# PERFORMANCE VISUALIZATION IN AIR TRAFFIC CONTROL USING COGNITIVE SYSTEMS SIMULATION

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## Abstract

*In the dynamic and multi-task condition of air traffic control, an Air Traffic Controller (ATCO) is required to construct effective control strategies to handle multiple aircraft simultaneously. Effective strategies can prevent potential collision of aircraft well in advance and can contribute to reduce ATCO's cognitive workload. Therefore, the strategy building skill is quite important for ATCOs in order to realize safe and efficient air traffic flows. However, it is sometimes difficult to transfer this kind of cognitive and situation-dependent skill from ATC training instructors to trainees with conventional education and training methods.*

*In the present research, a supportive function of education for an ATCO trainee which can visualize the difference of task performance resulted from the variety of possible control strategies has been proposed. The supportive function has been implemented using the framework of a cognitive system simulation of ATCO termed "COgnitive system Model for simulating Prediction-based behaviors of Air traffic controller in dynamic Situations (COMPAS)". Using this function, the effect of ATCO's control on air traffic flow has been successfully visualized, which helps trainee to understand the differences of the consequences of the different strategy. This result has strongly implied that the COMPAS equipped with performance visualization function can be utilized as a supporting tool for education of ATCO trainees.*

## 1 Introduction

The rapid increase of air traffic demand in recent years requires higher level of safety and efficiency in aviation operation. In order to achieve that goal, researches and developments of technical aspects for realizing future Air Traffic Management (ATM) have been extensively performed. However, the authors believe that another important issue for aviation safety is improvement and standardization of education and training for Air Traffic Controller (ATCO) trainees. It is definitely important to train skilled controllers efficiently.

The ATC task is characterized by multiple tasks under the time-pressure condition. ATCOs are sometimes required to control over 10 aircraft which have multiple performance and different demands at the same time. It means that the task environment of ATC essentially involves potential causes of human errors such as cognitive overload and inappropriate attention allocation. However, previous researches of cognitive task analysis for ATCOs [1][2] has revealed that they have typical skill to construct effective air traffic control strategies which can prevent potential conflict of aircraft well in advance and also can reduce their cognitive workload. Such strategy building skill of ATCOs is definitely important for enhancing safety and efficiency in the heavy traffic condition. However, in practice, it is sometimes difficult to transfer this kind of cognitive and situation-dependent skill from training instructors to trainees with conventional training methods.

Based on foregoing recognition, our research group has explored possible application of computer simulation as a support tool for acquiring strategy building skill in the basic training process of ATCO by visualizing performance of various strategies. In the ATC area, Fast Time Simulations (FTS) have already been utilized as a support tool for prediction of ATCO's workload, for evaluation of airspace design, and so on. However, as conventional FTSs have mainly focused on generating discrete ATC events, their problem solving strategy tends to be somewhat different from that of human controllers in a specific situation. That is because the cognitive processes concerning situation awareness and decision making by ATCOs have not been modeled enough in those conventional FTSs. Therefore, conventional FTSs have some difficulties to be utilized for educational purposes.

In the present research, the cognitive simulation including the detailed cognitive model of ATCO termed "COgnitive system Model for simulating Prediction-based behaviors of Air traffic controller in dynamic Situations (COMPAS)" has been developed. The prototype support function which visualizes performance of various control strategies for educational purpose has been implemented in the COMPAS. The validity of visualization function has been evaluated through a simulation experiment.

## 2 Overview of COMPAS

### 2.1 Architecture

As mentioned in foregoing chapter, the ATC task is featured as multiple tasks which are necessary to be performed parallel in appropriate time windows. Therefore ATCOs are required to prioritize control tasks depending on a situation and to execute them quasi-parallel under the ongoing context.

In the COMPAS, so as to simulate such quasi-parallel and adaptive task execution by an ATCO, Multi-Agent System (MAS) architecture has been adopted to implement ATCO's cognitive model. The MAS is a system which consists of multiple interactive agents. An important characteristic of the MAS is decentralization which means any central command agent is not existed in the system. Although one agent has simple function and local information, intelligence as a whole system such as adaptive behaviors or ability to solve complex problems can emerge through interaction among agents. Based on this MAS architecture, ATCO's cognitive functions are implemented as an assembly of various agents. Each agent has a specific cognitive function such as information acquisition from a radar screen, execution of communication with a pilot, storing a schematic knowledge. Those agents activate each other, and the activation levels of agents determine the overall behavior of the simulated ATCO (sATCO). At the same time, cognitive activity of the sATCO which is represented as operations to the external world or to internal cognitive processes by agents is limited by multiple cognitive resources based on Wickens's theory [3]; they are visual, auditory, cognitive and motor resources.

### 2.2 Basic Structure of COMPAS

The Fig. 1 describes basic structure of our COMPAS. As shown in Fig. 1, the COMPAS consists of three separated models which are External World Model (EWM), Human Interface Model (HIM) and simulated ATCO model (sATCO). The EWM represents situation of the airspace which includes sector boundaries, airways, aircraft and wind condition. The sATCO is a model of a human controller consisting of Situation Awareness Model (SAM) and cognitive agents The SAM involves not only raw data of the traffic situation, e.g. aircraft's speed, altitude, route, but also future prediction by the sATCO based on obtained external information and his inherent knowledge.

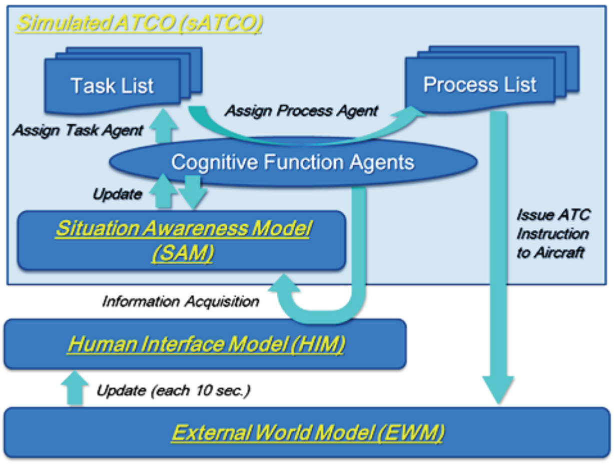


Fig.1 Basic Structure of COMPASS

The sATCO's behaviors are determined based on this SAM. In the COMPAS, the sATCO needs to update the SAM by information acquisition from the HIM, which represents human interface equipment like a radar screen because the sATCO cannot access and obtain information directly from the EWM directly in reality.

## 2.3 Cognitive Process of sATCO

The cognitive process of the sATCO has been designed based on a cognitive process model of an ATCO constructed with the help of the professional ATCO in our group. In the following part, detailed description of the cognitive process of the sATCO is given using an example traffic situation shown in Fig.2.

(1) Search and Detection of Objective Aircraft
In the COMPAS, the airspace is divided into multiple sectors same as the actual airspace, and the sATCO handles air traffic flow in one sector. At the first stage of his cognitive process, the sATCO grasps an upcoming objective aircraft which will take air traffic control services in the sector. In this stage, the traffic situation is recognized as a two-dimensional picture involving aircrafts' positions, directions and approximate ground speeds.

In the case of Fig.2, the sATCO detects the AC1 as an objective aircraft, and then recognizes lateral route of the AC1 taking cues from the aircraft's position and destination.

(2) Activation of Schematic Knowledge
The previous research [2] has revealed that ATCOs have schematic knowledge defined as "routine" involving dynamic descriptions of typical situations which can serve as a significant basis for comprehension and prediction of situations. It has also argued that routines involve the packages of heuristics to handle a situation efficiently.

Based on the results of the previous researches, the sATCO stores some types of routines for each destination and flight route of an aircraft as his heuristic knowledge. In the example of Fig.2, the routine for an aircraft which bounds for RJTT with coming from the northern sector is selected and activated for the AC1. The routine gives the sATCO recognition of the target state of the AC1 which is the altitude of 13000 feet at TLE point.

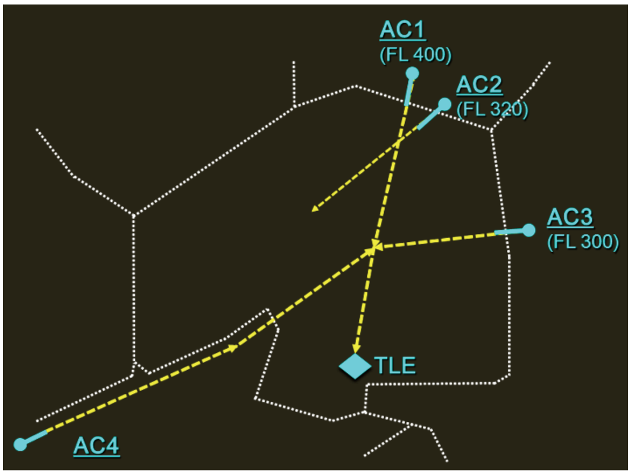


Fig.2 Example Traffic Situation

(3) Recognition of Related Aircraft
After the step of (2), the sATCO acquires detailed information, altitude and ground speed of the objective aircraft, by careful monitoring of the data block on the simulated radar screen. The activated routine provides three-dimensional flight image of the aircraft based on the acquired information. With using the flight image, the sATCO detects related aircraft meaning potential conflicting aircraft with the objective one. In the situation of Fig.2, the AC2 and the AC3 are recognized as related aircraft of the AC1 because their flight route will cross the descent profile of the AC1, and they have possibility to lose 5NM horizontal or 1000feet vertical minimum separation. As the routine stores basic knowledge to realize effective attention allocation depending on a situation, this detection process of related aircraft does not requires the sATCO to perform careful monitoring to all aircraft on the radar screen. For example, in the example case of Fig.2, the AC4 is not recognized as an object of enhanced monitoring to search related aircraft due to knowledge stored in the routine which indicates that the AC4 has no possibility to lose minimum separation between the AC1 according to positional relation of those aircraft.

(4) Recognition of Necessary Control Tasks and Strategy Building

Based on the situation awareness developed through step (1) to (2), necessary control tasks for the objective aircraft and their deadlines are realized. In the case of Fig.2, the sATCO recognizes following control tasks.

Task 1: Establish separation between the AC1 and the AC2

Task 2: Establish separation between the AC1 and the AC3

Task 3: Satisfy altitude restriction of the AC1 at TLE point

In the COMPAS, these tasks are assigned to the Task List of the sATCO as task agents (Fig.1). Through negotiation among the task agents, a control strategy in order to complete all tasks considering aircraft's performance is constructed. The control strategy in the case example is shown in below.

<u>Control Strategy</u>

Step 1: The AC1 should be given an instruction to descend to an altitude of 1000feet above the AC2 as soon as possible in order to make descent of Step 2 possible aircraft performance.

Step 2: To keep vertical separation between the AC1 and the AC2, the altitude of the AC1 should be maintained by passing the intersection with the AC2.

Step 3: To establish vertical separation between the AC1 and the AC3, the AC1 should be given an instruction to descend to an altitude of 1000feet below the AC3 after passing the intersection with the AC2.

Step 4: The AC1 should be given an instruction to descend to the target altitude of 13000 feet after establishing the separation with the AC3.

A procedural step to complete a control strategy as described above is termed "process" in the COMPAS. These processes are assigned to the Process List of the sATCO as process agents (Fig.1). Each process agent has a priority value and a Windows of Opportunity (WO) [4]. The priority value is determined and updated depending on the remaining time before the WO close and task type, e.g. collision avoidance, altitude change to cruise altitude. Multiple process agents of different strategies can be exited on the Process List. In that case, the agent with the highest priority value, WO open and availability of cognitive resources is executed.

(5) Provision of ATC Instruction

The sATCO performs intermittent monitoring to the objective and related aircraft until WO for provision of an instruction becomes open. Based on acquired information by the monitoring, the priority value and WO of each process agent can be updated. When an ATC instruction is issued, contents of an instruction like an assigned altitude is adjusted depending on the current situation.

## 2.4 Cognitive Features of sATCO

The architecture summarized in previous sections gives following cognitive features to the sACTO in the COMPAS.

*Uncertainty of prediction.* According to the interviews with ATCOs conducted by our research group, uncertainty of an air situation is an important factor affecting ATCO's cognitive workload and control strategies. In our COMPAS, the uncertainty of prediction concerning the future situation of aircraft (e.g. future trajectory and flight profile of aircraft, time delay of pilot's reaction to ATCO's instruction) has been taken into consideration. The proposed COMPAS can simulate ATCOs' behavior when future situation cannot be determined exactly, which requires the intermittent monitoring and the adjustment of strategies by the sATCO according to the ongoing situation.

*Bounded rationality.* sATCO's behaviors are determined based on the SAM which needs to be updated by information acquisition under the limitation of cognitive resources. This architecture realizes a simulation taking the model of bounded rationality into consideration. It also enables the COMPAS to simulate the situation in which chain of errors occurs resulting from the discrepancy between the SAM and the EWM caused by erroneous recognition of a parameter and inappropriate attention allocation.

## 3 A Performance Index of Air Traffic Control Tasks

For educational purposes, a visualization function of the Task Level which is a performance index of ATC tasks proposed by the actual ATCO in our research group [5]. The definition of each task level is shown in Table 1. Upcoming aircraft to the objective sector have various task levels from Lv. 1 to Lv. 3, but by completing necessary ATC tasks in the sector, the task levels of all aircraft are decreased to Level 1 by the time they are handed off to the next sector. Therefore, the transition of task levels depends on and reflects the efficiency of the applied strategy.

## 4 Implementation & Evaluation

The proposed COMPAS has been installed on the PC with using C++ language. For preliminary evaluation of proposed simulation, a numerical experiment has been conducted based on scenarios in which sATCO is required to provide descent clearance to specific aircraft with resolving conflicts among them so that each aircraft can accomplish its altitude target. In the simulation experiment, the COMPAS could successfully simulate the typical behavior of a human controller in the similar situations [6].

In addition, for evaluation of visualization function of the Task Level, additional simulation experiment based on the scenario shown in Fig. 3 has been conducted. In this scenario, the sATCO is required to accomplish the requirement of altitude target of BBB542, which is 13000 feet at TLE. Two departure aircraft, AAA573 and AAA736 have to be also controlled so that they can reach their cruises altitudes within this sector. The original flight planed route of AAA736 is indicated by dashed-dotted line in Fig.3.

However, in this case, it is inefficient to follow the original planed route because it can lead to confliction between descending BBB542 and climbing AAA736 near GOC. Therefore, human ATCOs often reroute aircraft in order to resolve the conflict effectively in such a situation. In this simulation experiment, two possible control strategies were given by an actual training instructor (Fig. 3). The strategy 1 is making AAA736 shortcut to the prior fix (CHINO) directly. The strategy 2 is to lead BBB736 to west by radar vector and then issuing an instruction to direct to the prior fix after crossing. Both strategies are for resolving the confliction between BBB542 and AAA736 by crossing both aircraft at earlier stage. The consequences of these strategies have been

Table.1 Definition of Task Level

| *Lv.* | *Situation* | *Display Color in the COMPAS* |
|---|---|---|
| 1 | Necessary ATC tasks are completed | Green |
| 2 | Typical tasks such as altitude change are existed | Yellow |
| 3 | Typical tasks and separation tasks (conflict resolution, intrail spacing) are existed | Orange |
| 4 | Situation of Task Level3 + Time pressure condition | Red |

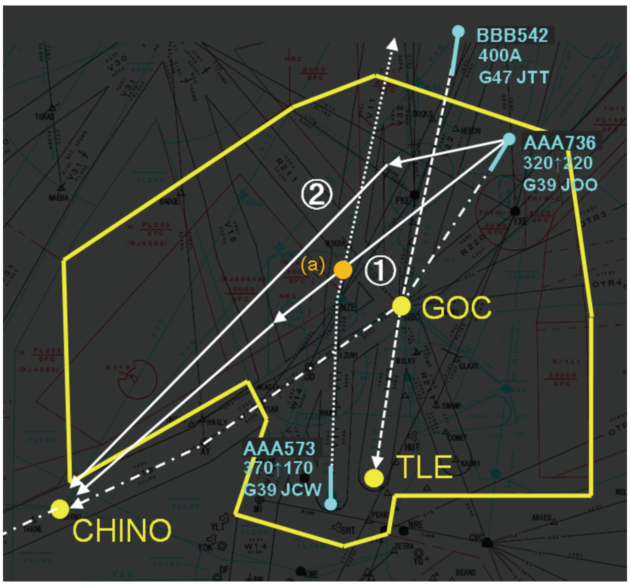


Fig.3 Scenario of Simulation Experiment

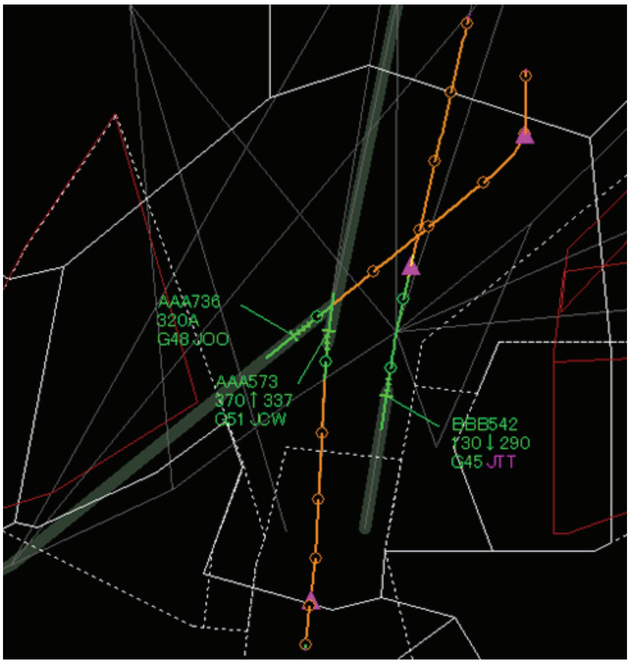


Fig.4 Simulation Result (Strategy 1)

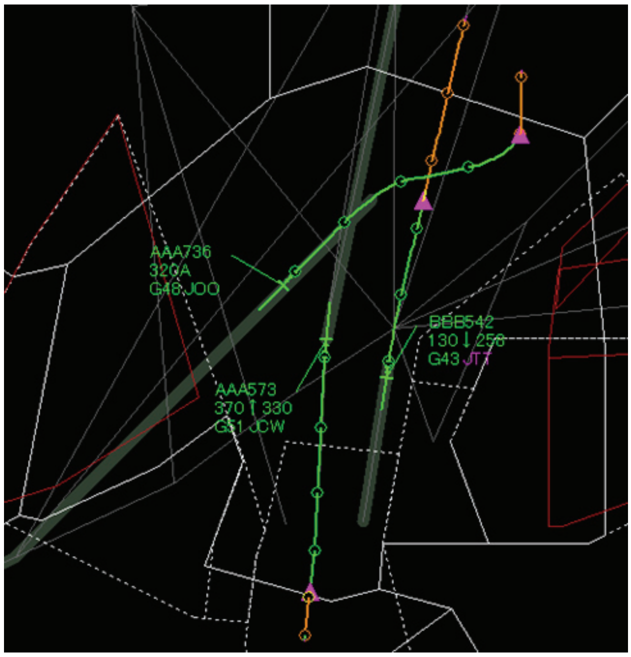


Fig.6 Simulation Result (Strategy 2)

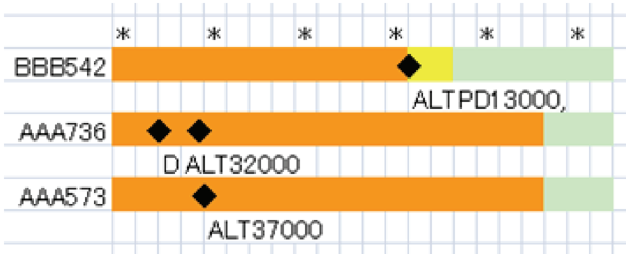


Fig.5 Simulation Result
(Strategy 1, Time Series Graph)

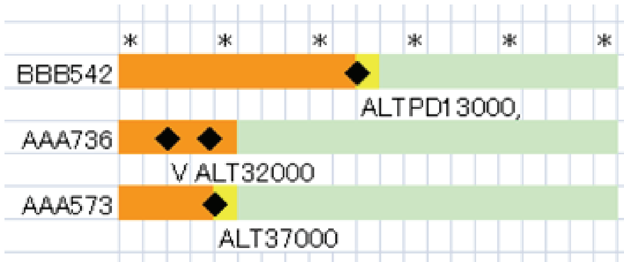


Fig.7 Simulation Result
(Strategy 2, Time Series Graph)

visualized and compared by using the COMPAS.

The result of the simulation has shown in Fig. 4 ~ Fig. 7. In the Fig. 4 and Fig. 6, the task levels are overlaid on the trail of each aircraft with color code. The Fig. 5 and Fig. 7 are time series graphs of task levels estimated by the COMPAS. The result of the simulation has indicated that the strategy 1 has led to continuous higher task levels due to another confliction between AAA736 and AAA573. On the other hands, strategy 2 could successfully resolve not only the confliction between AAA736 and BBB542 but also the confliction between AAA736 and AAA573 by displacing crossing point to north where AAA573 is certainly expected to reach enough high altitude to maintain vertical separation with AAA736. The task level has been reduced in the earlier time frame when strategy 2 has been adopted. This result has indicated that the strategy 2 has an advantage in terms of reducing possible risk of confliction. It can also contribute to reduce cognitive load of an ATCO to monitor and resolve conflicts.

Through the simulation experiment, the COMPAS could successfully visualize the effect of ATCO's control on air traffic flow for different strategies which is consistent with the opinions of actual ATCOs. This function of the COMPAS can helps ATCO trainee to understand the differences of the consequences of the different strategy more effectively.

## 5 Conclusion

In the present study, a cognitive system simulation of an air traffic controller termed "COgnitive system Model for simulating Prediction-based behaviors of Air traffic controller in dynamic Situation (COMPAS)" has been developed based on the results of cognitive task analyses of an ATCO. The function visualizing the difference of performance of control strategies has been implemented into the COMPAS. Using this visualization function, the effect of ATCO's control on air traffic flow has been successfully visualized. Although the development of this simulation framework is still underway, the result of the simulation experiment has strongly implied that the COMPAS equipped with performance visualization function can be applied as a supporting tool for education of ATCO trainees.

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