A Study on Distributed Cognition for Team Cognitive Process Modeling in ATC

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Abstract: 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. Since ATC is usually undertaken by a team of controllers, Team collaboration is a key issue for good performance in ATC. But it has not been studied compared with individual cognitive process. 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 work aims to construct a cognitive model of team cooperation. This research focuses on analysis of the ethnographic data of en-route ATC that was obtained by field observation and modeling controller's team cognitive process.

Keywords: Task Analysis, Cognitive Systems Science, Ethnomethodology, Distributed Cognition

1. INTRODUCTION

Air traffic control (ATC) is a complex process that depends to a large degree on human capabilities. Understanding how controllers carry out their tasks is an important issue for the design and development of ATC systems. From the cognitive process perspective, it is essential that systems developers have an understanding of the complex working processes that involve cooperative work of multiple controllers. Distributed cognition is one of the methodological frameworks to analyse cognitive processes that spans multiple actors mediated by technology. In this research, we attempt to analyse and model interactions that take place in en route ATC systems based on distributed cognition. We have taken the activity of a cooperative team of en route controllers as the unit of analysis from cognitive process perspective. We discuss the application of ethnographical analysis in ATC, and report on findings from the observation and analyses.

2. ETHNOGRAPHIC APPROACH

The workload of ATC has become heavier due to the increase in air traffic demands. Air traffic controllers are expected to continue keeping the safety of the air space and maintaining the air traffic flow to run smoothly. As work and tasks of controllers become more complex and the volume and types of information required to carry out these tasks become increasingly larger and more complex, the need for systems that are designed to support controllers becomes greater[1]. In order to design the system that can assure system safety, enhance usability, and increase operator reliability, it is critical for the developers of ATC systems to consider the specific nature of the control system operation and cognitive characteristics of controllers.

Automation tools have been used as effective support tools in various industrial sectors. However, human errors occur when mutually dependent relationships between controllers and machines break down. 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[2].

Such systems require a user model that explains the user behaviour from various aspects of cognitive processes such as awareness, memory, user knowledge and experience, context recognition, planning, intention formation, and even consciousness. User models can be used to predict users' cognitive processes which in turn can be used to better support them[2,3]. Thus, we consider that an effective way to understand user requirements is to analyse user tasks based on actual field data. The aim of this research is to analyse team cognitive processes and team situation awareness in normal (i.e., not accidental) situations for a team of en route air traffic controllers based on the distributed cognition approach so as to better understand current ATC systems.

3. FRAMEWORK OF DISTRIBUTED COGNITION

An ethnographic approach can be effectively applied when the problem involves the analysis of what knowledge and experience people use in the context of cooperative work. Ethnomethodology is a method of sociology to discover implicit orders, rules, or norms behind human activities through observation in the actual work environment. Distributed cognition is one of the analysis methods of ethnomethodology that serves as a framework for understanding interactions between people and technology so as to inform the design of interactive systems [4]. Distributed cognition can be effective in analysing cooperative work from the cognitive process perspective. Both the research on interactions in the aircraft cockpit by Hutchins[5], and that on the London Underground line control centre by Heath and Luff[6] are based on the approach of distributed cognition or ethnomethodology. A central tenet of distributed cognition is that cognition should be regarded as a property of a system of individuals and external representational artefacts, carrying out cooperative activities[7]. In this paper, we focus on the factors of team performance, in particular, how it is constructed by elements such as team situation awareness and mutual belief. As a first step to analyse how air traffic controllers work, we carried out data collection through observation and recording of actual work in the Tokyo Area Control Centre (TACC) control room.

3.1 Field Observation

We describe the cognitive model of an air traffic controller from the observation and analysis of experimental records in here. Kawano[8] mentions that there are some specific features in the work of ATC, in particular, the basis of work is prediction and instruction to secure and maintain a safe traffic situation. As for the radar controller in en-route control tasks, the controller predicts the traffic between five to ten minutes ahead. Meanwhile the coordination controller elaborates the instructions to keep safe separation of aircrafts in the previous state from the information available at present. Many interruptions will happen when the controllers have to handle more than two aircraft at the same time: call from another aircraft that is outside current interest, request of hand-off from another sector, and so on. The coordination controller has similar tasks with interruptions to keep coordination with neighbouring 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 formalised tasks such as assembly line operation.

3.2 Data Gathering

In this observation, we recorded motions and sounds by video, and system logs as basic data for the analysis. From these we reconstructed the controller's actions and protocol logs, and analysed the controller's tasks in each situation. The system has functions to record multiple types of time-series data such as video, audio and operation logs. This study covered 6 hours in 3 days.

As a team, a radar controller and a coordination controller frequently monitor the display of the radar control interface and flight-strips, and carry out controlling tasks while exchanging information.

For instance, when the radar controller projects the existence of an aircraft from the radar monitor that might lead to a conflict, a series of work of the radar controller is directed to the pilot by communicating appropriate instructions to avoid any conflict. The controllers then input the content of instructions to the RDP (Radar Data Processing) system, and make markings on the flight-strip. At the same time, the coordination controller also projects the situation from the radar monitor and the flight-strip (which contains the flight plan) in the same way as the radar controller. However, the role and task of coordination controller are different from those of the radar controller. For example, the coordination controller coordinates with adjacent sectors to keep the traffic flow smoothly so as to make it easier for the radar controller to carry out his/her tasks.

A sequence of controllers' tasks are described into the time line data that consist of the activity log for each controller (the radar controller and the coordination controller) and the protocol log based on video, flight-strips, and systems logs data. The situation is then segmented following the content of radio communication between the radar controller and the pilot, coordination with adjacent sectors and each controller's communication mainly based on the time line data of activity and protocol. The context of each segmented situation is analysed based on the activity and protocol data as well as the explanation of situation made by a supervisor who is also a qualified controller.

4. METHODOLOGY

First of all, we defined a model of Radar controller from observation analysis in our previous research[9]. It's a Routine Model. A Routine is a large chunk of expert knowledge and a radar controller uses routines for prompt and reliable execution of control tasks. Routines are shared not only by Radar Controllers but also by Coordinator Controllers, because each controller does the both roles by rotation. Sharing expert knowledge, routines, is important for Team Collaboration.

Another basis of the analysis is mutual belief. Mutual Belief is a fundamental idea to explain Team Collaboration. When someone performs actions for a particular purpose independently, he/she has Individual Intention. But Individual Intension is not enough for team Collaboration. A member in the team should be conscious also about "What do my colleagues intend to do?", "Are my colleagues aware of my intention?" and so on. These beliefs among team members are called Mutual Beliefs. An idea of Mutual Belief can also be applied to Situation Awareness or other team Cognitive Processes. Figure.1 represents a Notion of TSA based on mutual beliefs of two-member team.

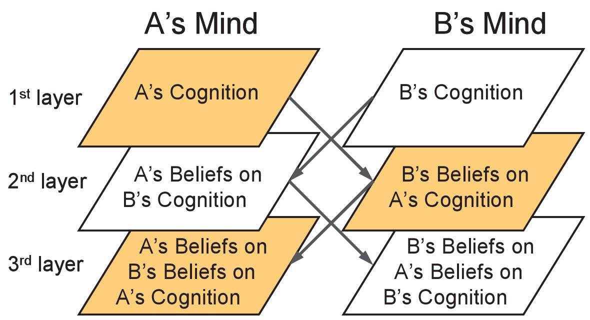

Figure 1 The model of mutual beliefs

The 1st layer is for describing individual cognition. The 2nd and the 3rd layers are for describing mutual beliefs.

The contents of the 1st layer are reflected in Partner's beliefs in the 2nd layer. And those in the 2nd layer are reflected in the Partner's beliefs in the 3rd layer.

Consequently, the belief in the 3rd layer should agree with the cognition in the 1st layer in the ideal situation.

We tried to confirm that these Mutual Beliefs are working in collaboration processes of an En-route ATC team.

We identified four major strategies along with the cognitive processes for their team situation awareness (TSA) and intention in establishing shared cooperative activities: 1) Communication, 2) Mental simulation, 3) Knowledge-based inference, and 4) examination of the consistency among their observable mutual beliefs. Kanno[10] proposed this team cognitive process model that can be used to trace and predict the processes of sharing team situation awareness and intentions in human cooperative activities, which can be used by the system to augment human performance in a cooperative manner.

1) Communication

Verbal communication fulfils an important role in team cooperation. Team members exchange various kinds of information related to their tasks such as awareness, plans, actions, etc., for effective cooperation. Beliefs regarding one's partner's mental components can be obtained by inferences based on his/her perceptions, though in most observed cases it was obtained by communication exchanges. In Endsley's model[11], information from team members is regarded as a part of each member's perception. We consider that high level mental components such as comprehension, projection, goals, and intentions are considered to be directly exchanged via communication.

2) Mental simulation

The ability to understand one's partner's mental state is usually considered to be an innate potential ability in humans[12]. If a team could exchange their mental components amongst each other explicitly in their communication, they could share their cognitive processes. However, this is not possible in almost any real settings. Therefore, a reasoning process is required regarding one's partner mental processes from the available information sources.

3) Knowledge-based inference

According to the Kanno's cognitive process model, inferences can take place across different layers. Some observable state changes from the environment and/or interface related to the task execution enable one to infer one's partner's awareness regarding intention or actions.

4) Consistency Check and Mutual Response

When the person noticed that his/her partner is not also aware of the information, communication to inform one's partner of one's awareness often takes place. It is suggested that one supposes his/her partner's cognitive processes and sometimes checks their consistency with his/her own mental models. This process tends to become observable and conscious when one notices any conflict, and this realisation then contributes to providing a trigger for confirming the soundness of their cooperative work. On the other hand, such consistency can also be confirmed through mutual responses in observable actions.

TSA is established and updated by theses schemes. And there are four strategies of TSA maintenance.

- The first one is to Complement one's own cognitive substance. It appears, for example, as an action of getting information about the situation.
- The second one is to Complement one's own mental simulation. It appears as an action of getting information on partner's cognitive process.
- The third one is Verification to keep consistency. It appears as an action of confirming information.
- The last one is to Support partner's mental simulation. It appears as an action to tell the partner one's own cognitive process.

TSA can be explained with interaction among team members based on these schemes and strategies. By observing these schemes and strategies in team interaction, Mutual Beliefs working in the interaction can be confirmed.

5. CASE STUDY AND FINDINGS

In this analysis, we observed one of the sectors of TACC. The target sector has various types of traffic such as climbing after taking off, descending for landing, over-flight, etc., which are characteristic tasks of this sector. Therefore, we could analyse the mutual communication and team situation awareness between the radar controller and the coordinator based on actual observations. We categorised how these mental processes are formed, shared, and modified in actual team cooperative activities based on observations and post-experiment interviews. We describe below an example of task flow and team cooperative work observed.

5.1 Field Observation

The observation was carried out at the Tokyo Area Control Center for 4days in May 2007.

Data were recorded with 2 VTRs for Controllers' Action, 1 VTR for the Rader screen and 1 voice recorder for Controllers' Conversation. And Regular journal Records of Radio Communication, Ground Line Communication and Flight-strips were obtained.

5.2 Target Sector

Kanto-north Sector covers northern area of Tokyo.

Air traffics departed from and approaching two large hub Airports and several smaller Airports and air fields pass through this sector. Since these traffics are of various types, this sector is suitable for observing different aspects of ATC tasks.

5.3 Case Study

The case shown in Figure 2, 3 kinds of traffics came into the sector all together and the controllers handled these traffics in collaboration. 3 aircrafts displayed in red and another one in green were descending to Narita airport. Another one in blue, which came from the south east, was descending to Hyakuri Air Force Base. Since these traffics might interfere each other within a narrow area, the controllers had to keep separation among them.

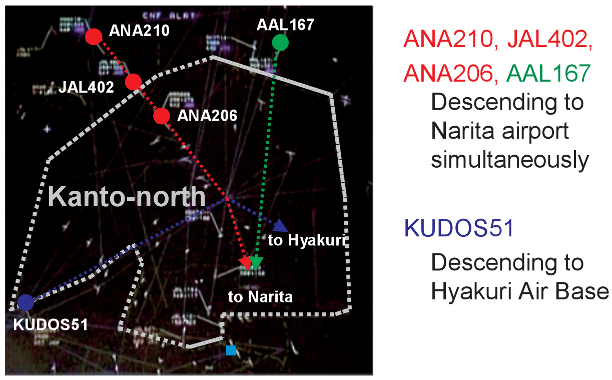

Figure 2 Case Study of Kanto North Sector

5.4 Process of Cooperative Work

The diagram shown in Figure 3 represents details of interaction between the two controllers along the time axis. Solid Line Arrows show verbal Conversation and Dashed Line Arrows Recognition of partner's action through non-verbal communication.

First, the Rader checked aircraft positions on the radar screen, and then the Coordinator inferred that the Radar was considering the traffics arriving at Narita. This inference was a mental simulation on partner's cognition. The coordinator asked a question to complement his mental simulation. Here the question was very brief and lacked details like "Tell me which something?" But the Rader interpreted partner's intention and replied properly. That suggests the Radar had a belief that the partner recognized his own action and intention. It's an evidence of mutual belief of the 3rd layer. Finally, the Rader Controller made a decision and informed the result to his partner.

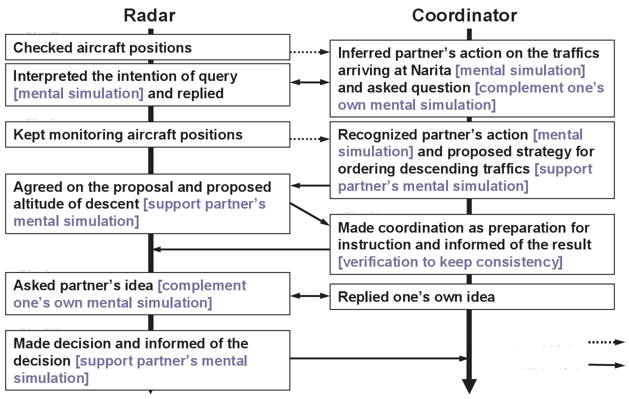

Figure 3 Interaction Diagram in Team Cooperative Work

After these processes, they handled the traffics following the Decision, but they exchanged few words stating who would do what in this stage.

5.5 Characteristics of Team Cooperative Work

In many cases, Controllers established TSA without verbal communication. They rather used verbal communication to maintain TSA. It is apparent that shared expert knowledge such as Routines allows controllers to establish TSA without verbal communication. Furthermore, each controller gets information from the environment such as the Radar screen and Flight Strips and they paid attention to partner's action each other continuously. As for TSA maintenance strategies, though verbal communication was more frequent, sometimes little concrete information was exchanged.

Furthermore, Controllers were aware of the tasks allocated to each other and executed them independently almost without any discussion.

This can be explained based on a team work version of the RPD, where shared routines include knowledge on the commitment of each team member.

6. SUMMRY

In this research, we introduced a technique for analysing tasks of en route ATC by the framework of distributed cognition as an approach to study problems of human factors in an ATC system.

From the analysis, we consider that a true partner is not an observer, but he/she needs to proactively interact with his/her partners to share their cognitive processes such as strategies and plans. We will continue the data analysis to enhance our understanding of detailed features of the cognitive process model of controller's team as a team cognitive process.

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