomes the need to interview ATCOs in order to decipher the thought processes that underlie their decisions during operational work. Furthermore, as each sector has its own unique characteristics and peculiarities, this model can be used to unearth various ATCO strategies used in each specific sector without disruption to the operational work of the ATCOs. These identified strategies can then be used in multiple ways. A personalized automation tool could be developed that alters its suggestions to match the style of the ATCO working thereby increasing automation acceptance and preventing the infamous out of the loop phenomenon. These strategies could also be used as training aids to improve ATCO skills and optimize their current set of strategies.

It is also worth noting the inherent limitations of model. While useful for identification of strategies used in en-route operations, it is not as effective when applied to data from aerodrome and approach control as both these cases are more dynamic and uncertain as this involves aircraft that have yet to leave the ground and thus do not yet appear on the radar. Thus, other information sources would need to be fed into the model for it to work as proposed. Second, since the model was designed for the identification of strategy, it does not work if no interventive actions were taken.

## 4 Conclusion

In this study, a new method of strategy identification was proposed to unearth strategies that were used by participants in a simulated ATC environment from raw data. Executed radar commands for flight level changes made by participants via mouse clicks were collected for this purpose. The results showed that the proposed approach was effective in identifying participant strategies and the conflict type in which it was used within. Furthermore, these strategies were subsequently validated by an expert panel for relevance and accuracy. The proposed strategy identification model has various implications on the development of automation tools for use in ATC. The future development of this research will be focused on looking into identifying strategy that utilizes other techniques beyond that of flight level changes such as changes in heading and speed.

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