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**Some Statistical Data**  
**on ATC Communication Congestion in Tokyo Area Control Center**

**by**

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# Some Statistical Data on ATC Communication Congestion in Tokyo Area Control Center\*

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## Abstract

A controller console was designed for the Phase I System of the ATC Automation Project. In order to evaluate the man-machine relations between the console and the human controller, an evaluation test was carried out in the control room of the Tokyo Area Control Center.

As one of the items of the evaluation test we observed and analyzed controllers' communication workload in Tokyo Area Control Center. Then we could obtain some statistical data on ATC communication congestion, and applied a simple queueing theory to the data. As a result we found that such data can be tangible indices to judge whether controllers are overloaded or not.

The former half of this paper contains the outline of the Phase I System, the design of the prototype console, and the summary of the evaluation test. The latter half contains the detailed data on the ATC communication congestion, and the discussions on the data.

\* Reprinted for general distribution from a limited distribution report dated July 1966, from Navigation Electronics Division of Ship Research Institute.

\*\* Navigation Electronics Division,

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## I. INTRODUCTION

The ATC Automation Project in Japan during the next decade is composed of three steps: Phase I, Phase II and Phase III. In the Phase I Step it is expected that controllers' clerical works in the Tokyo Area Control Center (Tokyo ACC) will be mechanized by employing an electronic data processing system. However, decision making will be done by still controllers as well as in the present system. Tokyo ACC is the agency which has the role to control all aircraft on the airways all over Japan. The Phase I System considered in the present paper is consequently a semi-automatic system of en-route air traffic control.

In March, 1965, Nippon Electric Company produced a prototype for controller console to be used in the Phase I System. The console based on this prototype will allow controllers to communicate directly with the on-line computer to be installed in Tokyo ACC.

During June, 1965, in the control room of Tokyo ACC the prototype console was put through an evaluation test on the subject of the man-machine relations by research staffs of Navigation Electronics Division of Ship Research Institute\* and controllers of Tokyo ACC.

As one of the items of the evaluation test we observed and analyzed controllers' communication workload at the present status, i.e., at the control system depending only on voice communication. Then we could obtain some statistical data on ATC communication congestion, and applied a simple queueing theory to the data. As a result we found that such data can be tangible indices to judge whether controllers are overloaded or not.\*\*

This paper is an extract from an official report released early in November, 1965. The present paper puts emphasis on the statistical data on ATC communication congestion in Tokyo ACC.

## II. BACKGROUND

### 2.1. Functions of the ATC Automation System Phase I

Tokyo ACC in Kurume-town, a suburb west of Tokyo, has jurisdiction over the air traffic control of Tokyo F.I.R., i.e., of the airways all over Japan and the northwestern part of the Pacific Ocean, with the exception of such areas as the terminal control area of Tokyo International Airport and the approach control areas of local airports. Each

\* On the 10th of July, 1967, the Electronic Navigation Laboratory was established by the staffs of the Navigation Electronics Division of Ship Research Institute.

\*\* The same assertion is found in "Research Methods in Air Traffic Control" by T. K. Vickers, 1960, The AGARD Aviation Panel Meeting [1].

of these excepted areas is under the jurisdiction of the control tower of respective airports.

The control region under Tokyo ACC is divided into nine sectors usually. At the time when the observation was made the total number of aircraft handled by Tokyo ACC was about 600 A/C per day, but the number is increasing year by year.

The flight informations necessary for controlling these aircraft are collected through the domestic and international fixed telegraph circuits from aeronautical aids offices in airports, from base operations in military bases, and from ACCs in adjacent F.I.R.s. Based on the teletypewriter-outputs assistant controllers make flight strips manually, i.e., by means of hand-writing.

The tools which controllers can utilize are only these flight strips and the voice communication system which allows the controllers to get position reports from aircraft or to issue instructions to aircraft. If a aircraft is within the coverage of the radio of Tokyo ACC, the controller can directly contact with the aircraft, but if without the coverage, the voice message is transmitted to a controller in a tower or in a radio station that is nearest to the aircraft through fixed landline telephone circuit, and the message is forwarded to the aircraft by this controller. Recently Tokyo ACC has possessed a 200 nautical mile range ARSR, but at the time when our observation was made the radar was under field adjustment and not under operation.

The ATC Automation System Phase I will make following changes in this present system :

- (1) Flight plans will be processed by a digital computer, and flight strips will be printed out automatically.
- (2) At the input of a position report or other information the computer will update the related informations stored in it, and check whether there will be conflictions or not.
- (3) The computer will reply to controllers' inquiries about such problems as the confliction-check on a hypothetical flight plan or the allowability of an altitude assignment.
- (4) Display equipments will inform controllers of the results of updating or confliction-check, the answers to inquiries, and other advices.
- (5) Statistical data on the traffic will be processed into an appropriate form and printed out when the system is idle.

In the Phase I Step, however, no change will occur in the voice communication system, and the ARSR will not be connected with the computer. Moreover, although clerical works in ATC will be mechanized, decision making will not be mechanized. The Phase I System is proposed to be completed in 1968.

## 2.2. Design of the Prototype Console

At this present, the controller in Tokyo ACC has nothing other than strip board on which strips are lined up, and voice communication equipment which is composed of switches, pilot-lamps, head-sets, etc. The controller makes his decision based on the strips, and has a talk with pilots, towers and other agencies by using the communication equipment.

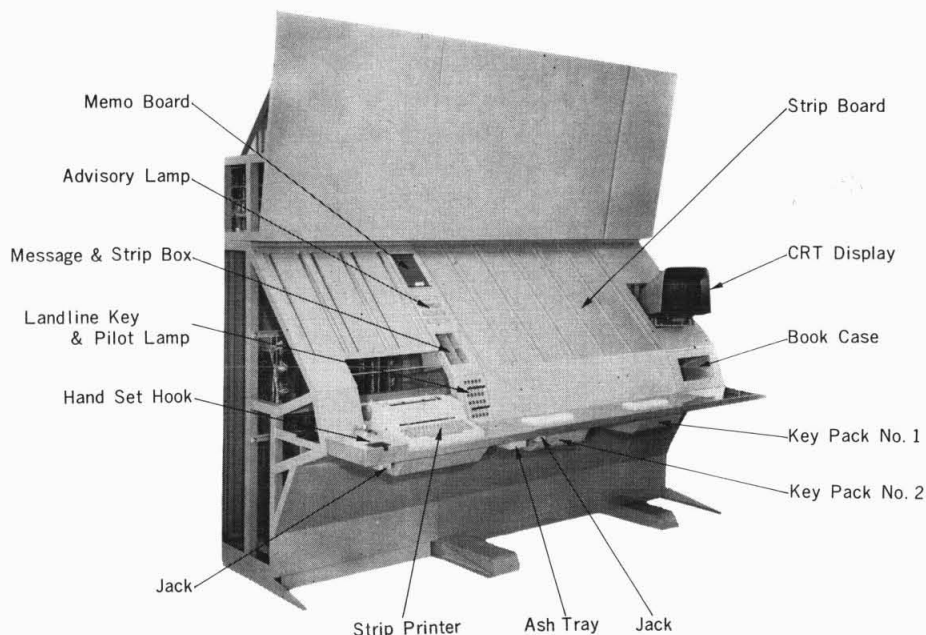


Figure 1. Prototype Console

At the completion of the Phase I System each controller will have a console such as the prototype shown in Figure 1. Its important parts and their functions are :

### (1) Strip Board

This is the same type as the board in the present use. The flight strip method is to be still followed in the Phase I System as the foundation of ATC.

### (2) Strip Printer

Flight strips are printed out automatically by this printer. Moreover this printer is used by the assistant controller in order to file flight plans into the computer or to draw out necessary informations from the computer.

### (3) Key Pack

When the controller gets a position report or other information, he updates the related informations stored in the computer by using

this key pack. If he wants to inquire something of the computer, he has to operate the keys following a certain format. But updating of flight strips is not mechanized in the Phase I System. The controller updates the flight strips manually as in the present system.

(4) CRT Display

The on-line outputs from the computer to the controller are displayed on this CRT display. For example, contents of confictions, answers for inquiries and other advices are displayed. Also this display can be used in order to allow the controller to check his key input operations. When he strikes a format, it appears on the display. After checking it, he is able to send it into the computer.

(5) Advisory Lamp

If there is any advice from the computer to the controller, this lamp flashes.

The capacity of the Phase I System is specified as follows :

- (1) Handles about 2,000 A/C per day.
- (2) Handles 200 A/C on time.
- (3) Processes 40 flight plans per 15 minutes.
- (4) Receives about 30 kinds of messages for updating and inquiries.
- (5) Processes 300 messages for updating or inquiries per 15 minutes.

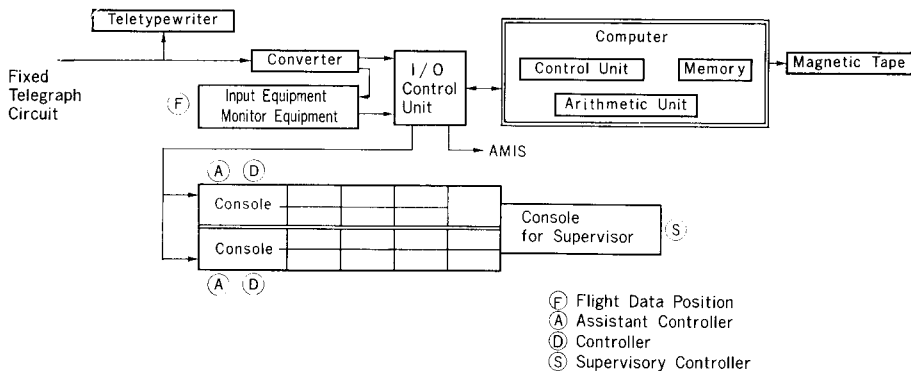


Figure 2. Block Diagram of Phase I System

These are specified based on the expectation of traffic in 1970. Figure 2 shows the block diagram of the Phase I System.

### 2.3. Outline of the Evaluation Test

The aims of the test was to evaluate the man-machine relations between the console and the controller as follows :

- (1) How will the controller's workload be reduced by introducing the

Phase I System? Will the controller be fully compensated his loss of time necessary for the key operations by the benefits from the system? Will he be able to fully distribute his notice to the Board, the Key Pack, the CRT, the Lamp, and the communication equipment while controlling air traffic in real time?

- (2) We can not say that the human controller will never mistake at the operating the key pack. Will the probability that the system may have a wrong information by such a misoperation increase?
- (3) What kinds of message should be selected, and what type of format should be defined for each message?
- (4) Will any modifications of the airspace structure be required for this semi-automatic ATC system?
- (5) What change will occur on the division of work between the controller and his assistant?
- (6) What layout of the console will be suitable for the controller from the standpoint of human engineering?

In order to evaluate these items satisfactorily, the evaluation test should have been carried out by using ATC Simulator producing air traffic control situations under a laboratory condition for studying ATC systems. But we had not such facility at the time when the evaluation test was carried out. Unfortunately, lacking balance to the progress of the Phase I System, we are out of data in the study of the method to evaluate ATC systems and in the development of ATC simulator and simulation techniques. Therefore, the test for the prototype console was forced to be done under very disadvantageous condition.

Thus we carried out the following procedures so as to achieve our aim as possible:

- (1) "Simulation"

Though we shall hereafter use the word of "Simulation," it does not imply the word what is called in the field of ATC dynamic simulation or fast time simulation. It means to have controllers use the prototype console under a realistic condition produced within our ability. In this "Simulation" test we observed the time necessary for each key input operation, the probability of erroneous input, the ratio of total key input time to total voice communication time in a certain time interval, the status of controller's fatigue, etc. Then we analyzed the controller's workload necessary for operating the prototype console.

- (2) Analysis of Controller's Workload in the Present System

We sampled five sectors from the nine ones and investigated the following items on each of them: the number of controlled aircraft, the variation of on-time traffic, the time and the content of voice

message, the communication delay caused by communication congestion, etc. Based on these data and the "Simulation" data, we made an estimate of the change of controller's workload which will be caused by the Phase I System. And then we discussed how to modify the airspace structure and how to make up the new relations between the controller and his assistant.

### (3) Enquete

By means of enquete we collected and analyzed the controllers' opinions about the key input method, the message format, the console layout, etc. The controllers offered also their opinions about the problem arising in transference of the present system into the Phase I System.

The test and researches were carried out spending about one month during June, 1965. After the analysis of the data and the discussions by the research staffs and the controllers, we released an official report of 39 pages with 99 figures and tables. We could write many useful data and comments in this official report, even though the evaluation test had been made in the disadvantageous condition as mentioned above.

However, the greater part of the data was concerned with controller's communication workload. It is entirely because it was most easily measurable. A remarkable conclusion which was obtained from the evaluation test is that a controller is considered to be overworked when the communication loading ratio (voice time plus key operation time/whole time) rises to a level of 60 or 70 per cents over an extended period. Although the fact had already been pointed out by T. K. Vickers [1] and other authors [2], we recognized it by our own data.

The next section 2.4 is concerned with a summary of the "Simulation" test. And then in Chapter III we shall describe the data obtained from the "Analysis of the Present System" in some detail putting emphasis on the problem of ATC communication congestion.

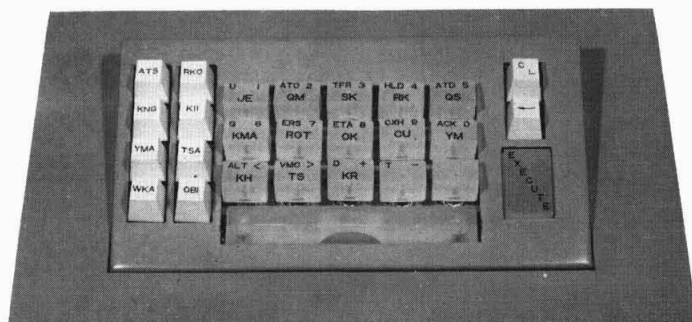
## 2.4. Summary of the "Simulation"

The purpose of this paper is not to describe the "Simulation" test in detail. We present here a brief summary of the test.

### 2.4.1. Test Method

We experimented with the "Simulation" test on the hypothesis that the prototype console was used by the controller who had jurisdiction over Kinki-Shikoku Sector, one of the nine sectors in Tokyo ACC. Figure 3(a) shows the key pack designed for Kinki-Shikoku Sector, and Figure 3(b) shows the key message formats used in this test.

Figure 4 shows the system of the "Simulation." As Kinki-Shikoku



(a) Key Pack

STROKE ORDER	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32								
1 SK 0005 80 QM 0015	U	A	T	O	1	2	3				S	K			0	0	0	5			0	8	0			0	0	1	5	E										
2 ATD JOO 0000	U	A	T	D	0	2	9								0	0	0	0			E																			
3 ↓ 80	U	A	L	T	4	5	7														0	8	0	E																
4 < QS ↓ 80	U	A	L	T	6	1	0				<	Q	S								0	8	0	E																
5 X YM 80 +	U	A	L	T	2	9	3				+	Y	M								0	8	0	E																
6 ↑ 120 XSK 90 +	U	A	L	T	0	8	5														1	2	0	E																
	U	A	L	T	0	8	5				+	S	K								0	9	0	E																
7 ↑ 120 <0005	U	A	L	T	1	5	1				<				0	0	0	5			1	2	0	E																
8 ↑ 120 5' < SK	U	A	L	T	5	5	3				<	S	K		T	0	0	5			1	2	0	E																
9 ↑ 120 15NM < SK	U	A	L	T	9	0	1				<	S	K		D	0	1	5			1	2	0	E																
10 HOLD SK	U	H	L	D	7	9	2				S	K																												
11 E HOLD SK	U	C	X	H	4	4	4				S	K			E																									
12 HOLD QM ↓ 50	U	H	L	D	3	5	3				Q	M									0	5	0	E																
13 ↑ 130 VMC	U	V	M	C	6	4	1														1	3	0	E																
14 ↑ 130 ↓	U	V	M	C	5	2	2														1	3	0	E																
15 M VMC TO SK	U	V	M	C	3	7	5				S	K			E																									
16 REVISE ETA KRO015	U	E	T	A	3	6	4				K	R			0	0	1	5			E																			
17 TFR MSG SENT	U	T	F	R	0	7	5				E																													
18 ERASE DATA	U	E	R	S	1	2	4				E																													
19 VMC ON TOP	U	A	L	T	2	6	7				E																													
20 QUERY	Q																																							

(b) Key Message Formats

Figure 3. Key Pack and Key Message Formats

Sector is without the coverage of the radio of Tokyo ACC, the controller is not in direct contact with the aircraft under his jurisdiction. He is in indirect contact with the aircraft by means of having a talk with towers and other agencies through the fixed landline telephone circuits as shown in Figure 5.

The "Tower" position in Figure 4 played the role of these towers and agencies, and performed simulate voice communications with the "Controller" position. The "Controller" controlled hypothetical traffics on the Strip Board, and performed simulate key operations.

The time of each key input operation was recorded one by one on the "U" and "EXECUTE" channel of the pen-oscillograph. When the "Controller" noticed a misoperation himself and corrected the misformat using the "BACK" key, it was recorded on the "BACK" channel.



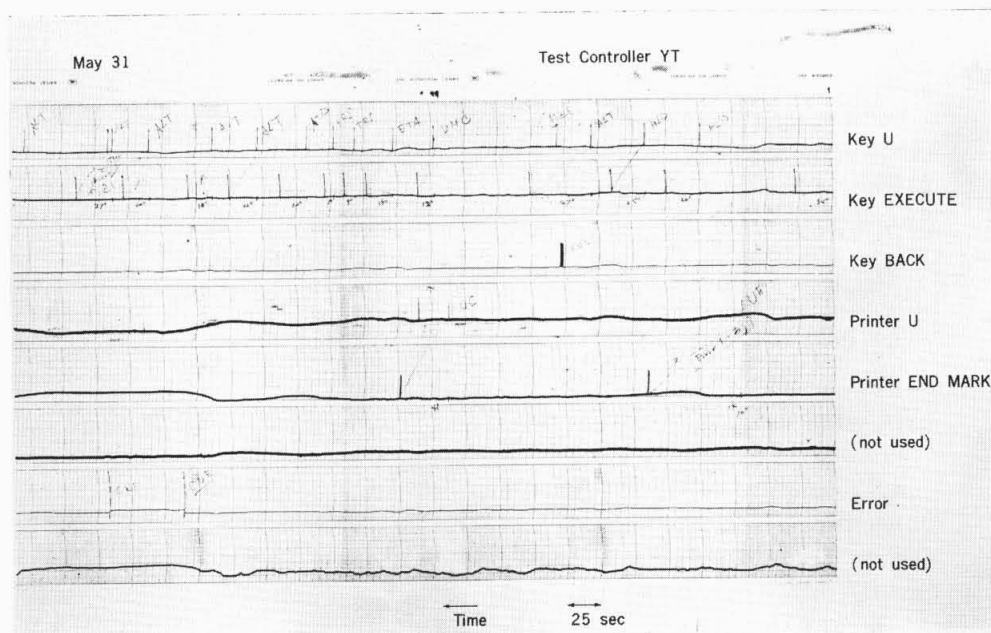


Figure 6. A Part of Pen-oscillograph

other, and experimented with a total of 37 test runs; each run took 30 minutes. However, the "Simulation" was made under a test condition widely different from the actual control situation. Therefore, prior to the description of the data, we shall remark here some important differences as follows:

- (1) Since the prototype console had not yet been connected with the computer when the "Simulation" test was made, it was not a comprehensive test of the Phase I System. It was a solo test of the console only. Therefore, the Printer, the CRT and the Advisory Lamp did not print out or display any informations from the computer. However, the CRT was connected with the key pack via a control unit, so that the "Controller" could correct misformats and the "Tower" could record erroneous inputs.
- (2) We used four kinds of traffic samples based on actual traffic data in Kinki-Shikoku Sector.\* However, none of them had any conflicts.
- (3) The actions of the "Controller" was limited to the voice communications with the "Tower," the manual updating of strips, and

\* We recognized one obvious drawback that the controllers soon became familiar with all flights in the traffic samples when they treated the limited samples over and over again.

the key input operations. He was not allowed to inquire anything of the computer.

- (4) The “Controller” was given voice messages keeping pace with his actions from the “Tower”. But this is contrary to the fact that messages arrive at random at the controller.\*
- (5) The controllers who joined in this test were all experts at their work.

### 2.4.3. Data

The following is a summary of the data:

#### (1) Controller’s Communication Loading Ratio

We experimented with a total of 37 test runs; each run took 30 minutes. Let  $K$  and  $V$  be respectively total time of key operations and total time of voice communication in each test run, and  $T$  be test time (i.e.,  $T$  equals 30 minutes for every test run). Figure 7 shows the distribution of the ratio of  $K$  to  $T$ , and  $V$  to  $T$ . However, this data shows the controller’s communication loading ratio under the test condition as remarked in 2.4.2. (4). The “Controller” was not allowed to have any idle time. However, he was given messages keeping pace with his actions.

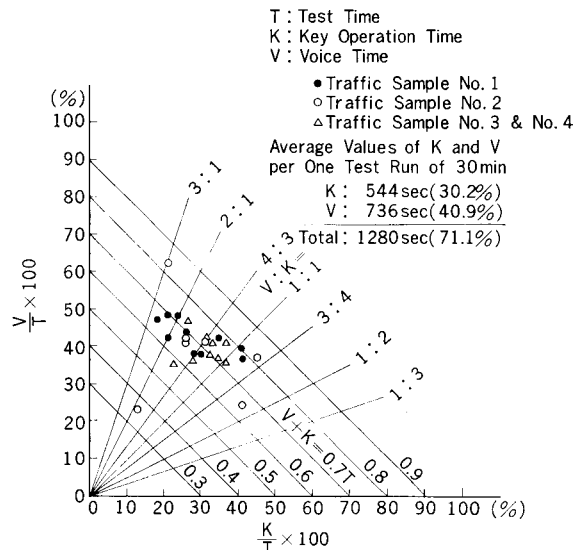


Figure 7. Distribution of Communication Loading Ratio

\* This “Simulation” test had two obvious drawbacks: the limited traffic samples and the nonrandom message arrivals. By this experience we realized that “randomness” is very important factor in such an evaluation test of ATC system. Then the techniques producing such randomness under a laboratory condition, i.e., ATC Simulator and Simulation Techniques, are considered to be essential in order to evaluate ATC systems [3], [4].

## (2) Frequency of Key Input Operations

Summing up the data of the 37 test runs, we calculated average frequency and average time of key operations per 30 minutes. Table 1 shows the data. The table shows also the nine kinds of message respectively in percentages. The ATOs form a large percentage both in the frequency and in the time. However, this data contains no inquiry message as remarked in 2.4.2. (3).

Table 1. Average Frequency and Average Time of Key Operations per 30 minutes

Message	No. of MSG per 30 min		Key Time per 30 min	
ATO	①	14.4 (48.7%)	①	344 sec (63.0%)
TFR	②	5.3 (17.7)	③	49 ( 9.0)
ERS	③	4.1 (13.9)	④	35 ( 6.4)
ALT	④	2.6 ( 8.9)	②	53 ( 9.8)
ATD	⑤	1.5 ( 4.9)	⑤	26 ( 4.8)
ETA	⑥	1.0 ( 3.4)	⑥	23 ( 4.3)
VMC	⑦	0.5 ( 1.6)	⑦	10 ( 1.9)
HLD	⑧	0.3 ( 0.8)	⑧	4 ( 0.8)
CXH	⑨	0.0 ( 0.1)	⑨	0 ( 0.0)
Total		29.7 (100.0)		544 (100.0)

1, 2, ... : Order

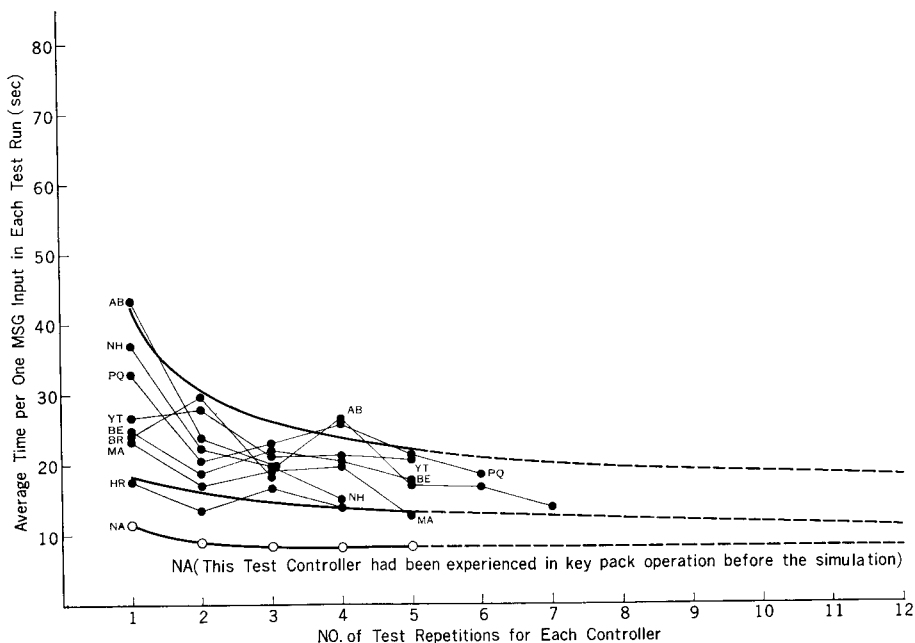


Figure 8. Training Effect on Key Operation Time

(3) Time of Input for one Message

There was a wide variety in time of input for one message according to the kind of message, to the degree of training for key input operation and to so forth. At first we paid attention to the training effect on key operation time. In order to find it we calculated the total average time per one message in each test run and made it relate with the number of test repetitions for each controller.

Table 2. Estimated Range of Average Key Operation Time per one Message Input

MSG		No. of Test Repetitions	5 th	10 th
Total Average per one MSG			13.5~22.0 sec	12.0~19.0 sec
Separately in the Nine Kinds of MSG	ATO		16.5~31.0	14.5~24.5
	ATD		11.0~20.0	9.5~17.0
	ALT		12.5~22.0	9.5~16.5
	ETA		10.5~23.0	9.0~19.5
	VMC		9.5~17.5	8.5~15.0
	HLD		5.0~13.0	4.0~11.5
	CXH		5.0~13.0	4.0~11.5
	TFR		4.0~10.5	3.0~ 9.5
	ERS		4.0~10.5	3.0~ 9.5

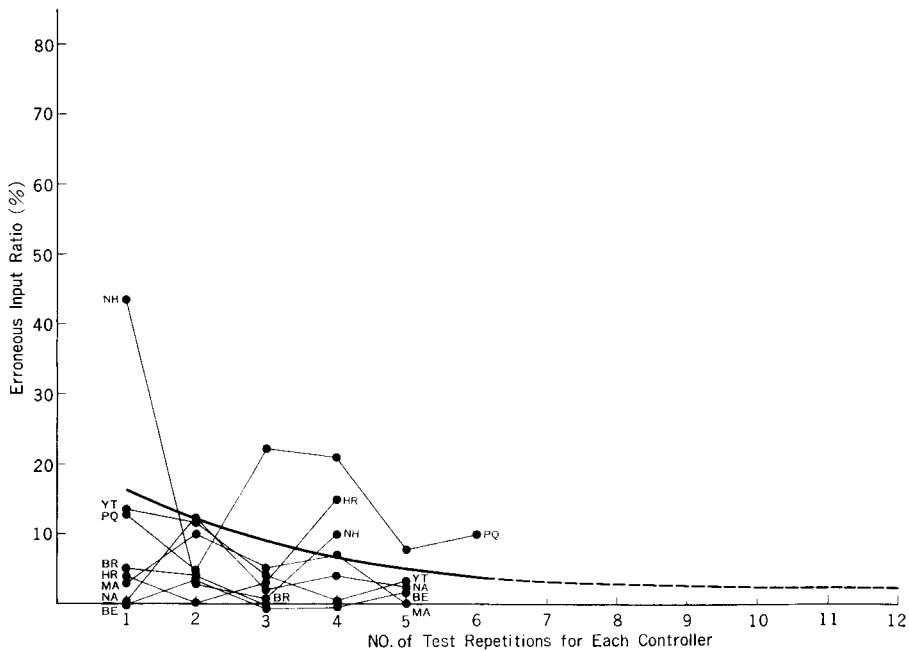


Figure 9. Training Effect on Erroneous Input Ratio

As the result we obtained Figure 8. We investigated also the same relations respectively in the nine kinds of message. However, we present here only Table 2 as an abbreviation of the data.

(4) Erroneous Input Ratio

The key input operations recorded on the pen-oscillograph are classified into three categories from the standpoint of accuracy.

1. Right.....The message format appeared on the CRT without error.
2. Corrected...The message format was corrected once or more, but finally it had no error.
3. Erroneous...The message format had finally one or more errors.

We calculated the "Erroneous Input Ratio" for each test run, i.e., the ratio of Erroneous Messages to total messages in each test run. Figure 9 shows the training effect on erroneous input ratio. However, this data shows the erroneous input ratio under the test condition as remarked in 2.4.2. (1). Since the console had not yet been connected with the computer, the system performed no validity check on controller's key operations.

### III. ANALYSIS OF CONTROLLER'S WORKLOAD IN THE PRESENT SYSTEM

#### 3.1. Sampled Sectors

The airspace under the jurisdiction of Tokyo ACC is composed of nine sectors as a basic. However, the sector composition is not rigid. It may be modified to some extent according to the air traffic situation. The controller disposition in each sector is also flexible. We sampled five sectors as shown in Table 3. The controller disposition in each of them was as follows:

Kanto C Sector is within the coverage of the radio of Tokyo ACC. Therefore, the Radio Controller was in direct radio contact with the aircraft in this sector, while the Controller was in communication with towers and other agencies through the landlines.\* However, the leadership in the execution of control was taken by the Controller. Kanto A Sector and Chubu-Hokuriku Sector were exactly similar to Kanto C.

Kinki-Shikoku Sector is without the coverage of the radio of Tokyo ACC. Therefore, there is no radio controller. This sector is controlled by one controller as a basic. However, when we observed this sector, there were two controllers because of heavy traffic. The controllers were in indirect contact with the aircraft via towers and other agencies

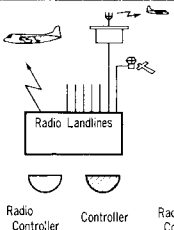
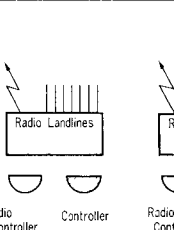
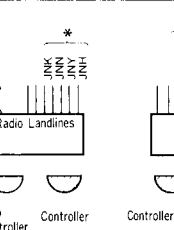
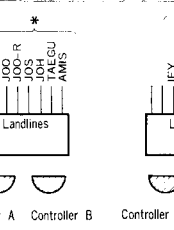
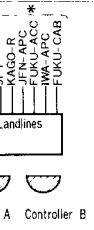
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\* "Fixed landline telephone circuit" is abbreviated to "landline" in this chapter.

through the landlines. The Controller A controlled the inbound and outbound traffic of Osaka International Airport, while the Controller B controlled the traffic relating to other local airports in this sector. They worked on the same board, but the leadership of control was taken by the Controller A.

Kyushu-Chugoku Sector is also without the coverage of the radio of Tokyo ACC. Kyushu Sector and Chugoku Sector are controlled separately one from the other as a basic. However, when we observed these sectors, they were combined into one sector. The Controller A controlled the traffic in Chugoku and Northern Part of Kyushu, and the Controller B controlled Southern Part of Kyushu. The leadership of control was taken by the Controller A.

Table 3. Sampled Sectors for Analysis of the Present System

Sector	Kanto C	Kanto A	Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku
Date	June 16 0515Z~0615Z (1 h)	June 18 2350Z~0020Z (30min)	June 17 0500Z~0600Z (1 h)	June 16 0015Z~0115Z (1 h)	June 17 0025Z~0125Z (1 h)
Communication System & Controller Disposition					
Controller's Workload	Normal	Light-Loaded	Overworked	Normal	Normal

\* These are the lines whose pilot lamp blinking situations were recorded. Idle lines were omitted.

According to controller's feeling and research staff's intuition, the degree of controller's workload in each sector was as follows:

1. Kanto C ..... Normal
2. Kanto A ..... Light-loaded
3. Chubu-Hokuriku ..... Overworked
4. Kinki-Shikoku ..... Normal
5. Kyushu-Chugoku ..... Normal

Kanto A Sector was observed only for 30 minutes because of the light traffic. The workload in Chubu-Hokuriku Sector was evidently out of the controller's capacity.

### 3.2. Method of Investigation

The voice messages in each sector were recorded one by one in the

same manner as in the "Simulation" test. We used the pen-oscillograph again, which was found very effective for such an investigation. The voice message recording was performed in each of the five sectors.

Analyzing the voice recording data, we could know the number of messages and the communication loading ratio over an extended period in each sector. But these were insufficient as precise scientific data on the subject of communication congestion in ATC.

In order to obtain more precise data, we paid attention to blinking of landline pilot-lamp. It represents the status of communication congestion evidently, though it is concerned with landline only. Then in addition to the voice message recording, the blinking situation of pilot-lamp in each sector was recorded on the pen-oscillograph with the exception of Kanto C and Kanto A. Figure 10 shows a part of the typical record.

After recording such data, we examined flight strips of each sector in order to investigate the variation of traffic load over the observation period.

In the following sections we shall present some extracts from the

From the landline pilot-lamp blinking record:

T	Transmitting Time	R <sub>1</sub>	ACC was called up from JOO. (Blinking)
RD	Receiving Delay Time	R <sub>2</sub>	Switched ON after a waiting time. (Steady)
RC	Receiving Service Time	R <sub>3</sub>	Talk over, Switched OFF. (Dark)
I	Interval between Successive Calls	T <sub>1</sub>	ACC called up for JOO. (Steady)
		T <sub>2</sub>	Talk over, Switched OFF. (Dark)

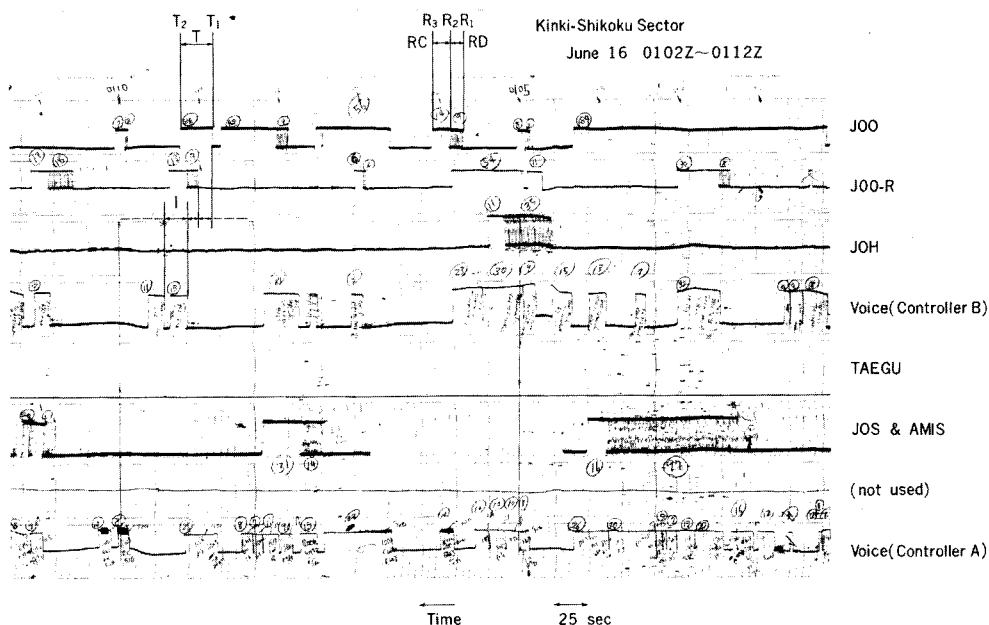


Figure 10. Record of Controller's Communication Load

results of the above investigations and some discussions on the data.

### 3.3. Traffic Load and Communication Load

#### 3.3.1. Traffic Load

The number of the aircraft which were controlled by each sector over the observation period and the distribution of controlled time dura-

Table 4. Distribution of Controlled Time Duration

Duration Rank $t_i \sim t_{i+1}$	Number of Aircraft $f_i$					
	Kanto C	Kanto A	Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku	Total
0~ 4 min	2	1				3
5~ 9	3	1	2	1		7
10~14	6	2	4	6	2	20
15~19	8	3	9	3	1	24
20~24	2	4	2	5	8	21
25~29	1	1	7	6	7	22
30~34	1		8	3	1	13
35~39		3	1	9	1	14
40~44			3	6	1	10
45~49	1		1	1	2	5
50~54				1	2	3
55~59			1	1	2	4
60~64			1	1	2	4
65~69					1	1
70~74					3	3
75~79						
Sum of Durations	383 min	310	1033	1301	1236	4263
Total No. of A/C	24 A/C	15	39	43	33	154
Duration per one A/C	15' 57"	20' 40"	26' 29"	30' 15"	37' 27"	27' 41"

(30 min)

1. Sum of Durations =  $\sum \frac{t_i + t_{i+1}}{2} f_i$
2. Total No. of A/C =  $\sum f_i$
3. Duration per one A/C =  $\frac{\text{Sum of Durations}}{\text{Total No. of A/C}}$

tion are shown in Table 4. We here use the term of “controlled time duration” as the meaning of how long time the aircraft was continuously under the jurisdiction of the sector.

Figure 11 shows the variation of on-time traffic at intervals of five minutes in each sector.

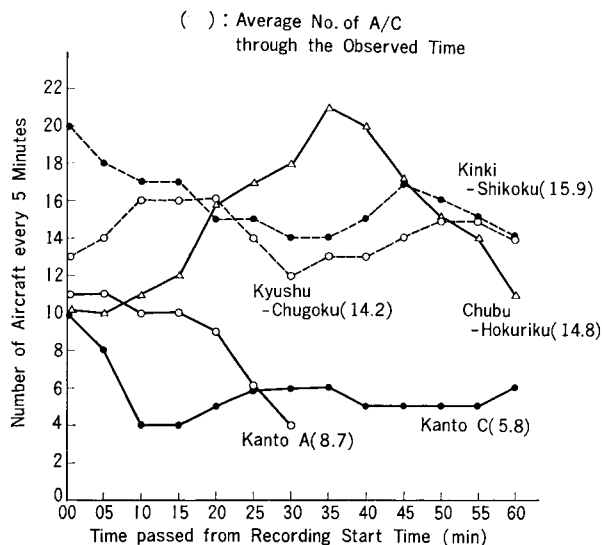


Figure 11. Variation of On-time Traffic

### 3.3.2. Communication Load

Each sector was controlled by one pair of controllers: Controller & Radio Controller or Controller A & Controller B. The communication load of each position is shown in Figure 12 and Figure 13. The former shows the number of voice messages in every time interval of five minutes, and the latter shows the communication loading ratio (voice time/five minutes).

### 3.3.3. Correlations of Traffic Load and Communication Load

We examined the correlations of on-time traffic vs. number of voice messages and on-time traffic vs. communication loading ratio from the data of Figures 11, 12 and 13. But we could not find out any obvious correlations. It is considered that observation in longer time is necessary for analyzing such correlations.

As mentioned in Section 3.1 the controller's workload in Chubu-Hokuriku Sector was judged as overworked. In order to make clear

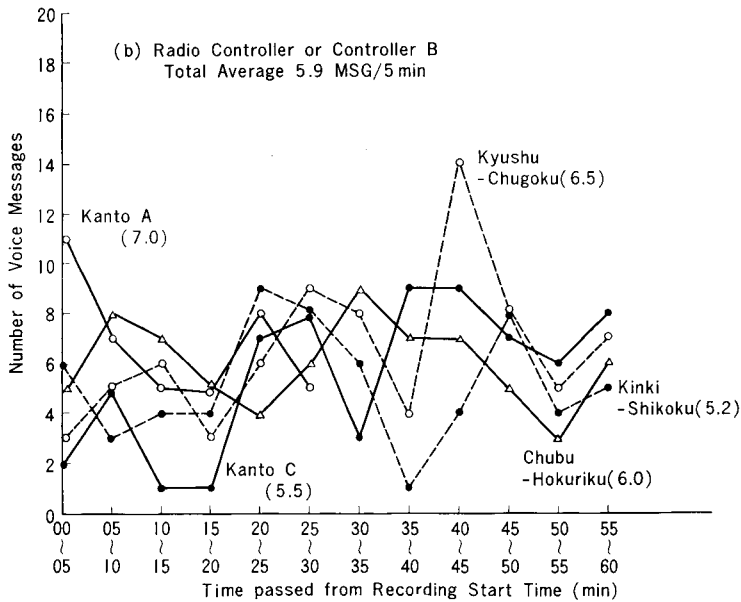
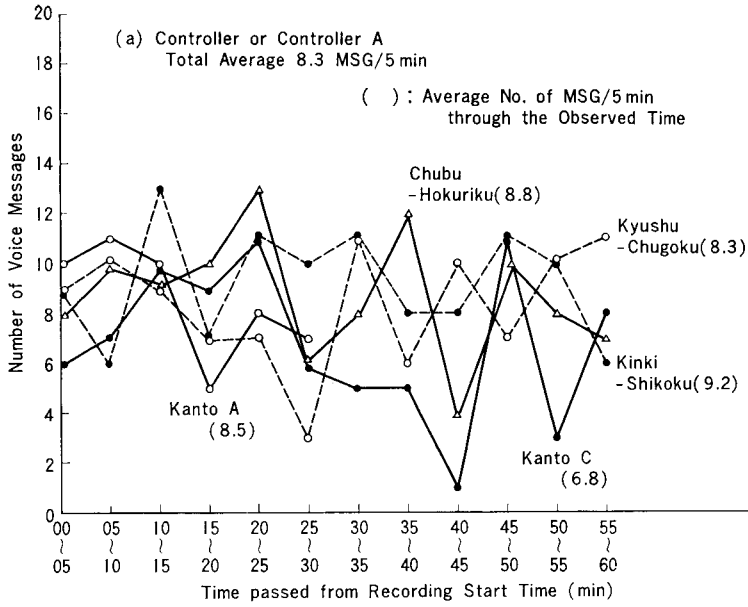


Figure 12. Number of Voice Messages

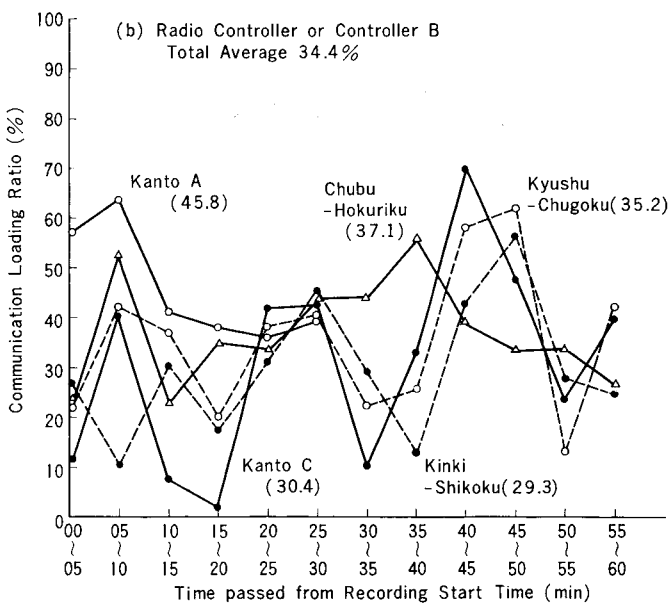
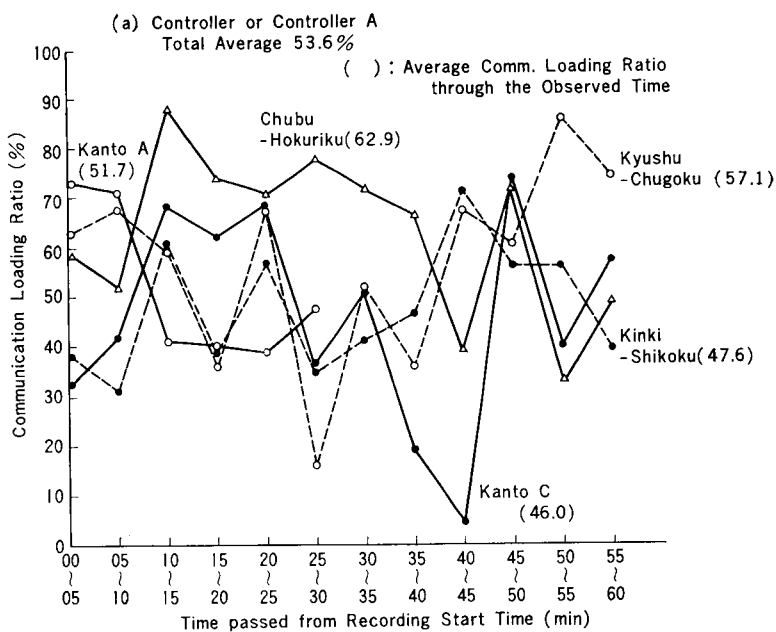


Figure 13. Communication Loading Ratio

what produced such situation, we summarized the above data on traffic load and communication load in Table 5. But we could not find out the reason in this table.

However, when we examined the landline pilot-lamp blinking record, we could find out a facet of the reason. The details are described in Section 3.5.

### 3.4. Voice Message Classification and Time Distribution

We collected all the voice message recordings in the five sectors and classified them into 22 kinds. The 22 kinds of message were divided into seven divisions from the standpoint of the key operation in the Phase I System. Table 6 shows the classification and the time distribution. Figure 14 shows the graph of the total time distribution in Table 6.

Table 5. Summary of Traffic Load and Communication Load

Sector		Kanto C	Kanto A	Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku
Sum of Controlled Time Durations		383 sec	310	1033	1301	1236
Total Number of A/C		24 A/C	15	39	43	33
Controlled Time Duration per one A/C		15' 57"	20' 40"	26' 29"	30' 15"	37' 27"
Average On-Time Traffic		5.8 A/C	8.7	14.8	15.9	14.2
Number of Voice MSG per 5 min	Controller or Cont. A	6.8	8.5	8.8	9.2	8.3
	Radio or Cont. B	5.5	7.0	6.0	5.2	6.5
	Total	12.3	15.5	14.8	14.3	14.8
Communication Loading Ratio	Controller or Cont. A	46.0%	51.7	62.9	47.6	57.1
	Radio or Cont. B	30.4%	45.8	37.1	29.3	35.2
	Total	76.4%	97.5	100.0	76.9	92.3
Controller Disposition		Cont. Radio	Cont. Radio	Cont. Radio	Cont. A Cont. B	Cont. A Cont. B
Controller's Workload		Normal	Light-Loaded	Over-worked	Normal	Normal

(30 min)

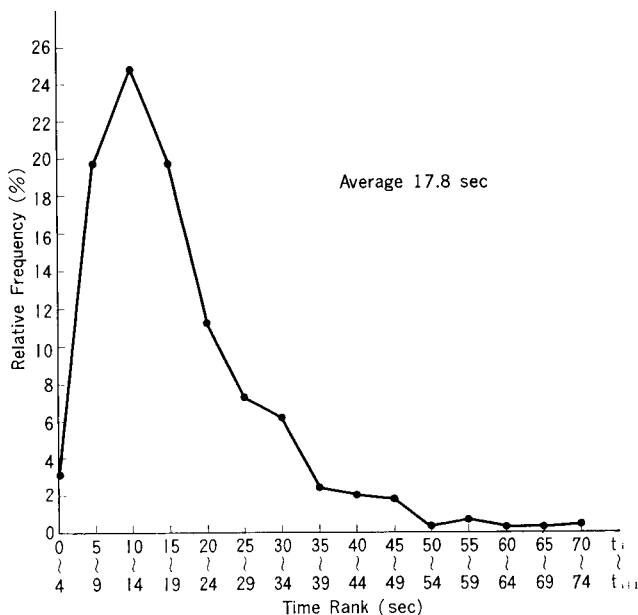


Figure 14. Distribution of Voice Message Length

### 3.5. Communication Congestion on Landline and Queuing Theory

#### 3.5.1. Model

According to the landline pilot-lamp blinking record of each sector, we could examine the following time points (See Figure 10):

In case of Receiving:

1. The time when the controller was called up from a line.  
.....Blinking
2. The time when he replied to the line.  
(i.e., when he switched ON) .....Steady
3. The time when the talk was over.  
(i.e., when he switched OFF) .....Dark

The time interval between 1 and 2 is "Waiting Time" or "Receiving Delay Time" (RD), and that between 2 and 3 is "Service Time" or "Receiving Service Time" (RC).

In case of Transmitting:

1. The time when the controller called up for a line.  
(i.e., when he switched ON and sent call signal) .....Steady
2. The time when the talk was over.  
(i.e., when he switched OFF) .....Dark

Table 6. Voice Message Classification

Division		Kind of MSG	Time Rank					
			0~4 sec	5~9	10~14	15~19	20~24	25~29
I Associated with Key Input	U-ALT	1 Iss Alt Change		4	6	3	6	2
	U-HLD	2 Iss Hold						1
	U-ATO	3 Rcv Position Report		18	30	23	22	13
	U-ETA	4 Revised ETA						
	U-TFR	5 Transmit TFR		4	7	11	7	5
II Associated with Printer Input	UC	6 Iss Clearance		4	7	12	5	10
	UR	7 Iss Route Change					1	
		8 Rcv TFR		3	5	2	2	1
III Associated with Query Input	Q-ALT	9 Req Alt Change	1	2	2	7	2	
	QR	10 Req Route Change						
	QC	11 Req Clearance	1	6	8	10	4	3
IV* Not need of any Key Input		12 Coord with Tower		8	16	10	2	1
		13 Coord with APC	1	30	21	20	8	4
		14 Coord with ACC	1	1	4	6	3	1
V** Reduced inevitably		15 Coord with Sector	12	26	32	18	7	6
VI Key Input or not? ...uncertain yet		16 Pass ATD to Assist	1	8	14	3		1
		17 Rcv MSG from A/C	1	6	6	5		
		18 Pass Info to AMIS			5	4	1	2
VII Independent of Key Input		19 Req Position Report		2	3	4	1	
		20 Advisory to A/C	2	4	2	1	4	1
		21 Initial Contact	1	12	11	3	4	1
		22 Others	2	8	5	4	4	1
		Total (%)	23 (3.1)	146 (19.7)	184 (24.8)	146 (19.7)	83 (11.2)	53 (7.2)

Middle Value of Rank:  $x_i = (t_i + t_{i+1})/2$ Average:  $\sum x_i f_i / \sum f_i$

and Time Distribution

$(t_i \sim t_{i+1})$ and Frequency $f_i$									$\Sigma f_i$	$\Sigma x_i f_i$	Average
30~34	35~39	40~44	45~49	50~54	55~59	60~64	65~69	70~74			
	1	1	1						25	535	21 sec
1									2	59	30
7	2		1						116	2057	18
6	4	3	3	1	2				53	1361	26
9	3	3	4	1	1	1	1		61	1647	27
									1	22	22
1									14	218	16
2									16	267	17
2	1		2						37	674	18
2		1					1	1	42	734	17
3	1	4	1					1	94	1508	16
3	2								21	422	20
4	1				1				107	1434	13
1									28	336	12
	1	1							26	280	14
1									13	236	18
	1	1							12	219	18
					1				15	245	16
2									34	448	13
1	1	1	1			1			29	523	18
45 (6.1)	18 (2.4)	15 (2.0)	13 (1.8)	2 (0.3)	5 (0.7)	2 (0.3)	2 (0.3)	3 (0.4)	740 (100.0)	13225	17.8

\* These MSGs may be reduced in number in the course of system improvement.

\*\* The Key Input Operation (I) will result in the reduction of this MSG in number.

The time interval between 1 and 2 is "Service Time" or "Transmitting Time" (T). In the case of transmitting it was impossible to distinguish actual talking time from waiting time (time interval over which the controller was being kept waiting).

If we consider these receiving and transmitting calls to be "Arrival Elements" and the controller to be "Service Station" or "Channel," we could treat the landline system of each sector as a "Queueing System." The system is rather complicated. We must take into account priorities among the lines. The mixture of receiving calls and transmitting calls should be treated as a Intersect Model [5] as well as the mixture of landings and take-offs of a runway.

In this paper, however, we shall restrict our discussions to the two basic models:  $M/M/1$  Model and  $M/M/2$  Model [6]. Prior to the application of these models, we shall arrange the data in some forms convenient for application of queueing theory.

### 3.5.2. Data

Table 7 shows the distributions of Transmitting Time (T), Receiving Delay Time (RD) and Receiving Service Time (RC) in each sector. We piled the transmitting time distribution on the receiving service time distribution and considered the combined distribution to be "Distribution of Service Time." Figures 15 (a), 16 (a) and 17 (a) are the graphs showing the service time distributions in the three sectors.

Figures 15 (b), 16 (b) and 17 (b) are the graphs showing "Distributions of Interval between Successive Calls." We here use the term of "interval between successive calls" as the meaning shown in Figure 10. Receiving calls and transmitting calls are treated together as "calls."

The average value of receiving delay time in each sector is considered to be "Average Waiting Time in Queue" ( $W'$ ). It should be noted the value of Chubu-Hokuriku Sector was extremely large.

### 3.5.3. Application of Queueing Theory

The simplest queueing theory requires the hypothesis of Exponential Service Time Distribution and Exponential Arrival Time Interval Distribution (i.e., Poisson Arrivals). The service time distributions in Figures 15, 16 and 17 are, however, rather different from exponential type. They appear rather to be Erlangian type. But we shall consider these service time distributions to be approximated by exponential type, since we are going to restrict our discussions to the simplest theory. The call interval distributions appear to be approximated by exponential type. After such considerations, we applied the queueing theory to the landline system of each sector as follows :

Table 7. Distributions of Transmitting Time, Receiving Delay Time and Receiving Service Time

Time Rank	Frequency $f_i$											
	Chubu-Hokuriku			Kinki-Shikoku			Kyushu-Chugoku					
	T	RC	RD	T	RC	RD	T	RC	RD			
0~ 9 sec	1	7	2	1	6	41	4	6	40			
10~ 19	2	7	8	5	21	6	5	26	5			
20~ 29		6	4	2	6	1	10	7	3			
30~ 39	1	5	9	2	11	2	6	6	2			
40~ 49	3	3	2	1	6	3	4	1	1			
50~ 59		3	3	4	1		3		1			
60~ 69	1	2					2					
70~ 79		2	1	1	2		1	2	1			
80~ 89		3	5				2					
90~ 99		1	2		1	1	1					
100~109		3				1		3				
110~119		1	2		1	1	1	1				
120~129		2	3									
130~139	1											
140~149			1				1					
150~159			1					1				
160~169			1									
170~179												
180~189			1		1							
190~199			1									
200~209												
210~219												
220~229			2									
230~239												
240~249			1									
250~259												
∴ ∴												
420~429			1									
∴ ∴												
830~839			1									
Average	$\frac{\text{sec}}{45.6}$	44.7	95.6	33.1	30.3	13.9	38.7	29.0	10.2			
Average Service Time	$\frac{1}{\mu}$	$\frac{\text{sec}}{44.9}$			31.0			33.4				
*	$\frac{\Sigma T}{\Sigma f_i}$	$\frac{\Sigma RC}{\Sigma f_i}$	$\frac{\Sigma RD}{\Sigma f_i}$	$\frac{410 \text{ sec}}{9}$	$\frac{2012}{45^{**}}$	$\frac{4876}{51^{**}}$	$\frac{530}{16}$	$\frac{1699}{56}$	$\frac{779}{56}$	$\frac{1564}{40}$	$\frac{1538}{53}$	$\frac{541}{53}$
	$\frac{\Sigma T + \Sigma RC}{\Sigma f_i}$	$\frac{2422 \text{ sec}}{54}$				$\frac{2229}{72}$			$\frac{3102}{93}$			

\* In this table, we calculated each average value using direct summation  $\Sigma T$ ,  $\Sigma RC$ , or  $\Sigma RD$ , not middle value of rank.

\*\* In each case of the six receiving calls of this difference, the pilot lamp became dark before controller's reply.

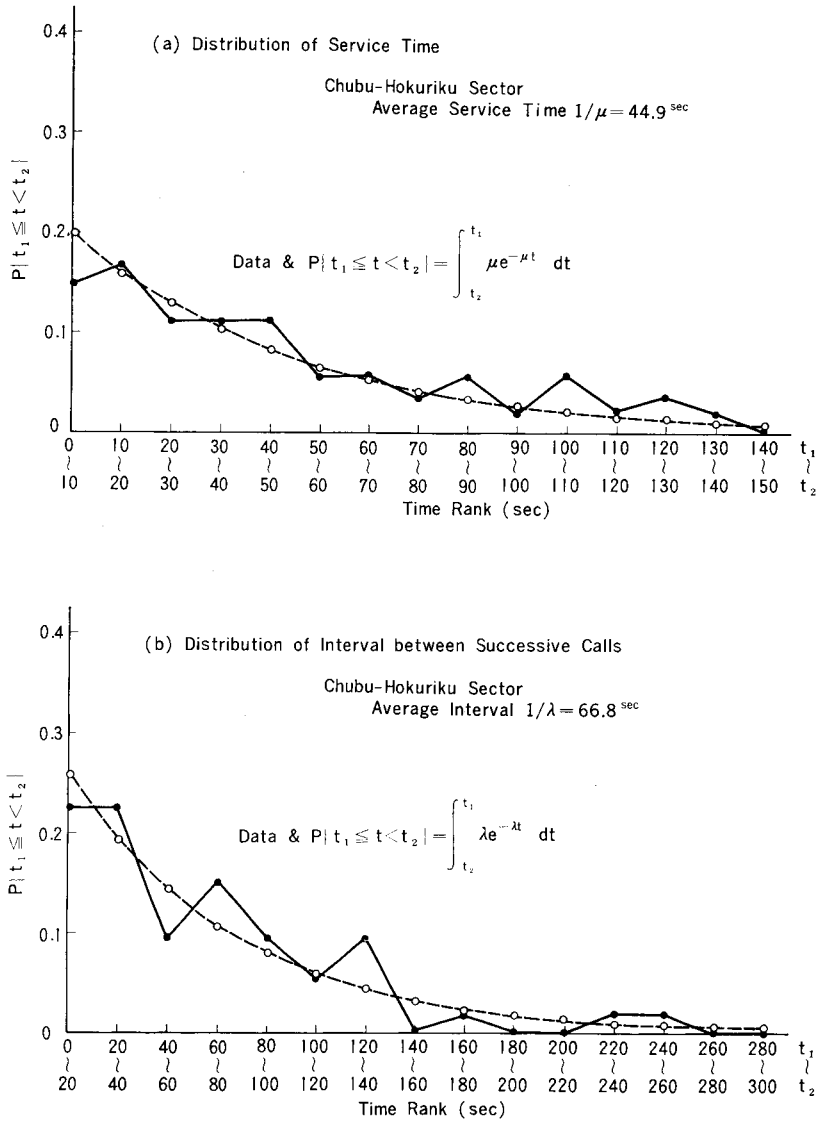


Figure 15. Communication Congestion on Landlines at Chubu-Hokuriku Sector. Data is denoted by full line and the Probability by dashed line.

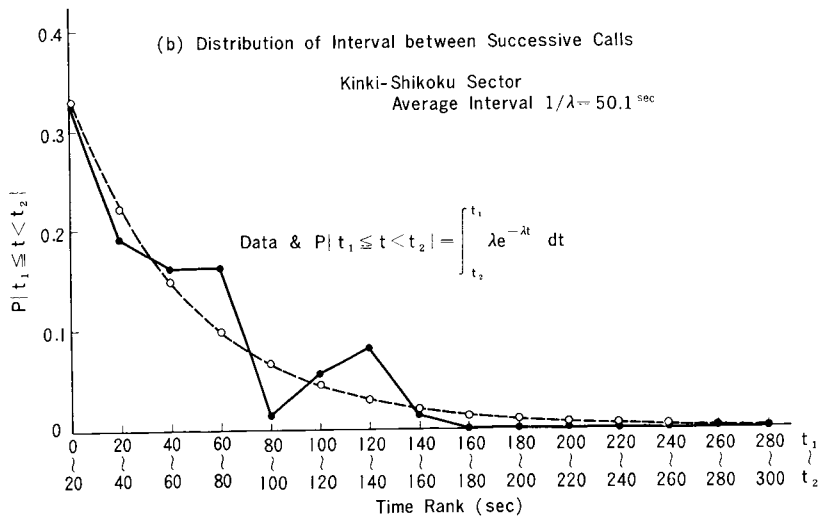
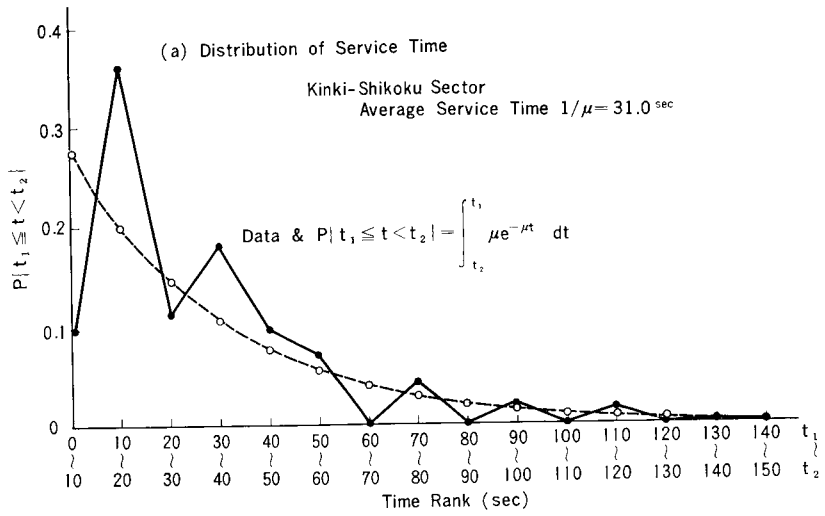


Figure 16. Communication Congestion on Landlines at Kinki-Shikoku Sector. Data is denoted by full line and the Probability by dashed line.

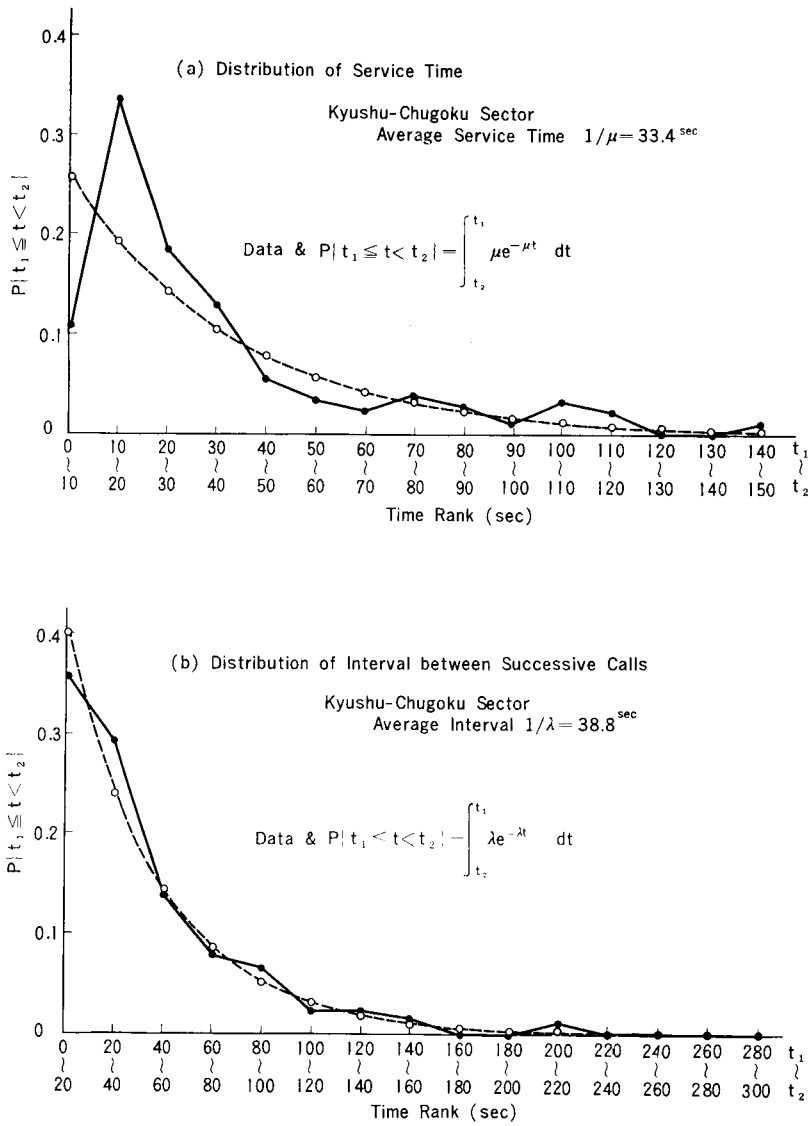


Figure 17. Communication Congestion on Landlines at Kyushu-Chugoku Sector. Data is denoted by full line and the Probability by dashed line.

### 1. Chubu-Hokuriku Sector :

The landline system of this sector was used by one controller. Then we applied the model of  $M/M/1$  to the system. Substituting the data of Figure 15 for the model, we obtained 92.0 sec as the theoretical value of "Average Waiting Time in Queue" ( $W$ ) (See Table 8). The observational value was 95.6 sec.

### 2. Kinki-Shikoku Sector :

The system was used by two controllers. If the system was divided into halves and they were used separately, the model of parallel  $M/M/1$ s should be applied to the system. If the controllers worked in co-operation with each other, the model of  $M/M/2$  should be applied to the system. However, the actual situation was ambiguous in this respect. Then we applied both of the two models to the data of Figure 16. The

Table 8. Observational Value and Theoretical Value of Average Waiting Time

Sector		Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku
Number of Service Stations for Calls on Landlines		1 Controller only	2 Controller A & B	2 Controller A & B
Average Interval between Successive Calls $1/\lambda$		66.8 sec	50.1	38.8
Average Service Time $1/\mu$		44.9 sec	31.0	33.4
Load Factor $\rho = \lambda/\mu$		0.672	0.619	0.861
Average Waiting Time (Theoretical) $W$	$M/M/1$	92.0 sec	—	—
	$(M/M/1) \times 2$	—	13.9	25.3
	$M/M/2$	—	3.3	7.6
Average Waiting Time (Observational) $W'$		95.6 sec	13.9	10.2
Formulas for $W$ On the hypothesis of Poisson Arrivals and Exponential Service Times;				
$M/M/1$ : $W = \frac{\rho}{\mu(1-\rho)}$				
$(M/M/1) \times 2$ : $W = \frac{\rho/2}{\mu(1-\rho/2)}$				
$M/M/2$ : $W = \left\{ \frac{\rho^2}{\mu(2-\rho)^2} \right\} / \left\{ 1 + \rho + \frac{\rho^2}{(2-\rho)} \right\}$				

$$W' = \frac{\sum RD}{f_i} \quad (\text{see Table 7})$$

results are shown in Table 8.

### 3. Kyushu-Chugoku Sector :

This sector was similar to Kinki-Shikoku Sector. The results are also shown in Table 8.

We thus obtained Table 8 as a result of the application of queueing theory to the landline systems. Though the models were not refined, rather very rough, the coincidence between the theory and observation is fairly good.

The controller's workload in Chubu-Hokuriku Sector was judged as overworked. We failed in finding out any tangible indices to the overworked condition in Table 5.\* The extremely large waiting time of this sector shown in Table 8, observational and theoretical, is considered to be a reliable index to the judgement on the workload. Such experience leads us to conclude that Queueing Theory may be of great use for ATC Systems Analysis.

### 3.6. Communication Load and Controller's Capacity

The following is a summary of the data concerning controller's communication load.

- (1) Figure 7 shows that the controller's communication loading ratios ranged from 60% to 80% under the test condition of non idle time, but keeping pace with the actions of controllers.
- (2) Figure 13 (a) shows that the communication loading ratio per five minutes rose rarely to the level of 80% in actual situation. The data of the figure is abbreviated as follows.

\* Notice to the following table. It shows two distinct appearances of communication load from the standpoints of voice recording and landline recording.

Sector	Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku
No. of Voice MSG per 1 hr (from the Data of Figure 12)	105*	172	178
No. of Calls on Landline System per 1 hr (from Table 7)	54	72	93
Comm. Loading Ratio on Voice (from Table 5)	62.9*%	76.9	92.3
Load Factor on Landline System (from Table 8)	67.2	61.9	86.1

(\* for "Controller" position)

One call from the standpoint of landline pilot-lamp blinking may be composed of two or more voice messages. On the other hand, off-record voice messages such as "Pass ATD to Assist" and "Coord with Sector" are not included in any pilot-lamp blinking record.

Sector	Kanto C	Kanto A	Chubu -Hokuriku	Kinki -Shikoku	Kyushu -Chugoku
Average Comm. Loading Ratio of Controller or Cont. A	46.0% (Cont.)	51.7 (Cont.)	62.9 (Cont.)	47.6 (Cont. A)	57.1 (Cont. A)

Among these sectors, only at Chubu-Hokuriku Sector the controller's workload was judged as overworked.

- (3) The relation of landline load factor and average waiting time was as follows (See Table 8).

Sector	Chubu-Hokuriku	Kinki-Shikoku	Kyushu-Chugoku
Load Factor	67.2%	61.9	86.1
No. of Stations	1	2	2
Average Waiting Time	95.6 sec	13.9	10.2

Judging from such data, if the communication loading ratio rises to a level of 60% or 70% over an extended period, whether in the present system or in the Phase I System, the controller is considered evidently to be overworked from the standpoint of communication workload.

### 3.7. Estimate of the Change of Communication Load by the Phase I System

This section is concerned with an estimate of the change of controller's workload which will be caused by the Phase I System.

As an example, we formed an estimate of the communication load in Kinki-Shikoku Sector from the data of the "Simulation" test and the Present System Analysis. The details are omitted here. The following is a summary of the result:

The controller of Kinki-Shikoku Sector has to spend 748 sec/hr for the key operations, but instead he can save the voice messages by 751 sec/hr.\* Then they are almost cancelled by each other. In addition to this, it is estimated that the voice communication of 549 sec/hr is omitted by modification of the airspace structure and improvement of the key input method.

In the above estimate we have not taken account of following

\* Professor Okada [7] says, "The controller has spend 443 seconds/hour for the computer communication using the key pack; however, he can save the coordination communication by 703 seconds/hour." The source of Professor Okada's estimate is the same with the data in this paper. Professor Okada assumed an averaged sector, but on the contrary, we are considering a specific sector.

factors :

- (1) Controller's reactions against the computer output.
- (2) Key operations for query input.
- (3) Change of the relations between controller and his assistant.

These factors should be investigated at the next stage of the system evaluations.

#### IV. ACKNOWLEDGEMENT

In addition to the "Simulation" test and the Present System Analysis, we collected many useful comments from the controllers who joined in the test, but we leave out the details.

We would like to express our gratitude to the controllers of Tokyo ACC and the staffs of Nippon Electric Company for their co-operation in the evaluation test. We are indebted especially to Mr. Norimoto NAKATA of Tokyo ACC for the practice of the test and research.

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