2005

Task Analysis for Safety Assessment in En-Route Air Traffic Control

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TASK ANALYSIS FOR SAFETY ASSESSMENT IN EN-ROUTE AIR TRAFFIC CONTROL

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The tasks involved in Air Traffic Control (ATC) make heavy demands on the information processing capacities of air traffic controllers. In particular, human factors problems that lead to both major and minor incidents are considered to be a serious problem for ATC in Air Traffic safety. Therefore, the need to analyze error mechanism, which occurs due to complex factors, and the need for developing systems that can deal with these errors are increasing. We examined the functional problems in an ATC system from the human factors aspects, and concluded that solution of this problem needs some kinds of measures. This research focuses on analysis of the air traffic controller's tasks for en-route ATC and modeling controller's cognitive process.

Introduction

Recently the workload of Air Traffic Control (ATC) has become heavier due to the increase in air traffic demands. Especially human errors that lead to both major and minor incidents are considered to be a serious problem for air traffic safety management. Human factors problems in ATC can be observed or tackled from various aspects. However, little has been known about the causal factors leading to human errors in the current ATC systems.

Thus, we need to understand details of basic functions of air traffic controller's tasks in the systems, in order to design more reliable interfaces or training programs for the controllers. This research focuses on task analysis of air traffic controllers in actual en-route ATC in an experimental approach. We first discuss the idea behind the experiment relying on principles of ethnomethodology, and then show some findings obtained from the experiment.

Approach

ATC is a very complex process that depends to a large degree on human capabilities. The design of advanced and efficient ATC systems for the future requires understanding of the nature of interactions between the controller and the basic available sources of information such as the radar display console, paper flight progress strips, aircraft pilots, and other controllers.

In order to design the system that can assure system safety, enhance usability, and support human reliability in the future, it is critical factor for an developer's engineer to consider the feature in the control system operation and the intention of the controller.

An effective method to understand user's requirements is to analyze user tasks based on actual field data. This research aims to make a model of cognitive process of an air traffic controller through task analysis, to find the problem from human factors perspective for improving design of future air control systems.

Suchman (1987) pointed out the need of an ethnographic approach on the site of work when it is the problem what knowledge and experience people use in a cooperative work. Ethnomethodology is a method of sociology to find out some implicit orders, rules, or norms behind human activities through observation in the actual work environment (Ando, 2003). Both the research of works in the cockpit of aircraft by Hutchins (1994), and the research of works in the London underground line control center by Heath and Luff (1992) are based on this idea of ethnomethodology.

We believe ethnomethodology is one of the effective methods for analysis of ATC tasks, because when we examine human factors problem, it is important to understand the actual work environment. In this research, an experimental task analysis was done by an ethnographic approach.

Experimental Setting

To analyze how air traffic controllers work, we built an experiment system for collecting data through simulator experiment. In the experiment, we recorded motions, sounds, and simulator logs as basic data for the analysis. From these basic data, we reconstructed controller's actions and protocol logs, and analyzed controller's tasks in each situation. The system has functions to record multiple types of time-series data such as video, audio and simulator logs.

Figure.1 shows the setting for video and audio recording in the simulator room. Fixed cameras record actions of the controllers, displays of instruments, the chart table, and projected situations from four angles. Three capacitor microphones can record all communications between the controllers in the room and communication for pilots.

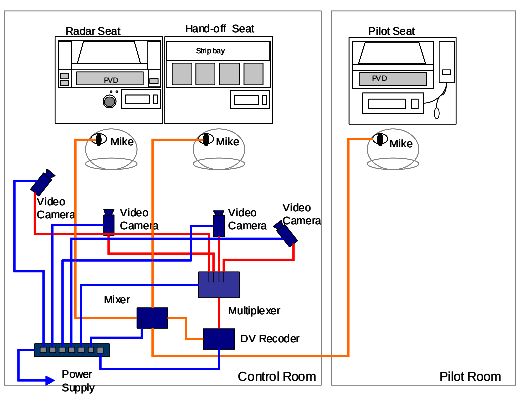

Figure 1. *Setting of experiment*

- Video (VTR) data - The VTR records air traffic controller's behavior like instruction, coordination, etc., in the control room. Four cameras record the situation of the entire control room from four directions including the radar screen, the flight-data-strip bay, the seat of radar controller, and that of coordination controller. Moreover, this system combines videos of the all cameras and audios from the radar controller, the coordination controller, and the pilot, takes synchronization, and then records them in a batch.
- Flight-data-strip - As for flight-data-strips, marks, notes, and so on are written down by the air traffic controller during controlling work. We understand clearance and instruction for individual airplane pilots and the content of coordination to other sectors from the records on these papers.
- Simulator track log - All the route patterns and parameters of each aircraft during experimental runs are recorded in the simulator as a log. These records together with records of video and flight-data-strips are used to understand behavior of the air traffic controller, the control situation at each moment, and consequence of controller's instruction.

Method of Task Analysis

The radar controller and the coordination controller, who takes charge of en-route ATC, frequently monitor the display of the radar control interface and data of flight-data-strips, and carry out controlling tasks while exchanging information. For instance, when the radar controller projects existence of a related aircraft from the radar monitor, a series of works of the radar controller is directed to the pilot by communication of an appropriate instruction to the aircraft to avoid conflict. The controllers then input the content of instructions to the RDP (Radar Data Processing) system, and mark the flight-data-strip.

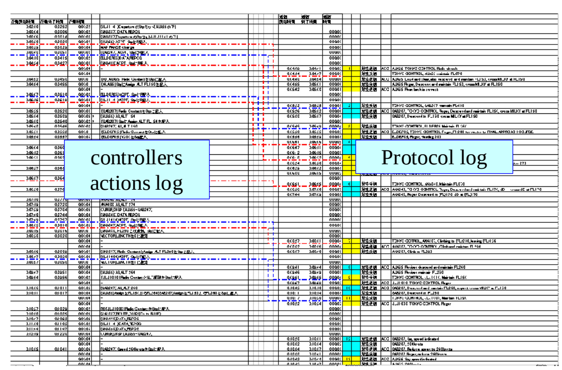

Figure 2. *Data logs in a time line*

A sequence of controller’s tasks are described into time line data that consist of action log and protocol log as shown in Figure.2 based on each data of videos, flight-data-strips, and simulator logs recorded with the experiment system. The situation is then segmented following the content of radar controller's communication mainly based on the time line data of action and protocol. The context of each segmented situation is analyzed based on the action and protocol data as well as the explanation of situation made by a supervisor (Figure.3). In addition, Goal-Means Task Analysis (GMTA) was performed on these situations (Hollnagel, 1993).

3:07:18	3:07:22	5		TOKYO CONTROL ENJOY01 270
3:07:22	3:07:26	5	ACC	ENJOY01 TOKYO CONTROL ROGER SAY
3:07:26	3:07:29	4		ENJOY01 HEADING 143
3:07:29	3:07:36	8	ACC	ENJOY01 TURN LEFT HEADING 130 DUE TO TRAFFIC EXPECT VECTOR TO FINAL
3:07:37	3:07:40	4		ROGER HEADING 130

<Explanation>
ENJOY01 was approaching to RJAH. The controller did not want it to go through GOC for avoiding conflict with AUA51. The controller used a vector as the method of control and directed ENJOY01 to Heading 130 here.

Figure 3. *Example of situation segments*

Result of Experiment

Conditions

The Kanto North sector shown in Figure.4 was used as the target of simulation experiment, and the subjects are professional controllers qualified for this sector.

We monitored behavior of a team of a radar and a coordinator controller working on a simulation scenario of about 60 minutes where they performed multiple tasks of handling many planes at a time. The controllers controlled 75 aircrafts in an hour. Table.1 shows the detail of the traffic handled in the scenario. The data of the first eight lines in the table correspond to the aircrafts that require climbing or descending instructions from the controllers in compliance with the control regulation in the sector. The controllers do not need to intervene these aircrafts as long as enough separation is kept. The number of over flights is three in total out of 75 aircrafts. It is the feature of this sector therefore that the major traffic is a flow of aircrafts climbing from or descending to airports. The amount of traffic assumed in the scenario is relatively heavy.

Table 1. *Detail of experimental scenarios*

	Bound	
Airport	DEP	IN
RJTT (TIA)	14	22
RJAA (NRT)	6	9
RJSF	3	2
RJTY RAPCON	5	4
RJTK	1	0
RJAH	4	1
RJTU	1	1
RJSS, RJSC	2	3
OVER FLIGHT		3

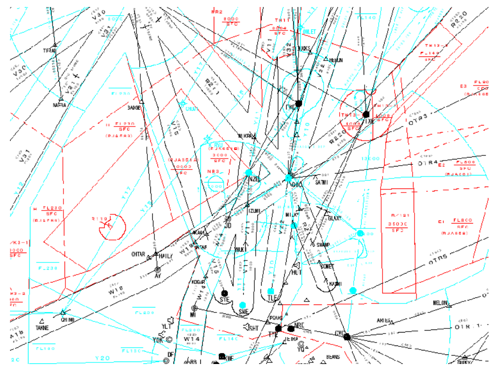

Figure 4. *Map of Kanto North sector*

The Data of Result

We have already finished analysis of data for three teams at present. Table.2 shows the number of communications and situation segments from the communications.

Table 2. *Number of communications and segments*

	Subject team		
	A	B	C
Number of communications	598	567	582
Number of segments	256	234	259

Some differences exist in the number of communications depending on the content or the way of communication. Instructions were issued for many purposes: initial contacting, clearance, spacing, radio frequency transfer (hand-off), etc.

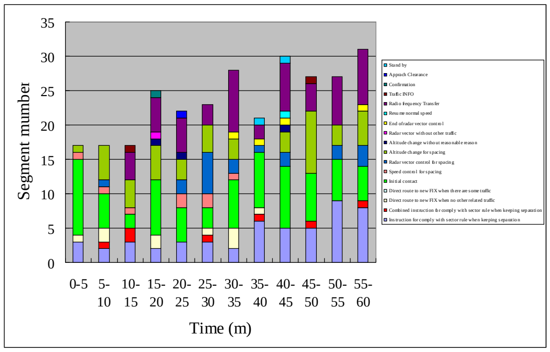

Figure 5. *Content of communication contents*

Figure.5 shows the number of situation segments totaled by every five minutes and classified by the content of communication. The peak of traffic comes in this experiment at 25 minutes and 40 minutes. We can see that many instructions for the spacing are concentrated on during that time. It can be understood that the radar controller put out a variety of control instructions along the situation for spacing. However, we do not understand the radar controller's cognition and decision making process from such a statistical method.

Case Analysis

It is difficult to understand the decision making process of the controllers how to decide particular instruction in particular situation. We analyzed an individual process of decision making that resulted in a single segment of communication. Since too many segments exist as shown in Table 2 to show every result of such analysis, one example will be given here that well reflects the geographic features and the regulation rules of this sector.

It is characteristic that a lot of aircrafts come into this sector from more than two sides of northern sectors to land at the Tokyo International Airport (TIA). The controllers should guide these aircrafts down to an altitude of 13,000ft by TLE, which is the point to transfer descending aircrafts to TIA RAPCON (radar approach control) and to handoff to the next sector, while keeping separation above 10 mile in the trail. The way and the content of instruction to aircrafts from more than two directions are important for the control tasks in this case. For instance, let us think about the relating situation of four aircrafts shown in Figure.6 from the experiment. In this situation four planes are coming from three districts in the north aiming at TIA. The controllers have to line up these four aircrafts at 13,000ft and keep separation in 10nm each aiming at TLE.

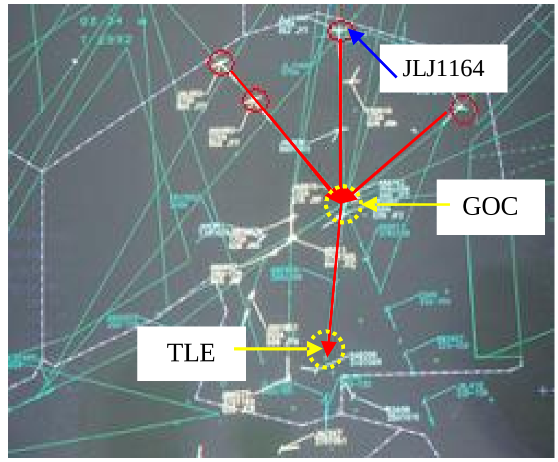

Figure 6. *Example situation for case analysis*

The radar controller directed the instruction "JLJ1164 FLY HEADING 170 FOR SPACING" at Figure.6. Figure.7 is a description of the situation to JLJ1164 at the situation that is shown in Figure.6. At this time, the radar controller considers JLJ1164 that is No.3 in-bound to TLE, and directs an instruction for spacing as the way of radar vector control.

Target:< To keep the safety interval of JLJ1164>
Task: To keep the safety interval.
Precondition: To understand the status of the aircraft.
Target:< To understand the status of the aircraft >
Task: Radar monitoring or confirmation by communication
Precondition: Clearance of related traffic.
Target:< Related traffic is cleared. >
Task: To examine the method of spacing.
Precondition: To examine the control method to the destination.
Target:< To examine the control method to the destination >
Task: Route retrieval.
Precondition: To examine the method according to the control rules.

Figure 7. *GMTA of the case*

The result of GMTA on one arbitrary segment related to the case situation is shown in Figure.7 as a schema. We can thereby understand the process of radar controller's decision making in one situation. GMTA defines descriptions of the task step and the feature of the tasks of the action in specific situations. We can observe the common performance modes of the controller by GMTA. The common performance modes are a convenient way of describing the impact of the context on the control of actions. The common performance modes can be determined from the outcome of the GMTA (Hollnagel, 1993).

We recognized the state of the controller's cognitive and decision making process as a model (ex: depth of the situation comprehension, accuracy of the projection) in a situation of the individual segment in this experiment. Especially, It can be expressed the relation between control mode of the controller's performance and cognitive process of the controller in this analysis. This result of analysis shows the level of the cognitive process model in individual tasks of the controller in detail. This schema, however, is for the situation of a single segment.

A comprehensive model is necessary to express a series of cognitive process until handoff is done. Situation analysis by observation and interview of the controllers can be repeated to reveal a series of cognitive process.

The strategy for each situation of an individual radar controller does not differ greatly, because conditions are limited from regional characteristics and the rules of the sector. Concrete methods, however, of applying the strategy had some individual variations. When keeping separation, for instance, one controller used speed adjustment several times without removing aircrafts from the route, but another controller used vector instruction rather than speed adjustment from the beginning.

Cognitive Model

Features of Tasks

This chapter describes construction of a cognitive model of an air traffic controller from the observation and analysis of the experimental records. Kawano (2001) mentioned that there are some specific features in work of ATC. Especially the basis of the work is prediction and instruction to secure a safe situation in the future.

As for the radar controller in en-route control tasks, he/she predicts from five to ten minutes ahead. Meanwhile the coordination controller elaborates instruction to keep safe separation in the previous state from the information available at present.

A lot of interruptions will happen when the controllers have to handle more than two aircrafts at the same time: call from another aircraft than that of current interest, request of hand-off from another sector, and so on.

The coordination controller has similar tasks with interruptions to keep coordination with next sectors. In addition, the controllers have to control all IFR aircrafts in their own sector. Since en-route ATC work have to deal with a variety of states and conditions of the sector, it differs greatly from well formalized tasks like assembly line operation.

Control Mode of ATC Controllers

The model presented here represents the routine task of decision making and performance of the radar air traffic controller as a flow chart. When issuing a conflict avoidance command to keep separation of airplanes, the priority is determined from the relative distance and velocity of airplanes, an appropriate avoidance method is chosen from the flight situation, and then the instruction is given to the airplane. The control modes of a controller in the above process can be defined based on the Contextual Control Model (COCOM) of Hollnagel (1993) shown in Figure.8. COCOM consists of four control modes of human performance.

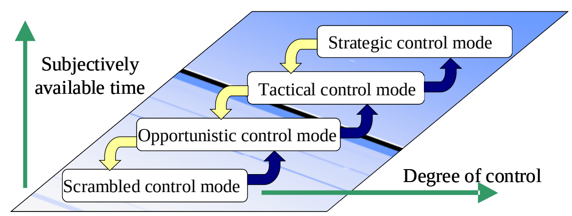

Figure 8. *Control modes of COCOM*

Usually the air traffic controller is working within a range from the strategic to the tactical control mode. It is well known that air traffic controllers are likely to err in the opportunistic mode, because they will take an action based on its face validity of situation without profound awareness. Talking about the control mode of each air traffic controller, the radar controller is almost in the tactical mode, because the time margin for his/her decision making is relatively restricted.

Cognitive Process of Radar Controller

In this research, we examined the basic cognitive process of the radar controller in a state of a single task. Controller's tasks are restricted by geographical features of the sector, the air route characteristics, the control rules, etc. In addition, the controllers are highly trained to handle the tasks efficiently and safely in a very restricted time interval.

The decision making process of an air traffic controller is defined as the model shown in Figure.9 from the observation of the experiment and the analysis of interview to the subjects. This basic model follows Endsley's model of Naturalistic Decision Making (Endsley, 1997).

This process will arrive at decision through search of the target by perception (perception), understanding of the sector situation (comprehension), prediction of the future state of aircrafts (projection), and execution of action.

It is highly depending on time margin available for each process whether the process of decision making is strategic, tactical, or opportunistic. Instruction becomes strategic if there is a lot of time margin in the all processes. We observed that the content of judgment could sometimes become unrelated with the time margin when short cut of the process happens by heuristic situation assessment in each process.

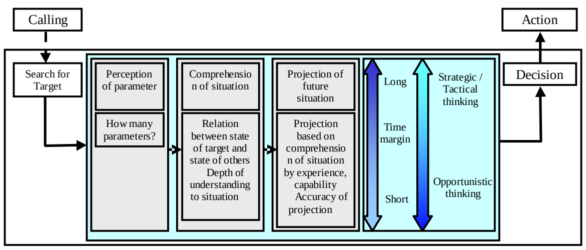

Figure 9. *Cognitive model of radar controller*

The radar controller executes such a cognitive process in a very short time. It seems that the experience of the controller has an important effect on his/her situation projection in this state. The air traffic controller has a model of situation assessment originated from his/her experience. We obtained an expectation that the controllers made a decision in this experiment by pattern matching with the data base of the model.

Conclusion

In this research, we proposed a technique for analyzing tasks of ATC by a method of ethnomethodology as an approach to study problems of human factors in an ATC system. We will continue the data analysis to understand detailed features of cognitive process of a controller team. We are going thereby to construct a model of team cognitive process and then a database for both the radar and the coordination controller.

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