AN EXPRESSION OF AIR TRAFFIC CONTROLLER'S WORKLOAD BY RECOGNITION-PRIMED DECISION MODEL

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Abstract

Workloads of air traffic controllers (ATCOs) tend to be increasing by recent dense traffic. To mitigate the workloads, investigation of present ATCOs' workloads is required. The objective of this paper is to visualize ATCOs' workloads and interpret ATCOs' skills. We investigate ATCOs' tasks and classify them into four task levels, correlated with RPD (Recognition-Primed Decision) model. Then, we conducted a Real-time ATC simulation to analyze the results and propose a new tabulated expression for the task levels. This expression proved that our method can express ATCOs' workloads.

1 Introduction

With increasing air traffic, ATCOs' workloads become heavier and heavier. Higher skills are needed for ATCOs to keep air traffic safety in dense traffic environment. In Japan, update of ATC systems was completed by introducing new or upgraded software and equipment in these two years. Training must be done for ATCOs in en-route control to get used to the update. Furthermore, in Japan, a lot of full-performance-level ATCOs are approaching to their retirement age. Appropriate training programs become important for a lot of new ATCOs to learn skills of their predecessors.

Human factors in ATCOs are one of the most important issues to enhance air traffic safety. It is well known that there is a close relationship between Human factors and Human workloads. Therefore, we must study the workload closely. Previous studies have implied that appropriate task planning is one of the key roles for ATCOs, because it can reduce ATCOs' workloads in various situations[1]. However, it is really difficult to express ATCOs' workloads exactly and timely.

This paper proposes a method to express radar controller's workload in en-route control. We investigate ATCOs' tasks and classify them into four categories: The task levels 1 to 4 according to the complexity of traffic. Then these task levels are correlated with the RPD model[2]. Real-time ATC simulation is conducted to analyze ATCOs' tasks. Tabulated expression of workloads is then presented. This expression can provide variation and duration of the workload according to the progress of ATC task by each flight and each ATCO. This expression is also employed to interpret ATCOs' skills.

The method to visualize ATCOs' workloads can be used for ATCOs' education and training. The method will also be used to compare current with new operations.

2 ATCOs' Tasks and workload

2.1 En-route Air Traffic Control in Japan

Fig. 1[3] shows the Flight Information Region (FIR) in Japan and its surround. Japan takes responsibility of providing en-route air traffic control service in Fukuoka FIR. Fukuoka FIR is divided into four Area Control Centers (ACCs) as Sapporo, Tokyo, Fukuoka, Naha and one oceanic control area.

The airspace covered by each ACC is subdivided into sectors taking into account the characteristics of the traffic flow, radar coverage, ATCOs' workload and other operational factors. Each sector is operated by a few ATCOs. ATCOs use radar control units in domestic area. 5 Nautical Miles (NM) in horizontal or 1,000 feet in vertical between each aircraft is set to be minimum separation. Generally, 15NM separation is applied during inter ACC radar hand off, and 10NM for an ACC and a terminal control facility.

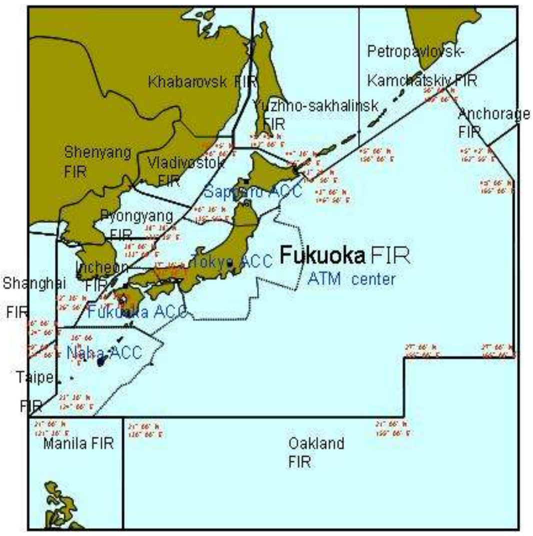

Fig.1 Fukuoka FIR[4]

2.2 ATCOs' tasks and workloads

ATCOs must prepare for unanticipated events, for example, equipment failure, bad weather, or pilot noncompliance with instructions. ATCOs will take flexible actions against those events to preserve safety even if the actions may temporarily disrupt efficiency.

One of the major features of ATCO's task is that different services must be performed in parallel. ATCO must set up his/her task planning prior to starting the tasks. In deciding priorities of tasks, ATCO has to recognize objective aircraft, possibility of future conflict, plan task that should provide separation within the area, select course of action and make decision. Then ATCO actually manages the time of issuing instruction, communicates with pilots, and confirms pilots' read-back after the communication. In complex and busy traffic situation, ATCOs must have heavy workload to make decision without enough time.

It is pointed out that workload is one of the most critical characteristics of ATCOs' tasks [1]. Increases in air traffic density and complexity have led to substantial demand increase in the mental workload of ATCOs. Some studies have reported that there is a correlation between ATCOs workload and spending time to communicate with pilots. But it is quite difficult to exactly estimate ATCOs' workload from the simple observation of his/her duties.

2.3 The Training Programs of ATCO

Recently, appropriate job training programs for ATCOs become more important than before in Japan. The training programs and entrance examination to Aeronautical Safety College are not systematic and integrated since they started. ATCOs are demanded to have a lot of experience in training to construct strategies and make decision quickly, because experienced ATCOs can quickly recognize the situation as prototypical and know what to do in a lot of cases. They have more comprehensive decision making than novices have. If a course of action first they choose does not work out, they can swiftly pick up others because they always compare one course of action to another and evaluate the options.

Over the past few decades, considerable numbers of studies have been conducted on workload and performance of ATCOs by Federal Aviation Administration Academy, EUROCONTROL, and other institutes. A lot of experiments have been done by universities, ATCOs and companies in planning their projects.

However, most of the investigations on workload or performance of ATCOs have never been conducted by ATCOs who are doing the actual work for the experiments like these because of a lack of ATCOs in ATC facilities in Japan. We propose a method of visualization of ATCOs' workloads because we have to educate a lot of new skilled ATCOs who can perform safe and efficient ATC.

3 RPD Model and Task Level

3.1 RPD Model

"RPD model" proposed by Klein, is often employed to interpret the flow of decision making in many professional jobs, for example, firemen's work, search-and rescue job and nursing in an intensive care unit. The RPD model has three variations as
Variation 1: Simple Match,
Variation 2: Diagnose the Situation, and
Variation 3: Evaluate Course of Action.
Among these variations, Fig.2 shows a flow of decision making by Variation 1. This flow means that when a decision maker faces a situation, he/she can immediately perceive the situation as typical and familiar. Then he/she will proceed to take an appropriate action.

More complex situations are described in Variation 2 and 3. Variation 2 occurs when a decision maker may have to devote more attention to *diagnosing* the situation and may need to gather more information than that for Variation 1 in order to proceed to take action. Variation 3 explains decision makers who anticipate difficulties in situation may need to *adjust* the course of action, or may *reject* it and look for another opinion.

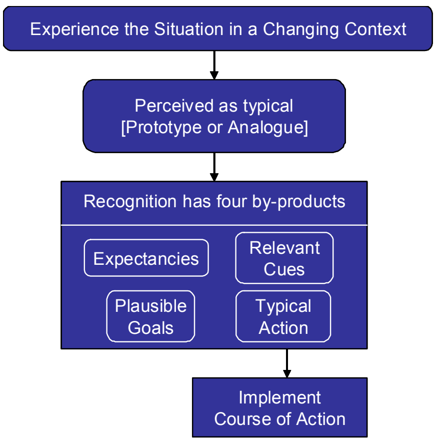

Fig. 2 Variation 1 in RPD Model

3.2 Task Level

ATCOs in all ACC depend on information from en-route radars which are supported by computer-based, partially automated radar displays. Thus, in this paper, we note the task of a radar controller. Each task that a radar controller performs is not independent but is correlated with each other. When an ATCO issues an instruction to an aircraft, then he/she waits for pilot's read-back, marks the flight strip, and/or inputs the computer for the instruction as the instruction is recorded in voice recorder or flight strip, or in their computer. He/she will observe the radar display as well. A task is regarded as a series of instructions as described above.

Table 1 Definition of Task Level 1-4

Task Level	Definition	Variation in RPD Model	Color of Task Bar
1	No instruction is necessary without any requests from a pilot	Var. 1	Green
2	A single task such as changing altitude is required which is regulated between sectors or facilities	Var. 2	Yellow
3	Multiple tasks such as changing altitude and conflict resolution are required	Var. 2 and/or Var. 3	Orange
4	Task Level 2 or 3 in time pressured situations	Var. 2 and/or Var. 3	Red

ATCOs' tasks are classified into four categories Task level 1-4 according to the complexity of traffic. Table 1 shows the definition of each Task Level, correlation of the Task level with the variation of RPD model. And four different colors are assigned to each task level to display the transition of the task levels.

It is regarded that the higher the RPD Variation, the heavier the workload becomes.

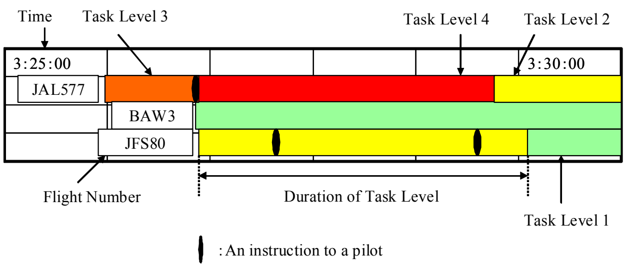

Fig. 3 Sample of Tabulation of Task Level

First, task level 1 is defined as the lowest level of all task levels. In this level, ATCO is needed to transfer the aircraft in the sector to another sector or facility. In this level, a single task is needed for all aircraft, ATCO is almost monitoring the aircraft on radar display.

Second, task level 2 is defined as a task positioned middle level and corresponds to variation 2 in the RPD model. This level is usual with ATCO, and ATCO has to do a fixed transaction to a controlling aircraft according to the agreement between the sectors or facilities.

Third, task level 3 is defined as a high level task and corresponds to variation 2 and 3 in the RPD model. This level often occurs in the situation that traffic is concentrating or by the timing of ATCO's instructions. When an ATCO looses or misses recognizing traffic or issuing instructions timely, the ATCO will suffer more workload than an ATCO will have in normal control, which means if an ATCO can issue appropriate instruction in appropriate timing to a controlling aircraft, the ATCO's workload and task level may decrease. Thus, the ATCO's operation will become safer and more efficient. Skill must be required for ATCOs to issue an appropriate instruction in appropriate timing. That skill can be obtained through specialized training.

Finally, task level 4 is defined as a task with time constraint to an ATCO added to task level 3. This level sometimes appears when a mistake is included in the ATCO's instructions and potential conflict may occur. When the ATCO notes the situation, he/she has to instruct the pilot to avoid the conflict as soon as possible.

4. Results

4.1 Real Time Simulation of En-route ATC

Real time ATC simulation was conducted at the real time simulation facility of ENRI in 2006. Eight full-rated ATCOs of Tokyo ACC were engaged in the simulation. Fig.4 shows the flight sector named "Kanto-North" in Tokyo ACC and its location in Japan. The figure also shows an example of traffic in the sector. This sector was chosen for the simulation because traffic pattern in the sector tends to be diverse in destination and purposes (civil and military).

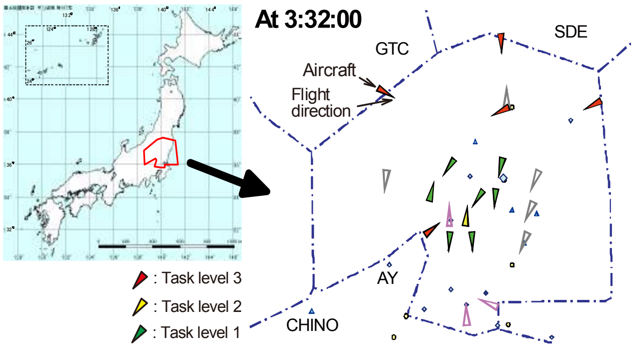

Fig. 4 Kanto-North Sector in Tokyo ACC

Table 2 shows examples of transactions conducted in the sector. By combining several transactions in the table, a scenario for the simulation have been generated. Operation rules in the sector are also taken into account to make the scenario. Simulation time is about 30 minutes.

Table 2 Examples of transactions in Kanto-North sector

Expecting an aircraft into the sector	A status of entering aircraft into the sector	Necessary transactions in the sector
Departed fromHaneda airport	In climbing Flight Level (FL) 210	Make climbed altitude (ALT) or FL as a request from a pilot
Arrived at Haneda airport	In level flight	Providing instruction to make descent 13,000 feet by assigned fix with 10 NM in trail
Departed from Narita airport	GTCTR: in climbing to FL250 according to AIP-J	GTCTR: Making climbed to FL250 according to AIP-J
Arrived at Narita airport	In descending to FL280 without any restriction	Instructing to make descent FL150 by assigned fixes with 10 NM in trail
Arrived at Fukushima airport	In descending to FL170 by Nikko NDB	Instructing to make descent Minimum Enroute Altitude and taking separation in non-radar control, then issuing approach clearance
Departed from Sendai airport	In climbing to ALT or FL as assigned by ATC	Instructing to make climbed ALT or FL as assigned by ATC within a sector
Arrived at Sendai or Niigata airport	In level flight	Instruction to make descent FL150 without any restrictions

Table 3 describes the details of seven complex events included in the scenario. Each event occurs at different areas. The areas move by the elapse of time.

There was no constraint for ATCOs joining the simulation about procedures and the number of instructions to deal with each event just as on their duty.

Table 3 Contents of events

Case in order	Events	Details and features of the events
1	10 NM in trail of 3 aircraft arrived at Narita	Necessity to take separation regulated between 3 aircraft on the same airway
2	10 NM in trail of 3 aircraft arrived at Haneda with crossing an aircraft in climbing from Sendai	Necessity to take separation regulated between 3 aircraft one from west and the other from north with order 1, added to an aircraft departed from Sendai in climbing and flying crossed route
3	A Fighter from Hyakuri crossing other aircraft	Necessity to carefully take separation between other aircraft because of having different performance and route of flight with a fighter and a civil aircraft
4	10 NM in trail of 3 aircraft arrived at Haneda	Necessity to take separation regulated between 3 aircraft coming from different direction, and to care of wind factor blew strongly
5	10 NM in trail of 2 aircraft arrived at Haneda added to case 4	Necessity to take separation regulated between 2 aircraft from north, and catching up to previous 3 aircraft by case 4 if without exact control for previous 3 aircraft
6	Crossing 2 aircraft in climbing departed from Narita and Fukushima	Necessity to estimate separation between 2 aircraft from Narita and Fukushima in climbing and crossing, and especially taking care to change one from Fukushima to under radar control
7	Conversing 2 aircraft in climbing from Narita and Yokota, and crossing additional aircraft in climbing from Sendai	Necessity to estimate separation between 3 aircraft from Narita and Yokota in climbing, conversing and crossing at same point, time, altitude, also to provide an appreciate altitude assigned to them

Simulation results have been analyzed by employing recorded voice communication and radar display. In the analysis, we noted the contents and timing of instructions, location of controlling aircraft, process of controlling, and the frequency of instructions. By estimating the workload of each instruction, we classified the instruction that an ATCO issued into four different task levels as shown in Section 3.2.

From the analysis, followings are shown:

1. The controllers chose three different procedures for event 4. The task level of event 5 was affected by the procedures chosen. In other words, if a better procedure is taken for an event, it can reduce the task level for succeeding event.
2. For similar events 1 and 4, one controller took different procedures, and the other controller took the same procedure to deal with each event. Such difference in chosen procedures will occur because each controller is different in realizing the events, and in estimation traffic volume.

4.2 Visualization of task level transition

In the simulation scenario, event 1 to 4 and 6 in Table 3 are included from 3:15:00 to 3:35:00. Among these events, we noted event 2 that occurred at 3:18:00.

Event 2 was dealt with by two different procedures (procedure A or B) by two different controllers (controller 2 or 5). Fig.5 - 8 are tabulated expressions of task level transition by above combination in which all flights in the simulation are included. We named this expression that we developed as CAPS (Chart of ATC Processing State). For example, Fig.5 shows variation of task level for all flights when controller 2 controlled all traffic in the Kanto-North sector by procedure A. In the figure, longer and higher task bars sometimes appear, we can say that workload of the controller becomes high during that period. On the contrary, when lower task bars often appear, we can say that workload of the controller is not high.

From Fig.5 - 8, we can estimate the number of aircraft to be controlled and the task levels for each aircraft at any time in the simulation. Therefore, we can estimate the variation of controller's workload by time elapse. Comparison of Fig.5 with Fig.6 shows that higher task level keeps longer in Fig.5 than in Fig.6 although the same controlling procedure was taken. Similar variation was found in Fig.7 and 8. This variation of task level duration will be caused by the difference in the content and timing of the instructions issued by each controller.

Procedures A and B are then compared in terms of workload to deal with the event 2. Lower task level keeps longer in Fig.7 and 8 than Fig.5 and 6. Thus, we can say that procedure B will need less workload to a controller than procedure A. Fig.5 - 8 also show that the task level for one flight can affect the task level for other flight. Therefore, we can say that these figures are valid to exhibit the interaction of task flow among all flights.

After the real time simulation was completed, participating ATCOs investigated our tabulated expressions. Then, they confirmed that the workload they felt in the simulation agreed well to that presented in our expressions, which means that our method of estimating task level by complexity of traffic is valid. Thus, we can say that our tabular expression is effective to interpret and analyze ATCO's tasks and demonstrate ATCO's workload.

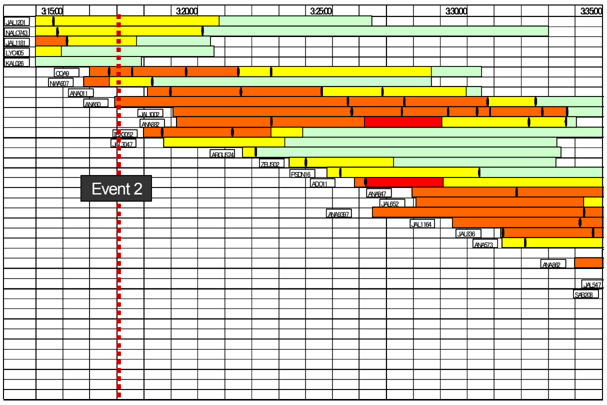

Fig.5 CAPS in process A by participant 2

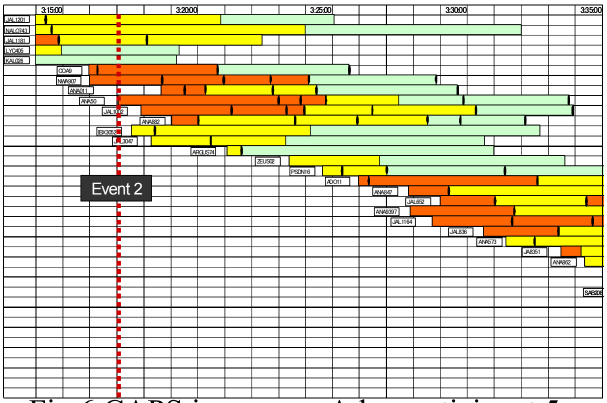

Fig.6 CAPS in process A by participant 5

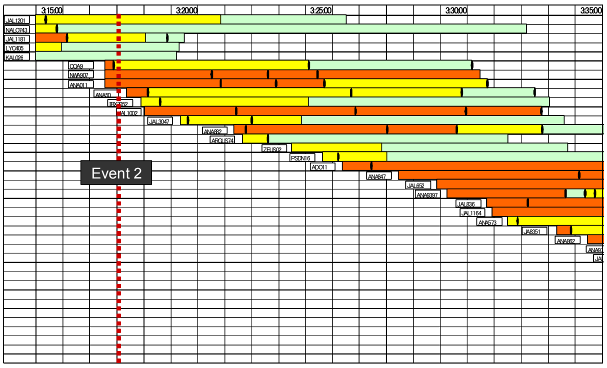

Fig.7 CAPS in process B by participant 1

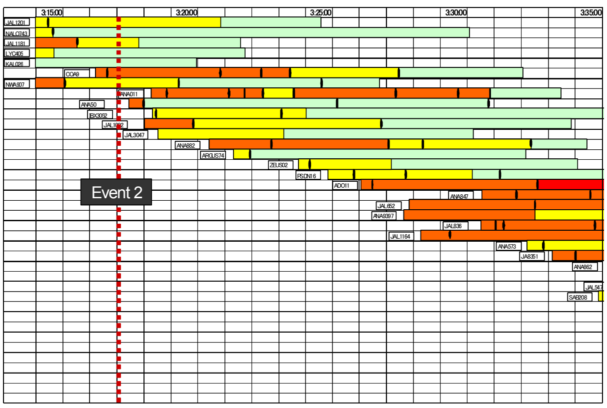

Fig.8 CAPS in process B by participant 3

5. Discussion

Formerly, there were no appropriate methods to measure workload of an ATCO in duty. Communication between air and ground or the number of controlling aircraft has been observed to estimate the workload. However, as an ATCO is free in choosing strategies of control, contents and timing of instructions, the estimation based on communication or the number of aircraft is not enough. Thus, in this paper, we note task level to represent workload. The tabulated expression of the task level (CAPS) also proposed. This expression enables to demonstrate interactions of whole traffic and whole task of an ATCO in duty. Thus, we believe our task level based analysis provides us with more precise estimation of workload.

As described in the last section, task level and its duration was different from one ATCO to another even if each ATCO took the same control procedure because the content and timing of the instructions were different. We believe that this difference is based on the skills of ATCOs. The variation of tabulated expressions as Fig.5 - 8 will then represent the difference in the ATCOs' skills. When we evaluate these expressions, we can choose preferable strategy in the given traffic environment. Therefore, we believe that this expression will be valid as a training material for new ATCOs.

6. Conclusions

En-route ATCOs' tasks are noted and classified into four levels as task level 1 - 4, which correspond to the complexity of traffic. These task levels are then correlated with the RPD model. A new tabulated expression is proposed to visualize the task level transition according to the time. Real-time ATC simulation was then conducted and analyzed. Followings are major results of this work:

a) ATCOs' workload can be represented by our task level based analysis.
b) A procedure taken to deal with an event can affect the procedure for succeeding event.
c) ATCO's workload can be more precisely estimated by observing task level than frequency or volume of communication.

d) Tabulated expression (CAPS) is valid to demonstrate the difference in each ATCO's control strategy.
e) CAPS can also represent the difference in skill of each controller.
f) The validity of our expression has been acknowledged by ATCOs who joined the real-time simulation.

As a future work, we are working to develop automated visualization tool to estimate the workload. We hope that the outcome of this work will be utilized to train ATCOs for safety and efficiency of ATC.

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