2007

Task Analysis for Team of Air Traffic Controllers in Enroute ATC

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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. In this research, 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

The workload of Air Traffic Control (ATC) has become heavier due to the increase in air traffic demands. 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. Moreover, to be of use, supporting systems require an accurate model of controller’s behaviour.

We focused on task analysis of air traffic controllers in actual en-route ATC in an experimental approach in this research. We first discuss the idea behind the experiment relying on principles of ethnomethod -ology, and then show some findings obtained from the experiment. At second, we present the model of cognitive processes of a controller. Finally, we conclude by discussing future efforts.

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 controllers and the basic available sources of information such as the radar display console, paper flight progress strips, aircraft pilots, and other controllers.

As work and tasks become more complex and the volume and type of information required for those tasks become increasingly larger and more complex, the need for systems that are designed to support controllers becomes apparent (Sheila, 2002). One of the promising strategies for systems to assist in task performance is the concept of cognitive systems that try to enable systems to interact with humans in a knowing manner that is similar to the way in which humans interact with one another (Forsythe et al., 2006). Such systems require being equipped with a user model that explains the user behavior from variety of aspects of cognitive processes such as awareness, memory, user knowledge and experience, context recognition, planning, intention formation, and even consciousness in order to assist in the user’s cognitive process by estimating them(Forsythe et al, 2006; Haikonen, 2003).

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.
At first, this research aims to make a individual model of cognitive process of Air traffic controllers in en-route through task analysis, to find the problem from human factors perspective for supporting ATC systems in the future.

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.

We consider that 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.

Result of Observation

In here, we describe construction of a cognitive model of an air traffic controller from the observation and analysis of the experimental records. Kawano 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, the controller 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.

Basic Control Mode of ATC Controllers

From the observation and analysis of the experimental records. We think that it can adopt the model as shown in Figure 1. The control modes of a controller in the above process can be defined based on the Contextual Control Model (COCOM) of Hollnagel shown in Figure 1 COCOM consists of four control modes of human performance.

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. And the coordination controller is also in strategic mode, because he/she has more long time margin than radar controllers.

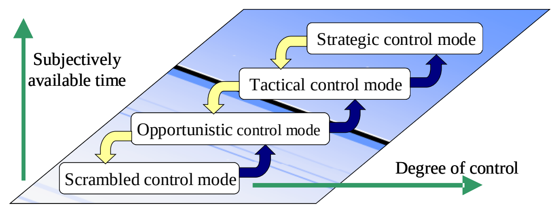

Figure 1. Control Mode of COCOM

Moreover, When we think about control mode of Controller based on SRK model of Rasmussen , the almost situations can be considered to be a rule based mode in general situation (without irregular situation). In the next simulation, we tried to examine model of controller’s cognitive process from human factors perspective.

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.

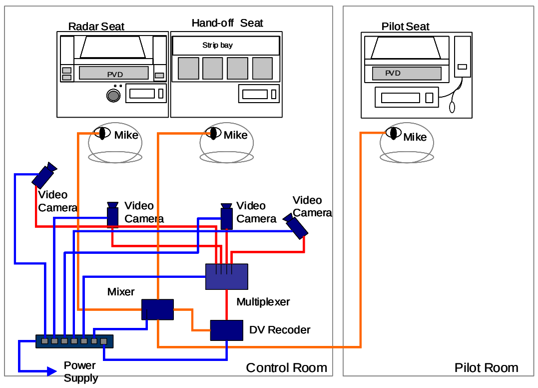

Figure 2. Setting of experiment

Result of Experiment

Conditions

The Kanto North sector shown in Figure 3 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 over 60 aircrafts in an hour. The controllers do not need to intervene these aircrafts as long as enough separation is kept. 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.

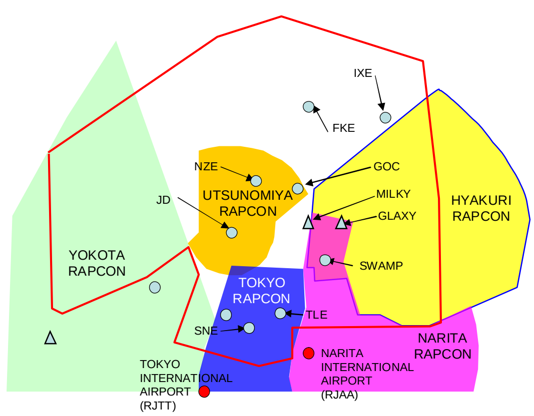

Figure 3. Map of Kanto North Sector and Adjacent RAPCON

The Data of Result

We have already finished analysis of data for three teams at present. Table.1 shows the number of communications and situation segments from the communications.

Table 1. 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. In this experiment, the peak of traffic comes in this experiment at 25 minutes and 40 minutes. We can observe 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 1 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.

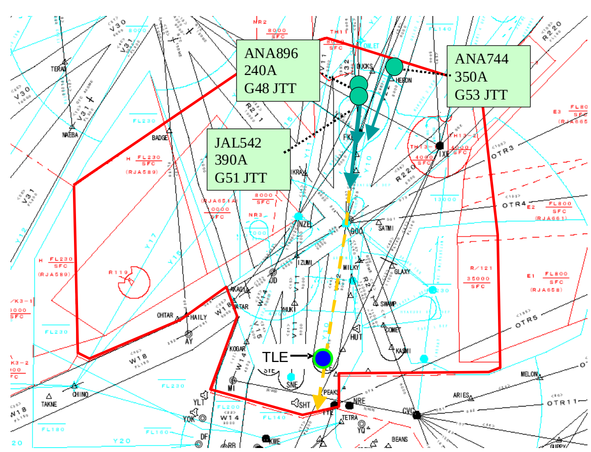

Figure 4. An Example Situation for Case Analysis

In here, it explains the method of thinking as a case study of the analysis what is the routine for the situation as a series of flow. 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.

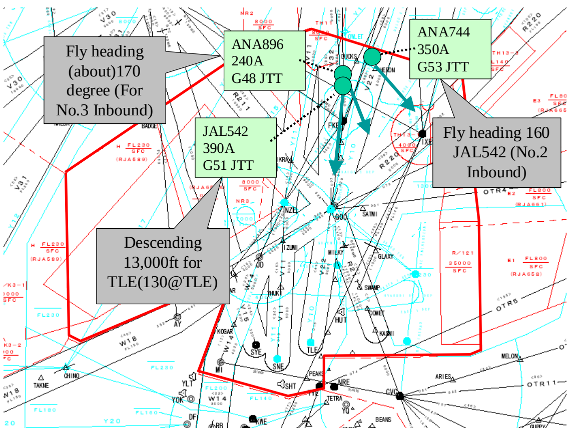

Figure 5-1. 1st state in the example situation

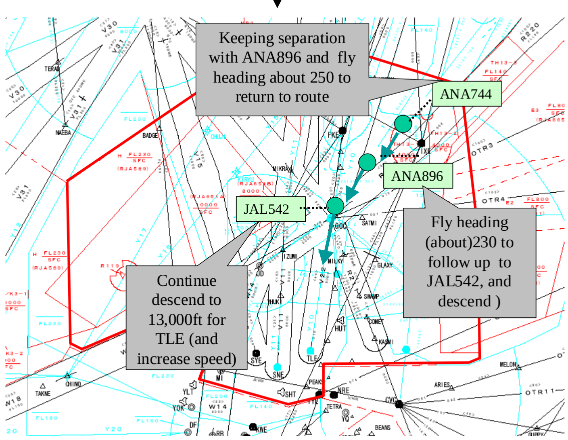

Figure 5-2. 2nd state in the example situation

For instance, let us think about the relating situation of 3 aircrafts shown in Figure 4 from the experiment. In this situation 3 planes are coming from three districts in the north aiming at TIA. The controllers have to line up these 3aircrafts at 13,000ft and keep separation in 10nm each aiming at TLE.

When the controller percepts this situation, he/she will do comprehension and projection such as follows routine matching.

The radar controller directed the instruction “JAL542, descend and maintain 13,000, cross TLE at 13,000.” at first in this situation. After that, the controller instructed “ANA896, fly heading 170 for spacing.” as No.2 in-bound to TLE. And then, the controller directed “ANA744 fly heading 160 for spacing.” Figure 5-1 is a description of the situation to these 3 airplanes at the situation. At this time, the radar controller considers JAL542 that is No.1 in-bound to TLE, ANA896 as No.2 and ANA744 as No.3 direct instructions for spacing as the way of radar vector control. Afterwards, the controller instructed each airplane to line up at 13,000ft and keep 10nm in trail in Figure 5-2.

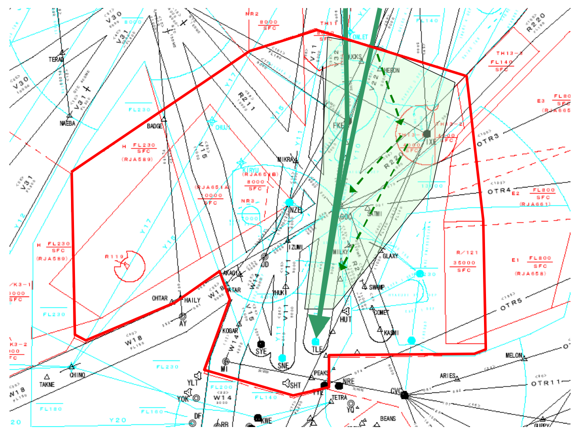

Figure 6. An Example of Controller’s Strategic Routine

Figure 6 shows one of the series of the radar controller’s strategic routine for spacing when two or more traffic come from the north side at a time. These strategic routines contain the way of control and timing of instructions.

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 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.

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.

In the same way of analysis, we were able to confirm a strategic cognitive routine of general basic traffic flow by 24 routines.

Cognitive Process of Radar Controller

From the observation and analysis of the experimental records. We think that it can adopt the Recognition -primed decision (RPD) model of Klein (1989). Klein described a RPD model of how people are able to make decisions in naturalistic settings without having to compare options. The key is that people use expertise to evaluate situations and recognize typical courses of action as the first ones to be considered. Expertise centers around situation awareness. The control modes of a controller in the above process can be defined based on the RPD model. Usually the air traffic controller use strategic routine as their experience to recognize a situation as familiar or typical and know what the typical reaction is.

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.7 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 (1997).

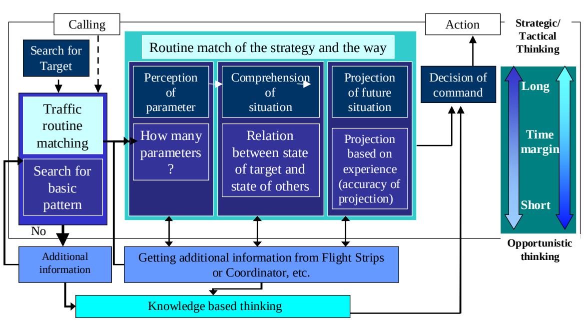

Figure 7. Cognitive Process Model of Radar

Controller

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.

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 routine matching with the data base of the model.

Modeling of Team Cognitive Process

It is based on the analysis so far, We are trying the data analysis to understand detailed features of cognitive process of a controller team.

A assisting system must be able not only to recognize the current situation and cognitive state of the human partner capable of assisting a person must be able not only to recognize the current situation and cognitive state of the human partner but also be able to sharer and interweave them in the way that humans do so in human-human cooperation. In other words, the machine partner must be equipped with a model for cooperation and be placed in-the-loop. Such a systems can understand that ”we” (not the user) are doing some cooperative tasks and be aware of the human partner’s cognitive state as well as bottlenecks in the cooperation.

Kanno proposed model is composed of three layers of cognitive process (2006): individual cognitive process, belied in the partner’s cognitive processes, and belief in the partner’s belief regarding one’s own cognitive processes. the 3-layered team cognitive process model based on a theoretical model of “we –intention.”

We-Intention

In the philosophical literature, we can find many discussions and analyses of various notions of intention behind cooperation. Some describe a cooperative activity as a whole, as if it were performed by a single entity. Conte used the term “collective mind,” which is external and independent of an individual mind. It is very convenient to explain a team cooperative activity using such an assumption. However it is questionable whether there is such an entity as an external mental component that represents and causes the actions of the team members. Moreover this assumption cannot explain conflicts because it does not deal with the internal relationships of individual intention and action. Others describe cooperative activity from the viewpoint of individuals. It is natural to think that team behavior is the result of nothing but individual cognitive processes and to describe it from a bottom-up viewpoint. Most researchers therefore use the notion of “We-intention,” “group intention,” or “joint intention” that can be reduced to a set of individual intentions and mutual beliefs(Tuomela & Miller, 1987;)

For simplicity, we assumed a dyadic case in which the team consisted of two members, A and B, as in the analysis by Tuomela and Miller. The analyzed we-intention as follows.When agents A and B intend to do some joint task, X, cooperatively the following conditions hold.

a) A intends to do his/her part of task X.
b) A believes that B will do his./her (B’s) part.
c) A believes that B believes that he/she (A) will do his/her part.

Beliefs that are hierarchically justifiable, such as conditions (b) and (c), are called mutual beliefs. We therefore constructed a three-layered model for team cooperation in this study.

Team Cognitive process

Based on the above theories, Kanno proposed a conceptual model of team cognitive processes (2006). The base assumption is that there is a multi-layered structure not only for team intention but also for the other processes of team cognition such as obtaining awareness, goal-setting, planning, and so on. Figure 8 illustrates the structure of the model.

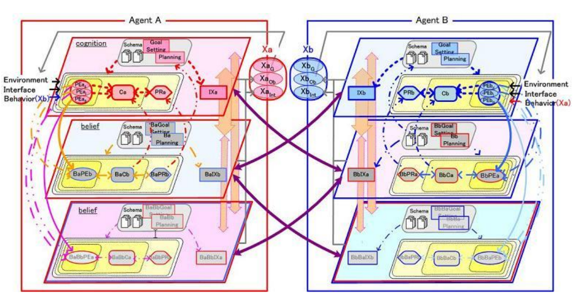

Figure 8. 3-Layered model of team cognitive processes.

The top layer represents the individual’s cognitive processes, the middle layer the belief in the partner’s cognitive processes (partner’s top layer), and the bottom the belief in the partner’s belief (partner’s middle layer). In this figure. Ba/Bb refers to A’s/B’s belief, respectively. For example, BaPEb/BaCb/BaP -Rb refers to agent A’s belief regarding each level of partner’s (B’s) belief in A’s awareness.

In team situations, we have different channels and mechanisms that augment our own perception from the environment and/or out interfaces for obtaining awareness, goals plans, and intentions. These channels and mechanisms specific to team situations are also utilized in obtaining beliefs regarding one’s partner’s mental components. Now, we try to analyse these mechanisms of team cooperation related to the sharing of mental components as well as provide a partial proof of the model from a task analysis of team cooperation in ATC tasks from.

Conclusion

In this research, we proposed a technique for analyzing tasks of ATC by a method of ethnomethod -ology as an approach to study problems of human factors in an ATC system. We will continue the data analysis to understand detailed features of model of cognitive process of controller’s team using by an idea of three layered model. We are going thereby to construct a model of team cognitive process.

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