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An Analysis of Communications for Arrival in Real-Time Air Traffic Control Simulation

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Air Traffic Control (ATC) communications between air traffic controllers and pilots are the most essential task in ATC operations. This paper describes results from an analysis of ATC communications in real-time (human-in-the-loop) simulation experiments. We analyzed communication data for arrival traffic of a radar control position in a Japanese terminal airspace. We assumed that particularly in a radar position, traffic volume directly influences ATC communication volume. In order to verify this assumption, we study on correlation between traffic volume and the amount of communication events issued by controllers. In addition, we examined ATC clearance phraseology and evaluated as a potential indicator of controller workload level.

Introduction

Significant airport expansion and construction programs are currently underway in Japan in order to meet the expected increase in air traffic demand. In every such airport expansion and construction project, airspace capacity estimation is one of the most important tasks. Tofukuji has asserted that air traffic controllers workload is critical to the airspace capacity, since they are directly involved in central ATC function such as decision making for control, ATC clearance issuance to pilots (Tofukuji 1993). Because it is easily observable, the amount of controller-pilot ATC communication event is often regarded as an indicator of controller workload.

Analyzing communication data from real-time ATC simulation experiments, we examined effect of traffic volume on controller-pilot communication amount. Controller-pilot communications have been assumed to increase as the function of traffic volume and other parameters (Manning *et al.* 2003). We analyzed communication data for arrival traffic of a radar control position in a Japanese terminal airspace.

In addition, we studied the effect of traffic volume and ATC communication event count on word omission in controller phraseology in order to examine the potential applicability of ATC clearance phraseology as an indicator of controller workload.

Data Acquisitions

Simulation System

The Electronic Navigation Research Institute (ENRI), a Japanese research institute for ATC systems and air navigation aids, has developed a large-scale real-time ATC simulation system for terminal and enroute radar ATC. The simulation system includes eight (8) radar displays for terminal ATC as well as several pseudo-pilot consoles.

During simulation experiments, all the communication events are recorded onto Magnet-Optical (MO) disk media by the simulation system. In order to issue communication events, controllers and pseudo-pilots press a push-to-talk button on the Plantronics® amplifier of their handsets. The time points at which the button is pressed (start-time) and released (end-time) are captured for each communication event. The recorded time points are then used to provide an efficient estimation of communication time.

The simulation system also has the ability to record aircraft trajectory data such as the temporal transition of position, altitude, speed and radar control position for each (pseudo) aircraft.

The Modeled Terminal Airspace

We conducted a series of real-time ATC simulation experiments for Japanese terminal airspace that was modeled in the simulation system and full performance level (FPL) controllers from the terminal radar ATC facility participated in the experiments. Figure 1 depicts the boundary line of the modeled airspace and the corresponding arrival flow, which is represented by arrows. The modeled airspace covers for 60NM radius from the airport up to 17,000 ft in altitude.

Depending on the flight phase, ATC arrival operations were divided into multiple radar positions. One radar position sequenced arrivals coming in from multiple directions and then, control of each arriving aircraft was handed off to other radar position that guided them through their final approach courses and assured the required separation between them.

In this paper, we focused on the radar position for final approach guidance. The oval in Figure 1 represents an example of area covered by the focused radar position.

Three (3) types of final approach course (FAC) were simulated, which, for the reminder of this paper, will be denoted as *FAC-A*, *FAC- B*, *FAC-C* respectively. We conducted four (4) experiments for each FAC type. Depending on the simulated FAC type, the experiments will be referred to as Experiment A1~A4, Experiment B1~B4, Experiment C1~C4.

An identical traffic scenario was applied to all experiments and each experiment was conducted for 75 minutes. In each experiment instance, the controllers rotated their assignment of radar positions once and therefore, in total six (6) controllers were assigned to the focused radar position throughout all experiments.

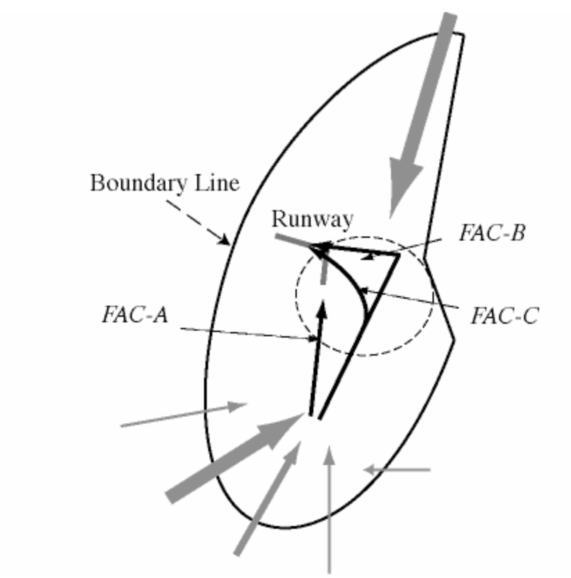

Figure 1. *Terminal Airspace Boundary Line and Corresponding Arrival Flow*

Communication Data

During the experiments, communication events between the controllers and pseudo-pilots were audio-recorded. Then, the audio data was transcribed to communication data, which contains start-time, end-time and contents for each communication event. Since these time points were measured based on the manipulations of push-to-talk buttons, there was always a possibility that the values were not as precise as the ones based on audio recordings. The start-time and end-time were recorded on the second time scale. The contents of each communication event were verbatim transcription of each audio-recorded communication event.

Data Analysis

Hypotheses

Regarding the effect of traffic volume on ATC communication events at the focused radar position, the following two hypotheses were made.

- Communication event count / time amount of communication event and traffic volume are positively correlated.
- Frequent communication events or heavy traffic volume incurs word omission.

The idea behind the first hypothesis is that heavy traffic volume triggers frequent communication events. The amount of Controller-pilot communication has been assumed to increase a) as a function of the traffic volume, and b) in airspace that utilizes complex procedures (Manning *et al.* 2003). Since the data analysis was performed on data from a radar position that was entirely dedicated to guiding arriving aircraft in their final approach courses, the airspace utilization procedures were not very complex and therefore, communication event count was assumed to be influenced only by traffic volume. Because the particular design of a FAC is also expected to influence the amount of communication events, the hypothesis was examined for each of the three types of FAC mentioned earlier.

In the second hypothesis, focus was centered on phraseology in ATC clearances. It was realized that, in some cases, controllers omit some words in their phraseology. Therefore, initially, word omission was assumed to occur frequently when controllers operate under high workload conditions and if the assumption was finally verified by the data analysis, the word omission count could then be used as an indicator of controller's response to high workload.

Analysis Methodology

After analyzing the ATC communication data issued at the focused radar position that covers the vicinity of the airport and the arrival trajectory data, the two hypotheses were verified. For the data analysis computations, each experiment was divided into fifteen (15) 5-minute time bins. These bins were combined across all four experiments for each FAC type and therefore, each FAC produced (4*15 =) 60 bins of data. For each bin, the following items were obtained and correlation between these items was calculated.

- Communication event count
- Time amount of communication events
- Word omission count
- Traffic volume

The duration of each communication event was computed by subtracting the event start-time from its end-time. Time amount of communication events in each time bin was accumulation of the duration. Because start-time and end-time were recorded on the second time scale, the time amount was also computed on the second time scale.

Word omission count was obtained by inspecting the contents of the communication events.

Traffic volume was calculated as the average number of controlled aircraft in each time bin:

$$Trafficvolume = \frac{\sum_i t_i}{\Delta T},$$

where ΔT represents length of the time bin (in this case, 5 minutes) and t_i represents the time periods during which each arrival was under the control of the focused radar position in the corresponding time bin.

Simulation Results

Communication

Table 1 shows the average and maximum values for communication event count and time amount of communication events across the 5-minute (300-second) time bins. In peak periods, the controllers issued ATC communication events approximately 25 times.

Table 1. *The Average and the Maximum Value for Communications*

FAC	Count		Time Amount (sec.)	
	Ave.	Max.	Ave.	Max.
A	12.6	23	56.8	104
B	15.7	28	66.2	114
C	16.1	25	65.4	118

Table 2 shows the correlation between the count and the time amount of communication events. As Manning *et al.* showed and as it is evident by the R^2 values in the table, they are highly correlated (Manning *et al.* 2001).

Table 2. R^2 *Values between Count and Time Amount*

FAC	Value
A	.95
B	.91
C	.96

The total duration of communications between the controllers and the pseudo-pilots was also examined and the results are presented in Table 3, where the duration of communication events issued by both the controllers and the pseudo-pilots are combined. The average percentage of the bin time spent for the communications ranged from 38.8%(*FAC-A*) to 44.1%(*FAC-B*). In the peak periods, the same percentage ranged from 61.3%(*FAC-A*) to 70.1%(*FAC-B*).

Table 3. *Time Amount for Communications between the Controllers and the Pseudo-pilots (sec.)*

FAC	Ave.	Max.
A	116.4	184
B	132.5	212
C	120.1	195

Word Omission

Table 4. *Percentage of Word Omission*

FAC	Percentage
A	4.1
B	5.5
C	5.9

Table 4 shows the percentage of word omission (WO) for the total communication count. For example, in *FAC-A*, 31 word omissions were detected whereas the total communication count was 758. The percentage is thus calculated as (31/758=) 4.1 %.

Some examples of the detected omission follow (the phrases in the parentheses represent prescribed phraseology for each case):

- “Heading 290” (Turn right/left heading 290)
- “Speed 230” (“Reduce speed to 230 knots”)
- “Contact Tower 1181” (“Contact Tokyo Tower 118.1”)
- “Approach” (“Tokyo Approach”)

Some controllers issued all their corresponding ATC clearances in using the same form of WO, in which case the omissions were considered habitual and therefore were excluded from the omission detection analysis. It should be noted that the omission percentages (as shown in Table 4) were rather low and even though some words were omitted, the instructions were sufficiently understandable for pseudo-pilots.

Traffic Volume

Descriptive statistics for traffic volume across time bins are shown in Table 5. Regardless of the value of the Standard Deviation (SD), the maximum values were more or less at the same level, because the controllers that handed off control of arriving aircraft to the focused radar position regulated the arrival transfer volume.

Table 5. *Descriptive Statistics for Traffic Volume*

FAC	Ave.	SD	Max.
A	5.9	1.9	9.4
B	6.9	2.4	9.2
C	6.6	2.7	9.4

Examination of Hypotheses

The First Hypothesis

To examine the first hypothesis, the correlation between traffic volume and communication event count / time amount of the communication events were computed for each FAC type. Table 6 shows these correlation results. The count and the time amount are both correlated with traffic volume for all FAC types, which confirms that they were both influenced by traffic volume. Although the level of the correlation varied slightly from on FAC type to another, there seems to be a stronger correlation level in the case of *FAC-C*.

To investigate the difference in correlation amongst the FAC types, the contents of the communication events were examined. The communication events were parsed into communication elements and these elements were classified according to their purpose (Prinzo 1997). Then, the frequency of principal ATC clearance elements for altitude, speed and heading were compared.

Table 6. *Correlations for Traffic Volume*

FAC	Count	Time Amount
A	.66	.62
B	.76	.74
C	.81	.77

Figure 2 represents the comparison results, which show that, compared to other types, altitude clearances were more frequently issued for *FAC-C*. This happens because, while in *FAC-A* and *FAC-B* the altitude clearances were issued entirely for the predetermined altitude of the final approach courses, in *FAC-C*, in addition to clearances for the predetermined altitude, altitude clearances were also issued to ensure separation amongst the arrival aircraft. This resulted to a larger number of altitude clearances elements in the case of *FAC-C*.

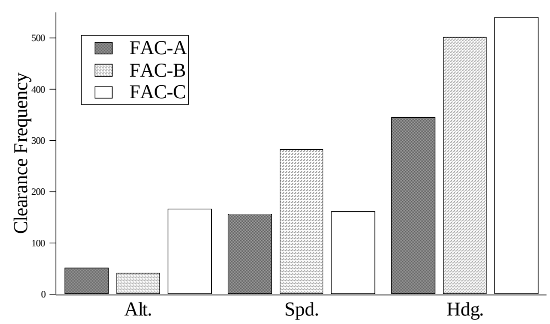

Figure 2. *Comparison of ATC Clearances*

Table 7 presents the correlation statistics between traffic volume and the principle types of ATC clearance elements. In *FAC-C*, heading and altitude clearances were strongly correlated with traffic volume.

Table 7. Correlation for ATC Cleanses

FAC	Altitude	Speed	Heading
A	.37	.49	.34
B	.27	.28	.73
C	.56	-.02	.74

The observed strong correlation of heading and altitude clearance elements to traffic volume and the higher number of altitude clearance elements observed for *FAC-C* confirmed the strong correlation between traffic volume and communication count / time amount of communication events recorded in Table 6. Furthermore, the varying frequency of the principle ATC clearances elements and the varying level of their correlation to traffic volume confirmed differences in arrival guidance methods among the three different FAC types. To further investigate the difference of influence of traffic volume among the FAC types, the guidance methodology for each FAC type should be examined and compared.

The Second Hypothesis

To examine the second hypothesis, the correlation of WO count to communication event count and traffic volume were computed and Table 8 shows the results. The superscripts “*” and “**” denote that the correlation is significant at $p < .05$ level and $p < .01$ level respectively. Except for the correlation to communication count in *FAC-B* and to traffic volume in *FAC-C*, correlations are found not to be significant. Also, the correlations are not found to be strong in any of the cases examined.

Table 8. *Correlation of WO Count*

FAC	Com. Count	Traffic Volume
A	.02	.16
B	.41**	.22
C	.22	.29*

Figure 3 represents the total count of WO for each experiment, which evidently varies a lot amongst all the experiments.

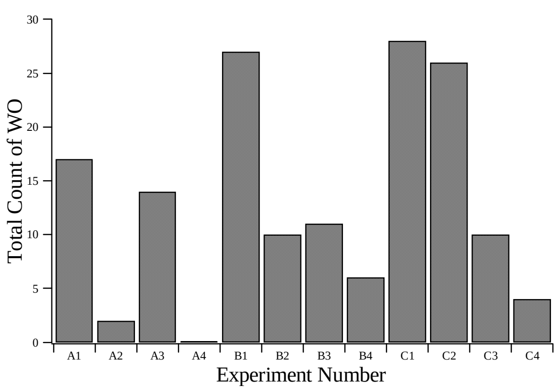

Figure 3. *WO Count on Each Experiment*

The temporal transition of WO occurrence in each experiment was also examined. The analysis results for temporal transition of WO count, communication count, and traffic volume on each experiment are shown respectively for each FAC tested in Figure 4, Figure 5 and Figure 6. Based on the FAC types, the temporal transitions curves are aligned for each experiment. The “A” to ”F” below experiment numbers represent the individual controller assigned to the focused radar position during the corresponding simulation time.

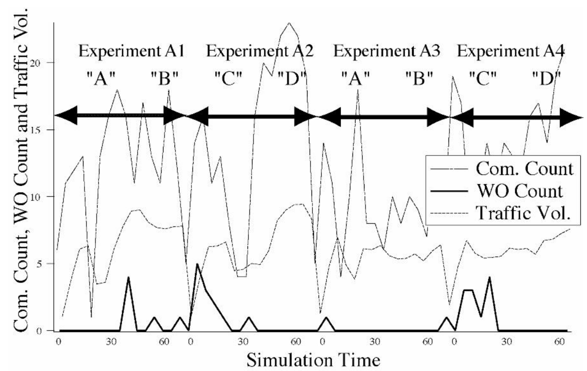

Figure 4. *Temporal Transition of WO Count for FAC-A*

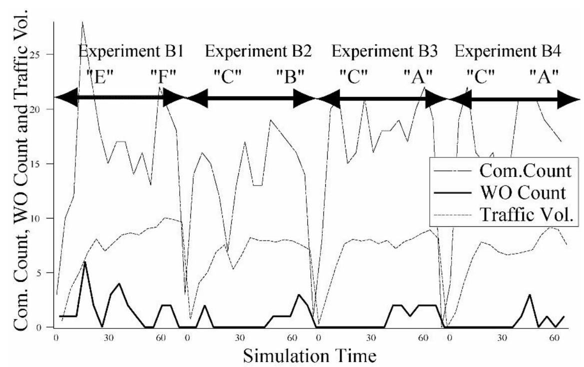

Figure 5. *Temporal Transition of WO Count for FAC-B*

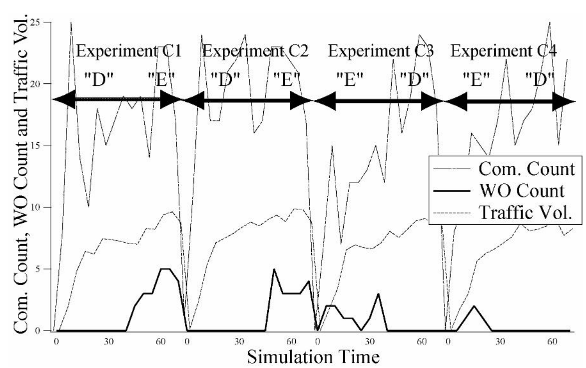

Figure 6. *Temporal Transition of WO Count for FAC-C*

It can be seen that among the different experiments, distribution of WO count is not constant and instead WO occurred frequently in certain time periods in most experiment cases. For example, while WO occurred frequently at the beginning of A2 and A4, it occurred frequently at the end of A1. In addition, WO occurrence appears to be controller-dependent in some cases. For instance, the "D" did not exhibit WO occurrence in any experiments, whereas the "E" exhibits WO occurrence repeatedly. The variation of WO count and distribution can be attributed to difference in habitual practice of individual controllers. Nevertheless, regardless of individual controller practices, a tendency for WO occurrence is observed when the controllers issued more communication events or when traffic volume was at a peak.

Summarizing, even though the hypothesis that communication event count and traffic volume influenced the WO count was not verified, there was still a possibility that frequent communication events and heavy traffic volume incurred WO in some cases.

Summary

Analyzing the communication data from real-time terminal approach radar control simulation experiments, the effect of traffic volume on ATC communication volume was studied. Analysis focus was shed on one radar control position that guides arrivals through their final approach courses and experiments were performed for three types of final approach course.

In the analysis, the correlation between traffic volume and the amount of communication events issued by controllers was examined. Although the correlation was generally strong, it appeared to be slightly different amongst the various Final Approach Course (FAC) types considered. To investigate the correlation difference among final approach course types, arrival guidance methodology must be examined and compared.

The influence of traffic volume and communication event count on word omission frequency was also examined, but no strong correlation was discovered and the omission occurrence frequency tended to be controller-dependent. On the other hand, in some cases there was a possible correlation observed between frequent communication events / heavy traffic volume and WO occurrence.

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