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ATC (Air Traffic Control) communication between air traffic controllers and flight-crews is the most essential task in the ATC operations. This paper describes results from an analysis of the ATC communication in two (2) series of real-time (human-in-the-loop) simulation experiments. We analyzed communication-line occupancy rate in a modeled sector of Japanese en-route airspace. In the analysis, we focused on phraseology in the communication. We standardized air traffic controllers' phraseology as well as flight-crews' one, because individual difference of phraseology had an effect on time amount for the communication. Then, the line occupancy rate was computed on the standardized phraseology. Communication events were classified into some categories. Some of the items were regarded as replaceable with CPDLC (Controller-Pilot Data Link Communications) system. Comparing the occupancy rate between the case in which all the items were included and the case in which the replaceable items were excluded, the reduction effect of the CPDLC system introduction for voice communication line-occupancy was studied. From the analysis results, although fluctuation was identified, the CPDLC replaceable items proved to account for 24% in one simulation series, and 32% in the other series.

Introduction

On ATC communication, air traffic controllers and flight-crews essentially share one voice communication-line. Due to projected traffic demand growth, the voice communication-line occupancy rate must be increased.

Voice communication-line occupancy rate represents the probability that the line is not available. The increased occupancy rate has a significant impact on ATC communication transmission in a timely manner. When the voice communication-line occupancy rate is high, air traffic controllers and flight-crews have difficulties in transmitting contact, clearance/request on the intended time points. Introduction of CPDLC system is expected to mitigate the high communication-line occupancy rate. Routine, repetitive and non-time critical communication items are expected to be replaced with CPDLC (Massimini et al, 2005, Shingledecker et al, 2005).

Because the same traffic scenario is repeatedly applicable for multiple trials, real time simulation is a valuable technique for the study of ATC communication. Thus, the communication data from the real-time simulation experiments were analyzed.

In this paper, ATC voice communication data from real-time simulation experiment instances were analyzed. Some communication items were regarded as replaceable with the CPDLC system. It was assumed that the items were to be transferred between air traffic controllers and flight-crews automatically and they were to be excluded from the voice communication.

Data Acquisitions

The Modeled Sector 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 en-route and terminal radar ATC.

We conducted two (2) series of real-time ATC simulation experiments for Japanese en-route sector modeled in the simulation system and full performance level (FPL) controllers from ACC (Area Control Center) participated in the experiments. Usually, active or retired air traffic controllers play the role of pseudo-pilots in real time simulation experiments. On the other hand, concerning phraseology, timing and other aspects, pilots who have worked in the actual operation should yield more realistic communication transmission. For this reason, professional pilots working for Japanese airline companies participated in the experiments as pseudo-pilots.

Figure 1 depicts the boundary line of the sector represented by solid-lines and the corresponding traffic flows represented by dot-lines and arrows. The modeled sector is adjacent to a terminal airspace. The traffic flows entering the sector in three (3) directions were merged into one stream and control of each aircraft in the merged flow was handed off to a radar position in the terminal airspace. The model was for arrival sector in which ATC task required sequencing and spacing tasks.

In the first simulation series (**Series1**), each experiment was conducted for 21 minutes and nine (9) pseudo aircraft were handled in the experiments. On the other hand, each experiment was conducted for 30 minutes and 16 aircraft were handled in the second simulation series (**Series2**). Because the applied traffic scenarios were different, the experiment results were analyzed for each simulation series. The experiments in the **Series1** are referred to as **Ex1** ~ **Ex8,** whereas ones in the **Series2** are referred to as **Ex9** ~ **Ex16** in this paper.

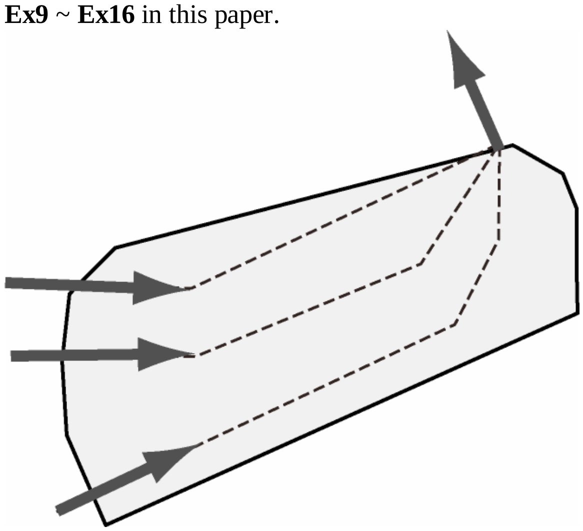

Figure 1. The Sector Boundary Line and Traffic Flow

Communication Data During each simulation experiments, all the communication events were recorded onto Magnet-Optical (MO) disk media by the simulation system. In order to transmit communication events, controllers and pseudo-pilots pressed a push-to-talk button. The time points at which the button was pressed (start-time) and released (end-time) were captured for each communication event. The recorded time points were then used to provide an efficient estimation of communication time.

Also, during the experiments, communication events between the controllers and pseudo-pilots were audio-recorded. Then, the audio data were transcribed to the communication data that contained 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

Phraseology The communication data were basically comprised of pairs of ATC clearances from the air traffic controllers and reading-back from the pseudo-pilots (flight-crews). Among the communication data, some phraseology differences occurred. The differences could affect the time amount of the communication data. For this reason, we examined and standardized all the communication phraseology. The time amount for each communication event was also adjusted responding to the standardized phraseology.

Referring to the Japanese ATC operational baseline documents, the ATC clearances phraseology were standardized. The following are examples of standardized phraseologies;

- To all the descend clearance for below the transition level, the altimeter setting phrase "Area QNH 2992" was added.
- For all the re-routing clearances, the phraseology "Cleared via present position direct *Point-name*" was applied.
- For speed instruction, instead of the phraseology "Maintain <u>Speed</u> *IAS-value*", "Maintain *IAS-Value*" was applied (All the words <u>Speed</u> were removed).
- The phrase "for Spacing" was allowed to be added only to radar vector instruction.

On the other hand, standardized phraseology for flight-crews was not available from published documents. Although standardized phraseology was not available, time amount of flight-crew-transmitted communication events accounted high proportion to total communication amount. Thus, we were on the view that flight-crews phraseology should be standardized as well as controllers one.

Flight-crews' phraseology standardization stood by the principle that the phraseology should be simplified. The examples of the simplification are as follows.

- In case it was redundant, the word <u>Roger</u> was removed.
- For answering the speed inquiries, the word <u>Speed</u> was removed. E.g. "250 knots", instead of "<u>Speed</u> 250 knots".
- For reading-back to radar vector instruction, the word <u>Turn</u> was removed. E.g. "Left 250", instead of "<u>Turn</u> Left 250".
- For reading-back to re-route clearances, instead

of the phraseology "Cleared via present position direct *Point-name*", "Direct *Point-name*" was applied.

Analysis Methodology In the ATC communication, it is desirable that communication items such as ATC clearances (from air traffic controllers) and requests (from flight-crews) are always issued on the intended time points. On the other hand, on congested communication line, air traffic controllers and flight-crews need to hold the transmission until the line gets free. As the traffic volume increases, the frequency of the transmission hold should increase.

It is expected that introduction of CPDLC system reduces the number of the transmission by replacing voice messages with electronic messages. CPDLC system has the potential to reduce the voice communication-line occupancy significantly. It is assumed that routine, repetitive, and non-time critical voice communication items are replaced with CPDLC system during the initial phase.

In the analysis, each experiment was divided into 1-minute time-bins. Then, voice communication-line occupancy rate $P_i (0 \le P \le 1)$ for time-bin i was calculated as follows;

$$P_i = \sum_{j}^{N_i} \frac{t_{i,j}}{60}$$

where N_i represents the number of transmitted communication events in the time-bin i and $t_{i,j}$ represents the duration of the communication event j issued in the time-bin i. The value of $t_{i,j}$ was obtained on the second time scale.

The value of P_i was regarded as the index of the possibility of ATC communication transmissions on the intended time points. The higher the index value was, the more difficulties controllers and flight-crews had in issuing communication on the intended time points.

The values of P_i were calculated in two ways. Firstly, the values were calculated from all the items. Secondly, the routine, repetitive, items are removed and the values were calculated. In the second calculation, it was assumed that the removed items were transferred into the CPDLC system and the communication amount for these transferred items was excluded from the voice communication-line. The remaining data were regarded as the voice communication data "with CPDLC", where as the original data were regarded as the ones "without (w/o) CPDLC".

It should be noted that, in the analysis, we exclusively focused on the availability of voice communication-line. ATC communication amount is often regarded as an indicator of controller workload (Manning et al, 2001). And the introduction of CPDLC system is expected to reduce the communication amount. However, the effect correlates closely with the design of the CPDLC system concerning human-machine interface. This analysis did not aim at measuring controller workload.

In this analysis, the standard value of P_i was tentatively set to 0.5. It was assumed that in case P_i exceeded the standard value, controllers and flight-crews had difficulties in transmitting communication event on the intended time points. It should be emphasized that the standard value was tentative one. To establish the standard value properly, detailed study needs to be conducted.

For all the experiment instances, the values of P_i were computed for the time-bin i. Then, the time-bins were combined among all the experiments for each simulation series. After that, the frequency of the cases in which P_i was more than the standard value (0.5) was compared.

Introduction of the CPDLC System Based on the contents, all the communication data were classified into some categories. Based on the aforementioned view, the following communication items were regarded as the CPDLC replaceable ones,

a. Transfer of Communication (TOC)
b. Altimeter-setting
c. Inquiry/answer for IAS (Indicated Air Speed)

It was assumed that in the CPDLC system, the above items were transmitted via data channel instead of current voice channel.

Results

Total Communication Time In the first place, after the phraseology standardization and corresponding time adjustment for each communication event, the total communication time was computed for each experiment. The total communication time equaled to summation of required time for all the communication events and it was classified into controller-transmitted and flight-crew-transmitted communication.

Figure 2 and **Figure 3** show the total communication time from the experiments in the **Series1** and the **Series2**, respectively.

In the figures, the numbers on the upper side represent the proportion of controller-transmitted communication time for the summation of controller-transmitted and flight-crew-transmitted communication time. The proportion was computed for each experiment instance.

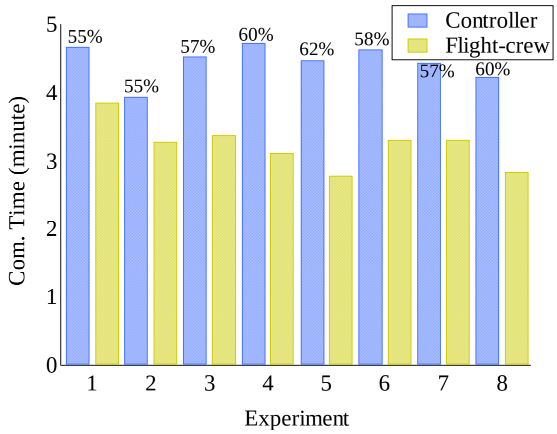

Figure 2. Communication Time from Series1

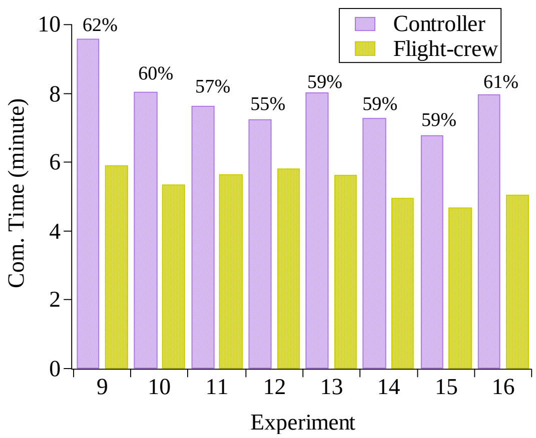

Figure 3. Communication Time from Series2

Because different controllers were assigned, the maneuver and traffic situation varied depending on each experiment instance. As a result, even though the phraseology was standardized, total communication time diverged. Also, because the traffic volume was heavier, more communication time was spent in **Series2**.

Although the communication time varied to a large extent among the experiment instances, the proportions of controller-transmitted communication time took the nearly constant value of 60% in all the instances. The fact implied that after the phraseology standardization, the ratio between controller-transmitted and flight-crew-transmitted communication time converged on approximate 3:2.

The CPDLC Replaceable Items For each experiment instance, time amount for the CPDLC replaceable items and its percentage to the total communication time were computed. **Figure 4** and **Figure 5** represent the percentage. The percentage of the CPDLC replaceable items combined was represented on the right side in each figure. It was observed that the TOC took large portion of communication time in each experiment instance. On average, the items combined accounted 24% (**Series1**) and 32% (**Series2**) to the total the communication time.

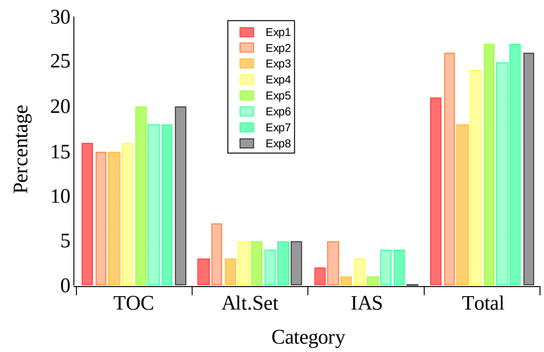

Figure 4. Percentage of the CPDLC Items (Series1)

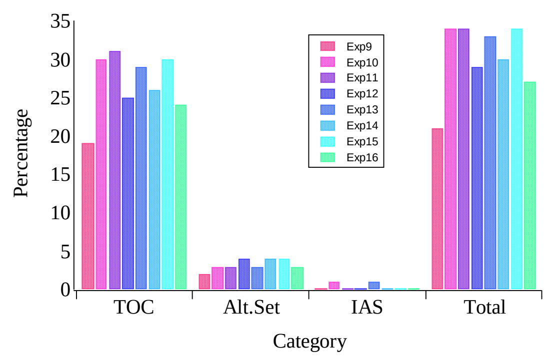

Figure 5. Percentage of the CPDLC Items (Series2)

The Probability **Figure 6** and **Figure 7** represent the relative cumulative distribution of P_i in each simulation series. In the charts, the cumulative distribution from the communication data "with CPDLC" and the ones "w/o CPDLC" are compared. In the charts, the horizontal axis represents the value of P_i, whereas the vertical axis represents the frequency that P_i is less than the horizontal value.

In **Series1**, the probability that P_i was not less than the standard value was 31% "w/o CPDLC", whereas 14% "with CPDLC". In **Series2**, the probability was 42% "w/o CPDLC", whereas 13% "with CPDLC". From the results, it was observed that the probability was reduced by around 55% in the **Sereis1** and 70% in the **Series2**, respectively.

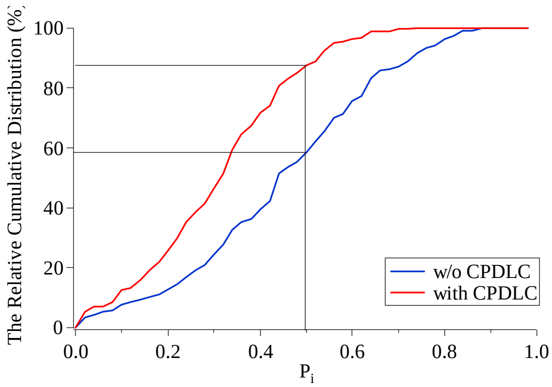

Figure 6. The Relative Cumulative Value (Series1)

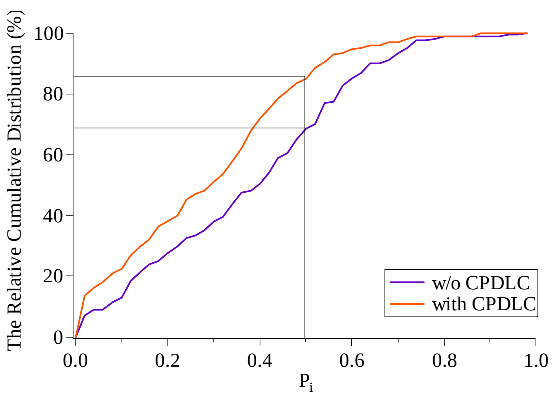

Figure 7. The Relative Cumulative Value (Series2)

It was observed that the CPDLC system introduction was more effective for **Series2** that involved heavier traffic volume. As the **Figure 5** implied, most of the CPDLC replaceable items were for TOC in the **Series2**. As handled traffic volume increased, the number of TOC communication events must be increased. It can give a good explanation of the reason the CPDLC system introduction in the **Series2** indicated more time amount reduction effect.

The Maximum Value In addition, the maximum value of P_i was compared for each experiment instance to examine the effect of the CPDLC system introduction in the communication-peak period. The maximum value of P_i in each experiment instance is denoted by $P_{\max}$. **Figure 8** and **Figure 9** represent the results from the comparison of $P_{\max}$ between "with CPDLC" and "w/o CPDLC". In the figures, the numbers represent the reduction percentage in each experiment instance. From the comparisons, it was confirmed that $P_{\max}$ "with CPDLC" was reduced in all the experiments.

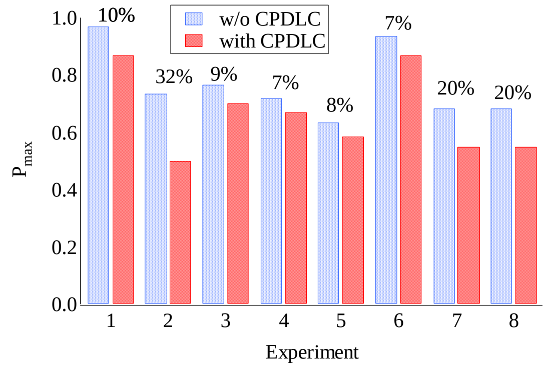

Figure 8. Comparison of $P_{\max}$ (Series1)

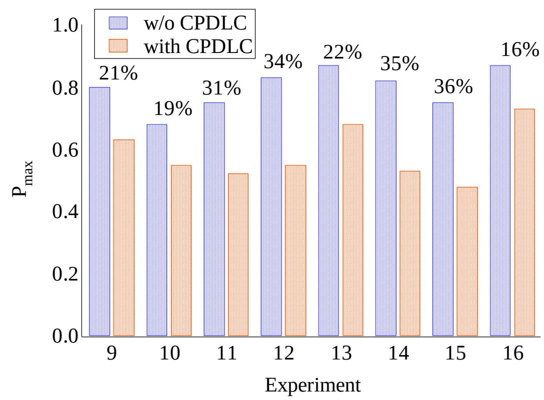

Figure 9. Comparison of $P_{\max}$ (Series2)

It should be noted that the reduction percentage varied among the experiment instances. It was because that the value of $P_{\max}$ depended on the traffic situation. For instance, during the time period corresponding to $P_{\max}$ in the **Ex2**, out of six (6) controller-transmitted communication events, three (3) altimeter-setting and one (1) TOC items were transmitted. In the **Ex15**, out of six (6) controller-transmitted communication events, two (2) altimeter-setting and one (1) TOC were transmitted. "With CPDLC", these items were removed in the time periods. As a result, the values of $P_{\max}$ were reduced considerably. On the other hand, for instance, in the time period in which all the transmitted communication events were for radar vector instructions, P_i was not decreased considerably even "with CPDLC".

Summary

Analyzing the communication data from real-time en-route radar control simulation experiments, the effect of the CPDLC system introduction for communication transmission in a timely manner was studied.

For this study, phraseology in the communication data was standardized. All the communication events were modified to the standardized phraseology. Time amount required for each communication event was modified according to the phraseology modification. After the standardization, in spite of the fact that the communication time varied to a large extent in the experiments, the proportions of controller-transmitted took the nearly constant value of 60% to the total communication time in all the instances.

All the communication events were then classified according to the contents. TOC, altimeter-setting and inquiry/answer for IAS were regarded as the ones that were replaceable with CPDLC system. The time amount for the items were removed. The remaining data were regarded as the communication data “with CPDLC”.

The communication-line occupancy rate was compared between the data “with CPDLC” and the ones “w/o CPLDC (original communication data)”. The occupancy rate was regarded as the index of the possibility of ATC communication transmission on the intended time points. Communication line occupancy rate was computed for each time-bin and combined among the experiment instances. Then, the frequency of the cases in which the line occupancy was not less than the standard value (0.5) was compared. From the comparison, it was indicated that by the CPDLC system introduction, the probability was reduced by around 55% in the **Sereis1** and 70% in the **Series2**, respectively. In the **Series2** with heavier traffic volume, the CPDLC system introduction had more reduction effect, because heavier traffic handling involved more TOC communication items.

It was confirmed that the highest occupancy rates in the experiment instances were reduced. For this purpose, because the degree of reduction depended on traffic situation, the reduction effect for the highest occupancy rate could not be assured.

The communication-line occupancy rate was computed for the index of the possibility of the ATC communication transmission on the intended time points. For this purpose, the appropriate standard value needs to be established. To establish the appropriate value, the relationship between line occupancy rate and communication issuance on the intended time points should be studied. To study the relationship, for instance, real-time simulation experiments need to be conducted.

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