5-1-2021

Task Modeling in Air Traffic Control With Trajectorized en-Route Traffic Data Processing System

Sungju Maeng

Makoto Itoh

Atsushi Senoguchi

TASK MODELING IN AIR TRAFFIC CONTROL WITH TRAJECTORIZED EN-ROUTE TRAFFIC DATA PROCESSING SYSTEM

Sungju Maeng, Makoto Itoh
University of Tsukuba
Tsukuba, Japan
Hiroko Hirabayashi, Atsushi Senoguchi
Electronic Navigation Research Institute
Tokyo, Japan

As the volume of flight is extended, it is expected that the task complexity of air traffic controllers will increase. In Japan, air traffic control in en-route airspace is operating with TEPS (Trajectorized En-route Traffic Data Processing System), which has functions to display information necessary for air traffic controllers' tasks. It has evolved to support the controllers with less workload, resulting in escalated interaction between controllers. However, paradoxically this means more information is provided and more workload would be required. In order to manage mental workload of air traffic controllers, detailed analyses of their tasks with TEPS are needed. In this study, we tried to develop a model of the air traffic control tasks conducted on TEPS by applying the Multilevel Flow Model (MFM). Based on the model, we clarified the task structure in which several controllers participated and assess contributing factors in workload.

Introduction

Since the COVID-19 crisis caused a great loss of airline industry, IATA (2020) reported that it will take a long time to return to pre-crisis levels. However, airline financial performance in Asia Pacific region is forecasted to recover faster than other regions because of large domestic markets and expected that the demands of flights will increase once recovery begins. Before the crisis, air traffic volume in global was in rising tendency, and the importance of performance and workload assessment of air traffic controllers have discussed for decades.

For supporting controllers, automation technologies have been developed continuously, and direct mediation task has been decreased but monitoring task being more substantial. In accordance with this recent change in tasks, Japanese en-route air traffic control operations are conducted with TEPS (Trajectorized En-route Traffic Data Processing System), which is the air traffic control system terminal used by controllers. To sustain the safety and efficiency of air traffic flow, controllers are working as a team, and their tasks are distributed by considering the characteristics. A set of a radar controller who mainly focuses on the radar screen and takes direct communication with pilots (called "R-seat" in TEPS) and a controller who takes coordinate tasks with other facilities such as airport and the controller of side sectors (called "C-seat" in TEPS) conduct en-route air traffic control operations on en-route airspace sector. Accordingly, to evaluate the expected workload and performance in the use of TEPS, the relationship and composition between the two seats needed to be considered. Conventionally, Modified Messerschmidt, Bölkow und Blohm (MMBB) Method (ICAO, 1984) was utilized for workload assessment of air traffic controllers in Japan, but this method was applied only for radar controllers.

Gregory et al. (2012) reminded the status that there are fewer studies related to team workload than the individuals, and suggested theory and assessment methods related to team workload. Their proposed Multilevel Team Workload Model implies work environment and task characteristics required to be identified.

For use in team workload research of air traffic controllers, this research aims to suggest the entire task flow on the utilized system, TEPS, supports performing air traffic control tasks and sharing information through the entire Flight Information Region (FIR) especially in en-route operations, at the point of means-end relationships using Multilevel Flow Model (MFM).

Trajectorized En-route Traffic Data Processing System

The entire system consists of multiple displays and input devices. In the monitor positioned at the center of a desk-type system, the system information region with the radar domain and the support domain, provide information required for entire tasks as shown in Figure 1. Above the center monitor, two screens are arranged and each of them is a sub-display screen with reference information and a total information display unit showing meteorological information and notice to airmen (NOTAM).

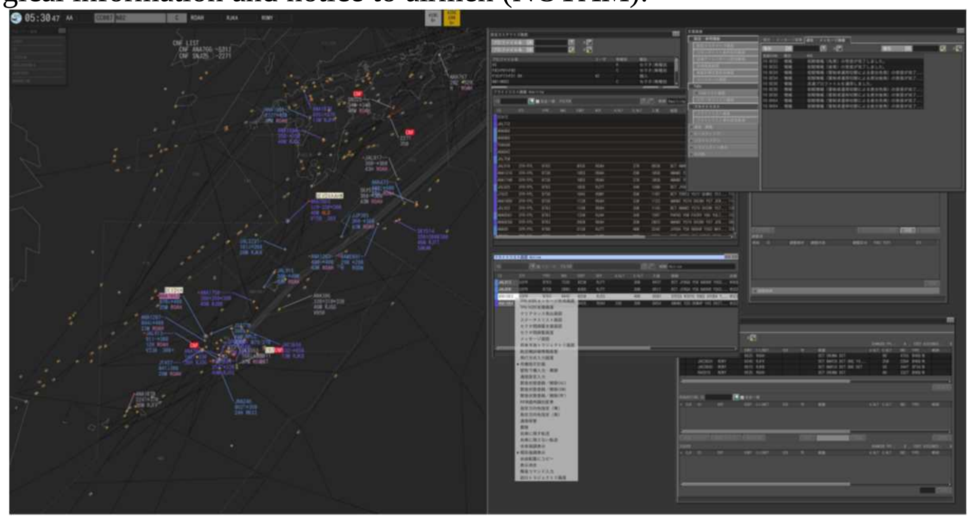

Figure 1. An example of TEPS main display. Left side shows the radar domain and the other side is support domain. The position information served by air route surveillance radar combined with flight planning information. (Ministry of Land, Infrastructure, Transport and Tourism, Overview of TEPS, Retrieved from https://www.mlit.go.jp/koku/content/001358999.pdf (In Japanese))

In the radar domain, data blocks in which simplified flight information containing call sign, altitude, ground speed, are deployed for each aircraft. To transfer and share the indication to pilots and whole system users, controllers perform tasks with input devices, such as a mouse, a keyboard, and a footswitch. They can take memos on the designated data block. The side of the radar domain is the support domain, selectable coordination windows pop up to show details of a situation and adjust the settings of the display. This domain contains the screen of flight list, departure clearance, sector coordination, AIDC (Air Traffic Services Interfacility Data Communications) transfer, etc. The downside of the main display, touch panels for taking communication with pilots and other facilities as other sectors or airports are prepared. Since whole displays are connected and have been automated, controllers who use the system are required to understand entire relationships and be trained for a considerable period to be used to.

Multilevel Flow Model

LIND (2011) introduced Multilevel Flow Model (MFM) as a qualitative modeling method for presenting the entire procedure of industrial system, representatively, Nuclear Power Plants. While the original step of MFM development was presenting Human-Machine Interfaces for complex systems with supervisory control, the model has been actively utilized in industrial areas because of the characteristics that identifying interconnected levels of means-end, part-whole abstraction, goals, and functions. Lind et al. (2014) suggested methodology for building MFM. Means-end hierarchy and relation diagram will have to be drawn first to survey the whole interconnected flow intending means-end relationship and between functions. The embodied MFM will have to be introduced with symbols shown in Figure 2.

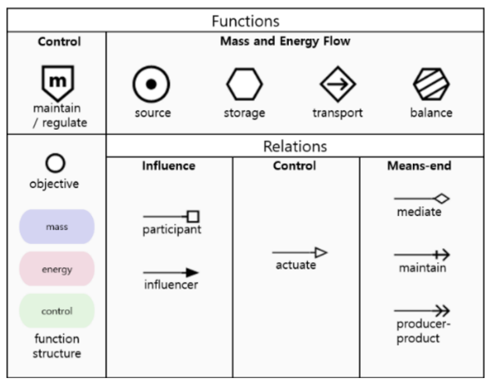

Figure 2. Basic symbols mainly used in this paper. TEPS comprises various functions and these are interconnected by relations symbols as participant and influencer.

Analysis and Results

Behavior analysis

Before undertaking the modeling work, we observed simulator trainings and analyzed the behavior of air traffic controllers using TEPS in need. Three typical scenarios performed daily were prepared, 6 participants (who are active-duty controllers) simulated scenarios 2 of them each, and the entire procedure was recorded as video data. Overall scenes were taken from behind for and the head-camera took the controllers' point of view. The first scenario was focused on the sector including traffic flow of descending phase to the Tokyo International airport from west. The second scenario included the cases of flights coming from the other FIRs, for example, from Incheon FIR of Republic of Korea to Fukuoka FIR of Japan. The last scenario was traffic flow of north of Tokyo area airports, and includes both departure and arrival phase.

To grasp the entire flow of tasks of R-seat controller and C-seat controller, video data were analyzed. Task categorized into three parts as Verbal, Behavior, and Visual. The verbal part was primarily recorded and focused on in this study. Behavior parts include actions using a keyboard, a mouse, and communication panels and Visual parts mean a rough record of where controllers' gaze is paying attention per designated time block. Recorded contents are sorted chronologically.

Multilevel Flow Model

Means-end Hierarchy and Relation Diagram Figure 3 shows the means-end hierarchy of TEPS. The general goal of TEPS is to achieve safe, efficient, and smooth air traffic management. Priorities (Abstract Functions) are divided into the management of aircraft represented inside of the sector and the coordinate work on the boundary of the sector in charge because the tendency of the tasks on each of priorities is different. Functions (Generalized Functions) accomplishes Priorities consisting of communication with other ACCs and Pilots, flight plan and intent check, instructions issue, real time position grasp, sector transition takeover and information sharing. Processes and Objects, as Physical functions and forms mounted on TEPS, directly represented. Based on the first hierarchy diagram, the means-end relation diagram was built within the range of the sector in charge. As the cornerstone of MFM, relation diagram focused on Processes.

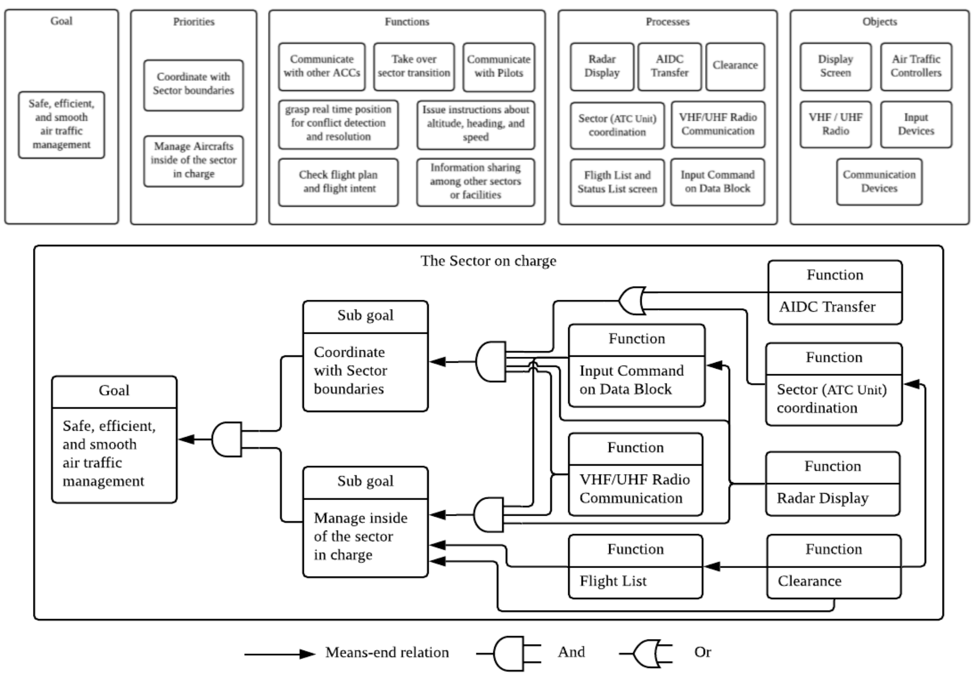

Figure 3. Means-end hierarchy and relation diagram of the sector in charge on TEPS.

The important point of coordination tasks at sector boundaries is safely taking over heading flights from or to the next sector or FIRs. In the case of "AIDC Transfer", almost tasks are automated. When taking over the flight, accepted clearance from another sector is needed. "Radar Display" function in which controllers can select the specific data block and input the command and "VHF / UHF Radio Communication" function are used for achieving both sub-goals.

On the side of management tasks in the sector in charge, controllers need to check "Flight List" which contains all flight information even not shown in radar display, and

“Clearance” offers the list of flights awaiting or accepting clearance. The issued flights by clearance function are renewed on the flight list.

Building MFM The MFM used for showing the entire flow of the system usually consists of a mass, energy, and control function structures. Figure 4 describes the MFM of TEPS. The information shown in the screen interface is treated as mass, and utterance content is assumed as energy. “Bal1” and “Bal2” in this model mean that normally tasks are processed to “Issued” storage automatically, but if the sector is in the situation with special circumstances such as sudden increase in volume, controllers are requested to manage takeover task manually and the aircrafts are temporally dropped in “Request” and “Input” storage to process.

The circle at the center contained in control function structure is the objective as the goal. The objective is maintained by 5 Function Structures, and “Bal1” and “Bal2” are regulated from that objective. “Input CMD” function conducted on “Radar Display” function. Therefore, two functions are presented in the same function structure. Most of Storage symbols represents windows for coordination in the support domain, except for “RadDis” means radar domain itself. “Tra10”, connected with “RadDis” storage shows flights on radar display updated by intervened information mediated by radio communication.

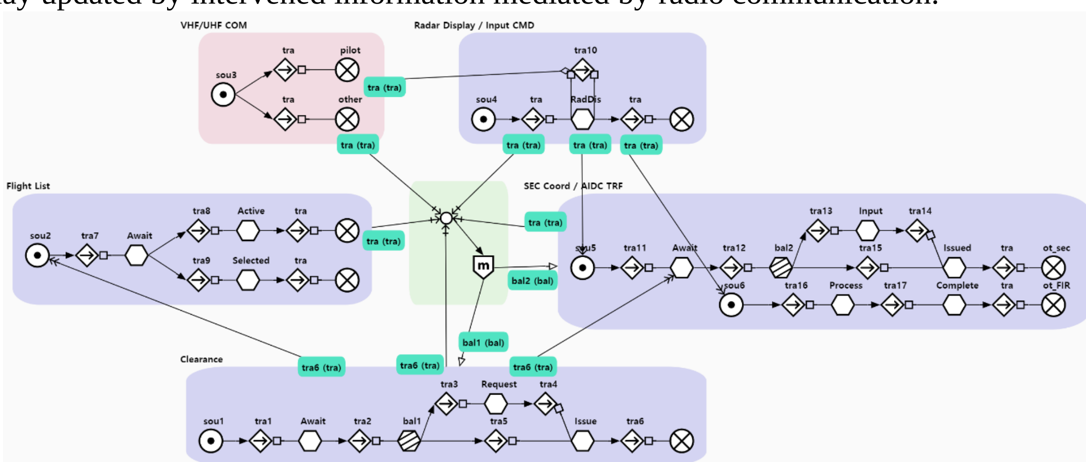

Figure 4. Multilevel Flow model of TEPS. Mass, energy and control flow are contained in the Function structure. VHF/UHF Radio communication is described as an Energy flow function. They are interconnected by maintaining, producing, and meditating relationships.

Limitation of represent who uses the Means One of the purposes of this research is to analyze the task as a team and used it for future work to clarify the relation which could affect team workload. With that point, we realize the limitation of MFM, not includes the detail of human operators who uses the Means as a function. The example of Kim and Seong (2018) are questioned the lack of representation of time to effect and detect in MFM and suggest the way to solve the limitation by writing the time under the arrow line. With this reference, our modeling diagram also includes the human operators, in this case, R-seat and C-seat.

Conclusion and Future Work

The paper presented a Multilevel flow model (MFM) of Trajectorized En-route Data Processing System (TEPS), the system supporting air traffic control tasks, especially on en-route traffic management in Japan ACCs, for illustrating interconnected means-end and Part-whole relationship of functions. The model combined with the means-end hierarchy and relation diagram and shows an entire flow of information transferring between functions and view of almost processes contained in TEPS briefly.

Although the complexity and connectivity of the system are identified comprehensively, there is the limitation that the original MFM cannot explains controllers who participate in the process. In the future work, it would be with the information of controllers who are involved in relations arrow and guess which function could be the potential of the workload.

References

Bedwell, W. L., Salas, E., Funke, G. J., & Knott, B. A. (2014). Team workload: A multilevel perspective. *Organizational Psychology Review*, 4(2), 99-123.

Glantz, E. J. (2006). Challenges supporting cognitive activities in dynamic work environments: Application to policing (Ph.D. thesis). University Part, PA: The Pennsylvania State University.

Gregory J. F., Eduardo, S., & Adam, S. (2012). Conceptualization and Measurement of Team Workload A Critical Need, *Human Factors*, 54(1), 36-51.

Hirabayashi, H., Senoguchi, A., & Toratani, D. (2020), A Study on Regional Characteristics of En-Route Air Traffic Control Sector Traffic Flow. In *The 58th Aircraft Symposium*, JSASS-2020-5159-3C02 (in Japanese)

IATA (2020), Economic Performance of the Airline Industry, *2020 End-year report*, Retrieved from https://www.iata.org/en/iata-repository/publications/economic-reports/airline-industry-economic-performance---november-2020---report/

ICAO (1984). ICAO Doc 9426 Air traffic services planning manual - part 2, section 1, chapter 1, appendix c.

Kim, S. G., & Seong, P. H. (2018). Enhanced reasoning with multilevel flow modeling based on time-to-detect and time-to-effect concepts. *Nuclear Engineering and Technology*, 50(4), 553-561.

Lind, M. (2011). An introduction to multilevel flow modeling. *Journal of Nuclear Safety and Simulation*, 2(1), 22-32.

Lind, M., & Zhang, X. (2014). Functional modelling for fault diagnosis and its application for NPP. *Nuclear Engineering and Technology*, 46(6), 753-772.

Suarez, N., López, P., Puntero, E., & Rodriguez, S. (2014). Quantifying air traffic controller mental workload. In *Fourth SESAR Innovation Days*, 1-6.