(SP Series)

A MONTE CARLO SIMULATION OF THE SACCS DATA PROCESSING CENTRAL

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ABSTRACT

In the design of large-scale systems with stochastic inputs, computerized Monte Carlo simulation is often of great aid. Design decisions can be made quickly, and on the basis of trial in a simulated system rather than on conjecture. Such a simulation for the Data Processing Central of the SAC Control System is described. Limitations and applications of the simulation are also discussed.

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I. Introduction

A major difficulty in the design process for a large-scale system with stochastic inputs is that generally the situation is so complex that it is virtually impossible to set up an analytical mathematical model or expression which can be manipulated to yield immediate answers of a type that facilitate a design decision. In such a situation, Monte Carlo simulation techniques can be used to great advantage. The complete system is divided into component parts each of which is readily describable by a probability distribution. At each point where a decision must be made, a random number is generated, which when applied to the distribution associated with the point serves as the decision maker. By this means experiments can be conducted on the model (simulated system) and the results noted. These results can be analyzed statistically to provide meaningful bases for design decisions.

An incidental but by no means insignificant additional benefit accruing from a simulation is that the details required for creation of a computer program often highlight gaps in the design and thus focus attention on specific problems which are as yet unresolved.

The present paper delineates the creation of a Monte Carlo simulation of the message traffic aspects of the Display Processing Central (DPC) of the Strategic Air Command Control System (SACCS), 465L. Hopefully, two results will be achieved: indication of the benefits available from future use of simulation in 465L design, and illustration of the application of Monte Carlo simulation to the design of a large-scale system.

II. Early Studies

The earliest traffic studies performed at SDC (SACCS Department) were in the form of deterministic models of the various components of the 465L system. For example, consider the case of the Electronic Data Transmission Control Center (EDTCC). The EDTCC's functions were divided into three categories: input, processing and output. Service times for each task were predetermined, and the time to process batches of messages with specified routing characteristics was calculated. Additional time was allotted if two or more messages had the same destination (were competing for the same output transmission link).

Subsequent studies were statistical in nature allowing for random arrivals of messages and random service times for each function; that is, the arrivals and services followed predetermined probability distributions. The models also represented more closely the detailed equipment operation. For example, some crude consideration was given to the effects of message priority and internal processing sequence priority, the latter being particularly applicable to the EDTCC. It should be noted that mean message arrival rates and service time data were obtained from message and equipment studies paralleling the efforts in the traffic area. In the execution of the traffic studies assumptions were made for which the primary justification was mathematical tractability of the model, and it became increasingly clear that to achieve more accurate results and to be able to evaluate design proposals in terms of their effect on traffic, more detailed and flexible models were needed. This led to the present effort--a computerized, Monte Carlo simulation of the DPC.

III. Operation of the DPC*

A block diagram of DPC operation is presented in Fig. 1.

Message Priority

The DPC recognizes three message priorities: Flash, Display Request** and Regular. Flash messages are processed immediately on arrival, interrupting all processing except other Flash messages. Display Request and Regular messages are collected (batched) until a pre-specified time interval (the intervals for each are not necessarily the same) or a pre-specified number of one kind or the other are in the batch. When one of these conditions obtains, a request is initiated for operation of a Control Cycle.

The Control Cycle

The Control Cycle operates as a sequence of tasks performed in pre-specified order. There are a few cases where deviations from this order occur, but these are unimportant from a traffic point of view and have been ignored. The first task to operate is Data Preparation. This task sorts the messages in the batch according to the task with which each is associated. It also does some processing of each message. However, this is of no concern here, except insofar as it affects the operating time of the task. If there are any Display Requests to service, the next task to operate is Data Presentation. Display Requests are processed in order of arrival, and the displays outputted. Following Data Presentation, the Regular messages are processed, starting with the messages associated with the highest priority Regular task and proceeding in order of task priority until the messages associated with the lowest priority task have all been processed. Within each task

* The DPC operates via several program subsystems; e.g., Control, Planning, Training. Only the Control subsystem has been simulated. The simulation reflects the thinking on the Control subsystem as of January-February, 1962, and may have changed since.

** The priority name is actually "Special." However, "Display Request" is the only message with this priority. Moreover, the operating rules are written for a one-message class.

the messages are processed in order of arrival. The content of a message can force other tasks (usually of a lower priority) to be operated. However, with the exception of messages forcing display outputs (and consequently, operation of Data Presentation) this effect is relatively minor from a traffic viewpoint. Only displays can be forced in the simulation. If messages force displays, completion of processing on these messages is deferred until all messages associated with the task have been completed. Data Presentation is then operated and the requisite displays outputted. The next lower priority task is then operated.

Flight Plan Processing

The lowest priority Regular task is Flight Plan Processing. However, this task is not part of the Control Cycle, and therefore is discussed separately. When all Regular messages have been processed, unless a request for initiation of Control Cycle exists, the Flight Plan processing task will operate. Flight Plans will be processed until all are completed or a Control Cycle request is made. It should be noted that once a Control Cycle begins, it is not interruptible by a request for a new Control Cycle -- only Flight Plan processing is interruptible.

Message Arrivals

Messages can arrive and be accepted by the DPC at any time. However, processing of these messages will be delayed as described in Message Priority and Flight Plan Processing.

IV. DPC Simulation

The simulation is described by the block diagram of Fig. 2, and a list of the input parameters selectable by the user, is given in Fig. 3. Note that the characteristics of the distribution of time for each processing function as well as the input message characteristics can be selected. A listing of the program instructions with explanatory notes is presented in the Appendix. Certain features of the simulation are described below.

Decision Making and Service Time Selection

Associated with each decision (including time interval selection) in the simulation is a probability distribution. When decision points are reached in the simulation, a random number is generated by the computer and combined with the probability distribution to result in a decision.

When the decision is the selection of a service time, t_s is incremented by the service time selected.

<u>Example</u>: Determination of time to operate Data Preparation Task.

Let us say $t_s = 56.2$ sec. and the service time for operation of Data Preparation is equally likely to be anywhere between 10 and 25 sec. A random number is generated, say 0.7. The time interval for operation of Data Preparation is thus $10+0.7 \times 15 = 20.5$ and $t_s = 56.2+20.5 = 76.7$ sec. after completion of the task.

<u>Random Number Generation</u>

Because of the large number of decisions which are made in the course of operation of the simulation, a large supply of uniformly distributed random numbers is required. The congruence equation:

$$X_{n+1} \equiv X_n\ (2^7+1) + 227,\ 216,\ 619 \text{ MOD } (2^{28})$$

is used to generated pseudo-random numbers uniformly distributed between 0 and 1024. These are then scaled to the interval (0,1).*

<u>Message Arrival Time</u>

It was decided to generate messages by means of the time between arrivals of messages (inter-arrival time) rather than in terms of the number of message arrivals in a given time interval. The latter method suffers from the lack of a fixed arrival time for a message (its arrival can be placed only as somewhere in the time interval). Also, a knowledge of the distribution of number of arrivals for one size time interval gives no knowledge of the number of arrivals in a different size time interval. The need for such knowledge will become apparent in the next section.

<u>Arrivals During Processing</u>

Since there exists no source of messages other than the simulation itself, a technique was necessary for permitting the arrival of messages between increments of t_s. The technique used is the following: t_s advances discontinuously by the amount of time required to execute (service) a processing function. After each selection of service time, a routine is entered which checks whether the time of arrival of the message in the input register has been exceeded because of the increment in t_s. If not, processing continues. If yes, then the message type is determined and the message is logged in. The handling of Flash messages is described in the next section. After the message is entered, the time interval before the arrival of the next message (inter-arrival time) is determined

* For further details, see Journal of the American Statistical Association, Vol. 56, No. 295, September 1961, "Bias in Pseudo Random Numbers" by P. Peach.

by generation of a random number and conversion to time by means of a probability distribution. t_i is incremented by the inter-arrival time and if it is still less than the present t_s, the message type is determined and the new message is logged in. This procedure is repeated until t_i for the next message is greater than t_s. The program then returns to where it left off (a service time had been determined and t_s incremented), and proceeds until the next incrementation of t_s.

Flash Messages

When it has been determined that a particular message is a Flash, normal processing is interrupted and the Flash message is processed. t_s is incremented by the processing time. After processing the Flash message, the program proceeds as described in the previous section and a new inter-arrival time is generated.

Continuation of Example of Decision Making and Service Time Selection

t_s has jumped from 56.2 to 76.7 sec. Say t_i = 60.0 sec. The message type subroutine would be entered. If the message were a Regular, it would be stored and the Regular message counter incremented. Then a new Δt_i would be generated, say 15.5 sec. The new t_i would be 75.5 sec., and therefore, the message type would be determined and the message accepted. Say the message is a Flash. T_{FL} is determined, say .1 sec., and added to t_s, making t_s = 76.8 sec. An output is generated indicating the processing of a Flash message. Then a new Δt_i is generated, say 3.0 sec. making t_i = 78.5. Since $t_s < t_i$ the message is not accepted yet, and processing resumes.

Output

Each time a message is processed or a Control Cycle request is issued because of the size of the collection batch, an output is generated. The output formats are shown in Fig. 4. The limited format used for the output of Flash and Flight plan messages and Control Cycle requests is due to storage limitations in the computer.

The data is also punched on paper tape for input to an as yet unwritten program which will perform further statistical analysis.

V. An Example of Simulation Operation

Figure 5 is a sample of the simulation output. The numbers were contrived to illustrate various aspects of simulation operation. A description of the events causing this output is given below. Note the use of the word "output" with regard to a message does not necessarily correspond to actual output of a message, but refers to completion of processing and output by the simulation.

At 150 seconds, a Control Cycle is in operation, and a Task 6 Regular message has been output. The times and queue lengths are as indicated. The time averages relate to Regular messages here. At 152.1, another Task 6 message is output. Note that while this message was in process, one Flight Plan and one Display Request arrived. Thus the total queue in the system actually increased by one after processing one message. At 153.5, a Task 6 message which forced a display was output; i.e., the forced display was output. Note this message arrived earlier than the previous Task 6 message processed, but was delayed until the completion of Task 6 before its processing was completed. There are no messages for Tasks 7-14. Thus at 154.2, a Task 15 message is output. Note it arrived before some Task 6 messages, but was delayed because of its low priority. In this case, one Regular arrived during the processing of the Task 15 message. Therefore, the Regular queue did not decrease.

The new Control Cycle begins, and at 180.0 the first Display of the new cycle is output. The time averages relate to Display Request messages here. Display Request processing continues until the last Display is output at 195.0. At 195.5, the first Regular message of the cycle is output. It is a Task 3 message. While the next Regular message is in process, a Flash message arrives. It is processed immediately (requiring .2 sec.), and output at 195.8. There are no Task 4 messages or Task 5 messages not forcing a display. Therefore, the next output, at 196.2 is a Task 5 message forcing a display. The processing continues.

VI. Limitations of the Present Simulation

The simulation was run on the Bendix G-15 located at SDC, Paramus. With the exception of two subroutines (one of them being the random number generator) the entire program was written in Intercom 1000, an interpretive language. Only 1200 locations were available for program and data storage. As a result, many desirable features had to be omitted from the simulation. In the next phase of this simulation effort, a program will be written for a much larger machine, the DPC itself, and it should be possible to eliminate all the limitations discussed. Some present limitations are the following:

In the simulation, messages are categorized only by the task which they cause to operate and later by whether they force a display. In actuality, there are approximately 100 different message types, so that several messages operate the same task. Since there was no room for storage of rules and processing time distribution for each message, the present "grouping" scheme was adopted. Since present message studies give relative frequency of messages by type, further processing is required before this data is input to the simulation.

The DPC requests a Control Cycle when it has collected 250 Regular messages or 125 Display Requests. In the simulation two locations are required for each Regular message (other than Flight Plans) and one location for Flight Plans and Display Requests. In the case of Regulars and Display Requests, these figures must be doubled because one batch is being collected while the previous batch is being processed. The simulation is able to store only 100 Regular, 50 Display Request and 50 Flight Plan messages. This requires 550 of the 1200 available locations. Thus in running the simulation, parameters must be selected in such a manner that steady state queues in excess of these limits do not develop.

As indicated in the section on output, a limited amount of statistical calculation is done by the simulation. It would be valuable to compute certain other statistics as part of the output routine; e.g., length of queue or waiting time such that the probability of exceeding this value is less than P, where P is input at the start of the simulation. These statistics should be computable by message type, message task, or message priority.

The only probability distributions built into the simulation are, discrete, uniform and exponential (Poisson distributed message arrivals are generated by an exponential inter-arrival time distribution). Several functions would be more realistically simulated by distributions which peak at about mid-range.

There is some flexibility built into the present simulation in that the parameters characterizing the probability distributions are input parameters. However, to function effectively as a design aid, a system option selections is required which would enable the designer to vary operational discipline and to select the probability distribution associated with each function.

It is characteristic of the Monte Carlo approach that to obtain statistically meaningful steady state results, the simulation must run "several" times for a given set of parameters, or assuming the process to be ergodic (which seems reasonable in this case after the steady state is reached), the simulation could be run for a "long" simulated time instead. The simulation on the G-15 runs about 12-1 slow; that is, to simulate 30 minutes of DPC time requires 6 hours on the G-15. This precludes the type of production running necessary to obtain statistically meaningful results. Simulation on the DPC should speed up the running time by a factor of between 200 and 1000, making production running practical.

VII. Some Applications

As an indication of the usefulness of the simulation and to illustrate the kind of questions the designer can ask it, some applications will be presented.

Control Cycle Request Criteria

In order to make the most efficient use of the DPC, messages should be batched for as long as possible to minimize for a given number of messages, the number of times the Data Preparation task must be operated and the number of times the various tasks must be loaded into core memory. This is particularly important if the task is permanently stored on tape, since the access time is very high. On the other hand, long collection periods mean that the DPC files do not contain the latest data, and that requests for displays are delayed. Thus, it is important to know the tradeoff of computer efficiency and message waiting time vs. batch collection time. One can determine these tradeoffs by running the simulation with various collection times and studying the relevant outputs.

Processing Time, Input Load

The effect of time required by any processing function can be studied by running the simulation for a variety of values of that parameter. The effect of input frequency can be studied similarly.

Message/Task Priority

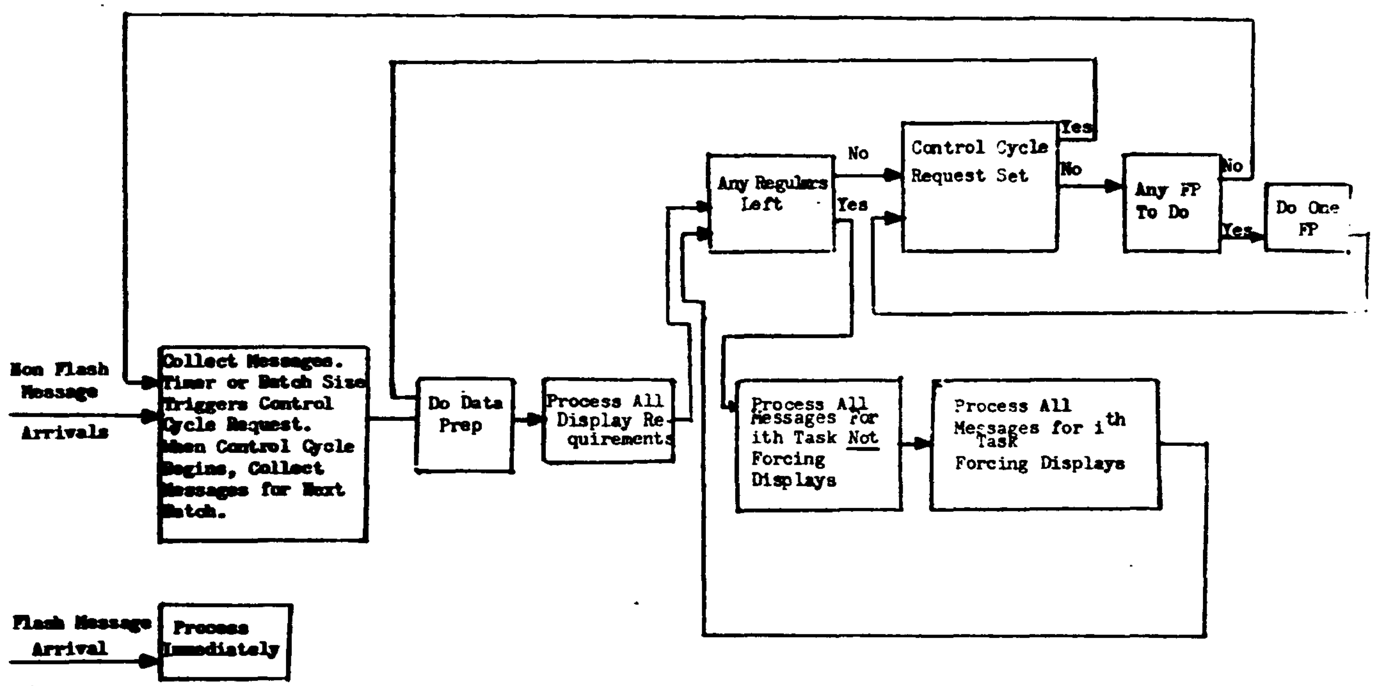
One of the factors determining the priority which a message or task should be assigned is the waiting time until that message or task is operated. This could be studied (in the next simulation) by outputting statistics on the waiting time for that type of message or task.

Measures of Effectiveness

Often in "analytic" models only a limited number of measures of effectiveness can be computed; e.g. average queue size, average waiting time, maximum allowable input frequency. In the simulation virtually any statistic of any variable in the system can be determined.

FIGURE 1

A BLOCK DIAGRAM OF DPC OPERATION



NOTE: 1 - Messages can arrive and be accepted at any time.

2 - After each message is processed the data relating to it is outputted by the simulation.

FIGURE 2

A BLOCK DIAGRAM OF THE SIMULATION

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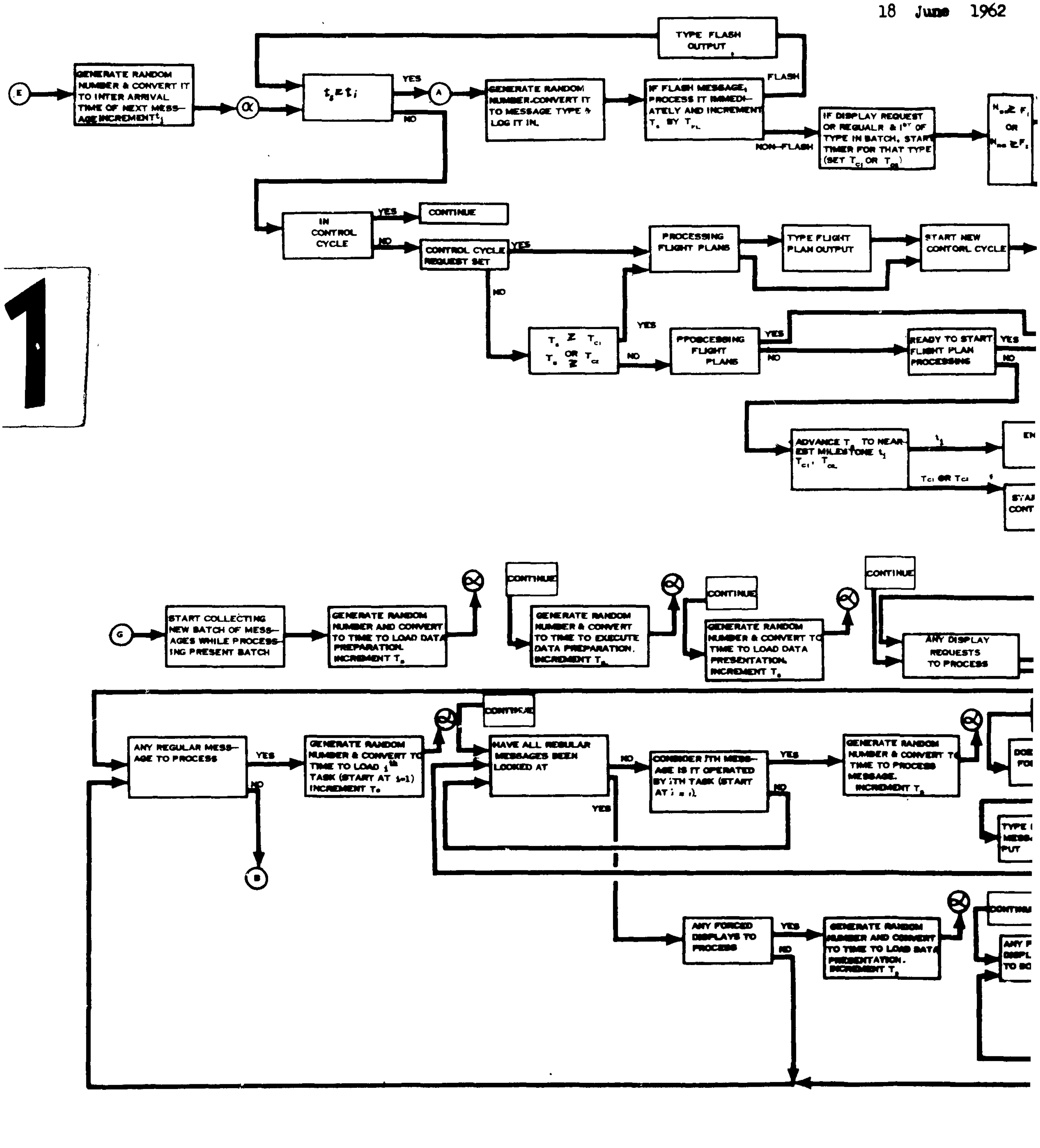
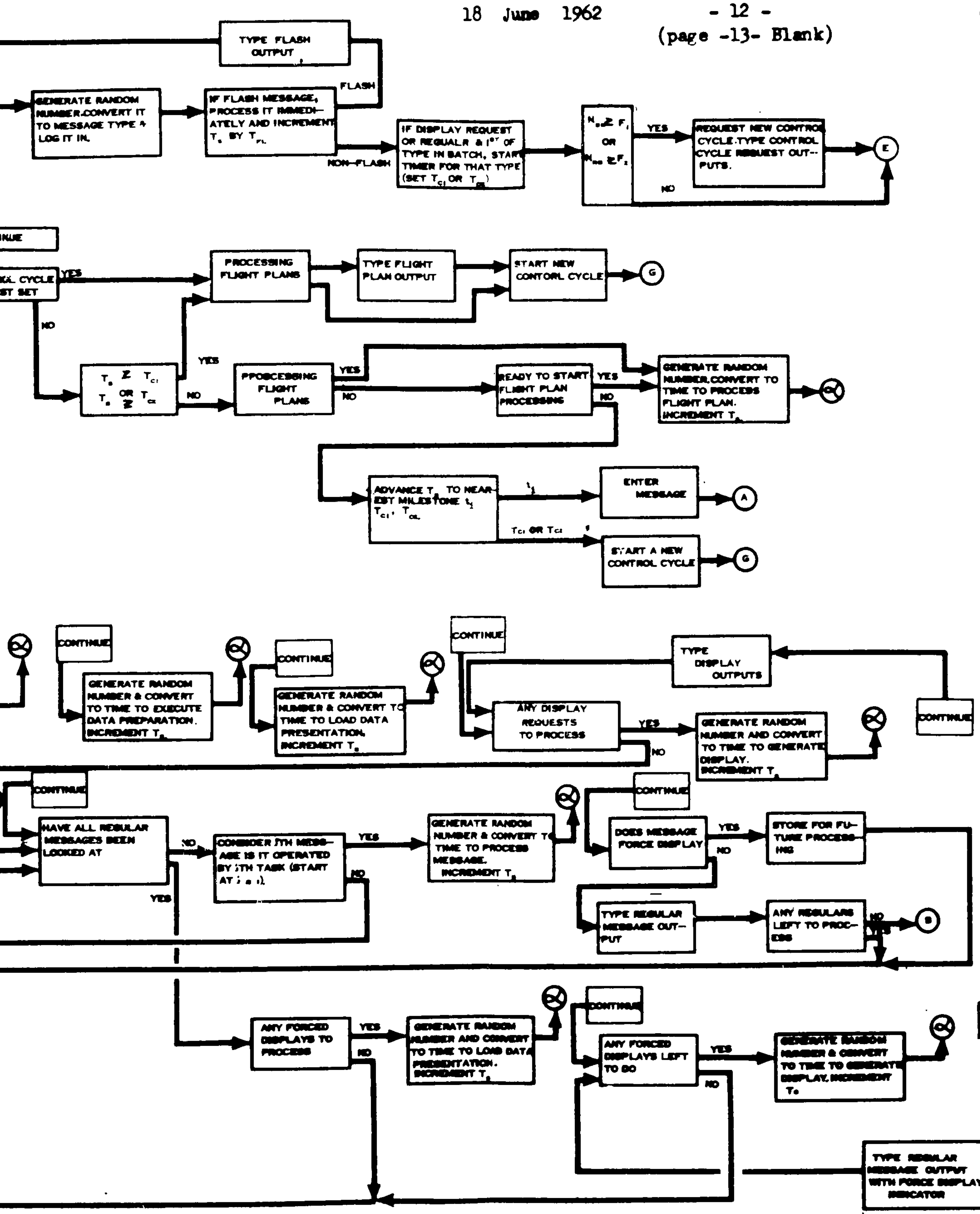


FIGURE 2

A BLOCK DIAGRAM OF THE SIMULATION



2

FIGURE 3

INPUT PARAMETERS

Item	Selection
1 - Inter-arrival time (exponential distribution)	Mean
2 - Message type - Flash, Flight Plan, Display Request, 14 Regular Tasks	Relative Frequency (% of total)
3 - Probability of message forcing display	Probability
4 - Maximum collection time for Display Requests before Control Cycle request	Time
5 - Maximum collection time for Regular messages before Control Cycle request	Time
6 - Maximum number of Display Requests in batch before Control Cycle request	Number
7 - Maximum number of Regular messages in batch before Control Cycle request	Number
8 - Task entry time, common to all tasks (uniform distribution)	Lower Limit Width
9 - Time to execute Data Preparation (uniform distribution)	Lower Limit Width
10 - Time to process (generate) a display, including forced display (exponential distribution)	Mean
11 - Time to process a Regular Message, common to all Regular messages (uniform distribution)	Lower Limit Width
12 - Time to process a Flash message (uniform distribution)	Lower Limit Width
13 - Time to process a Flight Plan message (exponential distribution)	Mean

FIGURE 4

OUTPUT FORMATS

Standard Format (Display Request & Regular)

t_{output}	Message type[1,2]	t_i	t_{tot}	$t_{tot,avg}$	
t_w	$t_{w,avg}$	N_{FP}	N_{DR}	N_R	N_{total}

Flight Plan Format

t_{output}	Message Code for Flight Plan 201.	t_i			
		N_{FP}	N_{DR}	N_R	N_{total}

Flash Format

t_{output}	Message Code for Flash 1.	t_{tot}

Control Cycle Request Format

$t_{request}$	Number of Messages in Batch Causing Request. N_{SB} or N_{RB}

Notes

1 - Regular Message Type 301, 401,-----1601.
If Forced Display 302, 402,--------1602.

2 - Display Request Type 101.

FIGURE 5

SAMPLE SIMULATION OUTPUT

150 45.0	601 47.0	104 12	46.0 7	48.0 67	86
152.1 26.5	601 46.6	125 13	27.1 8	47.5 66	87
153.5 37.0	602 46.5	115 13	38.5 8	47.4 65	86
154.2 45.6	1501 46.5	108 13	46.2 8	47.4 65	86
154.9	201	105 12	8	65	85
155.5	201	120 11	9	65	85
156.0	10.0				
157.1	201	128 11	10	66	87
180.0 47.5	101 33.7	131 12	49.0 14	35.0 73	99
180.9 42.9	101 33.9	136 12	44.9 13	35.3 73	98
⋮	⋮	⋮	⋮	⋮	⋮
195.0 38.1	101 34.8	156.0 14	39.0 2	37.0 80	96
195.5 56.9	301 46.7	138 14	57.5 2	47.6 79	95
195.8	1.	.2			
196.2 58.2	502 46.9	135 14	61.2 3	47.9 78	95

GLOSSARY

t_s	- present time in the simulation
t_i	- time of arrival at the DPC of an input message
t_{tot}	- total time spent in the DPC (t_s of message output - t_i) by a particular message
$t_{tot,avg}$	- average t_{tot} for a class of messages; e.g., Display Request, Regular (non Flight Plan)
t_w	- waiting time in the DPC for a particular message (t_s of message output - t_s of start of processing of that message)
$t_{w,avg}$	- average t_w, similar to $t_{tot,avg}$
Processing Batch	- that group of messages which the present Control Cycle is operating
Collection Batch	- that group of messages being collected for processing in the next operation of a Control Cycle
N_{FP}	- number of Flight Plan messages awaiting processing
N_S	- total number of Display Requests awaiting processing including those in the processing batch and in the collection batch
N_R	- similar to N_S but applies to Regular messages
N_{total}	- total number of messages awaiting processing ($N_{FP} + N_S + N_R$)
N_{SB}	- number of Display Requests in Collection Batch
N_{RB}	- number of Regular messages in Collection Batch
T_1	- time interval from arrival of first Display Request in Collection Batch to time a request for operation of a Control Cycle is made
T_2	- similar to T_1 but for Regular messages

T_{C1}	- t_1 of first Display Request in Collection Batch + T_1
T_{C2}	- t_1 of first Regular message in Collection Batch + T_2
F_1	- number of Display Requests in Collection Batch which cause Control Cycle request
F_2	- number of Regular messages in Collection Batch which cause Control Cycle Request.

SDC **INTERCOM PROGRAM**

Prepared by ________ Page __ of __

Date: ________

PROBLEM DPC SIMULATION Line: ________

NOTES	Location	K	OP CODE	Address		(A) or (AA)
(C^4) Reset In Cycle Indicator	0700		49	11	8	
Go to (C)	701		29	8	90	
(T')	702		42	11	7	
Type t_s	703		33	21	1	
	704	5	49	12		
	705		42	11	68	
Type Message Type	706		33	21	1	
Continue output at (1007)	707		29	10	7	
(E) START OF PROGRAM	708		40	11	13	
Set $-\mu$IA for exponential routine	709		49	11	71	
	710		42	11	58	
Set IA Indicator	711		49	11	31	
Generate random no.	712		8	11	84	
Convert to IA time, T_{IA}. Go To (EX)	713		28	9	85	
	714		42	11	5	
	715		43	11	75	
Store $t_{1, NEW} = t_{1, OLD} + T_{IA}$	716		49	11	69	
	717		49	11	5	
	718		42	11	7	
(K)	719		41	11	5	
If $t_s \geq t_1$ to to (A)	720		20	9	2	
	721		42	11	8	
If not in cycle, go to L+2	722		23	7	24	
If in cycle - return	723		16			
	724		42	11	23	
If cycle req. not set - Go to L+3	7[illegible]5		[illegible]	7	[illegible]8	

SDC

INTERCOM PROGRAM

Prepared by ____________ Page ___ of ___

Date: ____________

PROBLEM DPC SIMULATION Line: ____________

NOTES	Location	K	OP CODE	Address		(A) or (AA)
If cycle req. set. Go to (FP7)	726		28	10	80	
Cycle req. set - Go to (G)	727		29	7	51	
	728		42	11	7	
	729		41	11	27	
If $t_s \geq T_{c1}$, go to L-4	730		20	7	26	
	731		42	11	7	
Finish test routine at (1066)	732		29	10	66	
(J) Subroutine to advance t_s to nearest milestone.	733		42	11	27	
	734		41	11	29	
If $T_{c1} \geq T_{c2}$, go to L+10	735		20	7	45	
$T_{c1} < T_{c2}$	736		42	11	69	
	737		41	11	27	
If $t_1 \geq T_{c1}$, go to L+4	738		20	7	42	
	739		42	11	5	
Set $t_s = t_1$	740		49	11	7	
Go to (A)	741		29	9	2	
$t_1 \geq T_{c1}$	742		42	11	27	
Set $t_s = T_{c1}$	743		49	11	7	
Go to (G)	744		29	7	51	
$T_{c2} \leq T_{c1}$	745		42	11	69	
	746		41	11	29	
If $t_1 \geq T_{c2}$, go to L+2	747		20	7	49	
If $t_1 < T_{c2}$, go to L-9	748		29	7	39	
	749		42	11	29	
Set $t_s = T_{c2}$	750		49	11	7	
(G) Start Control Cycle	751		42	11	59	

INTERCOM PROGRAM

Prepared by ____________ Page ___ of ___

Date: ____________

PROBLEM: DPC SIMULATION Line: ____________

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Set T_{c1} large	752		[illegible]	11	27	
Set T_{c2} large	753		49	11	29	
	754		42	11	58	
Set In Cycle Indicator	755		49	11	8	
	756		42	11	89	
Set no. Display Req.	757		49	11	39	
	758		42	11	88	
Set no. reg. in Cycle	759		49	11	93	
Set no. reg. LEFT in Cycle	760		49	11	40	
	761		41	21	1	
Reset Task Ident. to 0	762		49	11	99	
Reset Cycle Req. to 0	763		49	11	23	
Reset Reg. Input Ctr. to 0	764		49	11	88	
Reset Disp. Reg. Input Ctr. to 0	765		49	11	89	
Set index registers for collection and processing batches.	766	1	74	2		
	767	1	70			
	768	7	70			
L + 10	769	1	77	7	79	
	770	1	73			
	771	7	73	2		
	772	1	74	1		
	773	3	[illegible]			
	774	8	70			
L + 7	775	3	77	7	82	
	776	3	73			
	777	8	73	1		

SDC **INTERCOM PROGRAM**

Prepared by ________ Page ___ of ___

Date: ________

PROBLEM. DPC SIMULATION Line: ________

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Go to (D)	778		29	7	83	
	779	1	73	2		
	780	7	73			
L-9	781		29	7	72	
	782	8	73			
(D)	783		8	11	84	
To enter Data Prep., go to (TE)	784		26	10	53	
	785		8	11	84	
To execute Data Prep., go to(^{T}DP)	786		26	10	88	
	787		8	11	84	
To enter Data Pres., go to (TE)	788		26	10	53	
	789		42	11	39	
If no. Disp.Req. Left = 0 Go to (M-2)	790		23	8	18	
	791		41	11	58	
Store no. Disp.Req. Left to do	792		49	11	39	
(R)	793		42	11	7	
Store time processing started on ith Disp. Req.	794		49	11	61	
	795		40	11	17	
Store/M Disp.Proc. for exp. sub-routine.	796		49	11	71	
	797		8	11	84	
Convert to display processing time Go to (EX)	798		26	9	85	
DISP. OUTPUT	799		42	11	97	
Message Type	800		49	11	68	
	801	8	42	17		
Time of arrival, t_1	802		49	11	69	
	803		42	11	62	

SDC **INTERCOM PROGRAM**

Prepared by ______ Page __ of __

Date: ______

PROBLEM DPC SIMULATION Line: ______

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Total t_{tot} for displays since $t_s = 0$.	804		49	11	1	
	805		42	11	35	
Total displays processed since $t_s = 0$.	806		49	11	2	
	807		42	11	63	
Total t_w for displays since $t_s = 0$.	808		49	11	3	
Go to (T') to continue output.	809		26	7	2	
	810		42	11	1	
New total t_{TOT}	811		49	11	62	
	812		42	11	2	
New total no. of displays processed.	813		49	11	35	
	814		42	11	3	
New total t_w	815		49	11	63	
Go to (T") to finish output	816		26	10	33	
Increment #8 WD Base & look for next display. Go to (R-4).	817	8	76	7	89	
	818		42	11	32	
	819		49	11	37	
	820		42	11	40	
If no Regular's, go to (C")	821		23	7		
	822	2	70			
	823	7	70			
Subroutine-Reset #7 CH Base	824		8	10	72	
	825		42	11	37	
	826		43	11	11	
Set task number.	827		49	11	37	
(s)	828	7	42	13		
	829		41	11	37	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
If task done, go to (N)	830		22	8	48	
	831		41	11	11	
If $>_o$ task hasn't been reached yet, Go to (N).	832		20	8	48	
	833		42	11	7	
Store time processing started in ith message of ith task	834		49	11	01	
	835		8	11	84	
Convert to time to process regular message, go to (TPR).	836		26	10	92	
	837		8	11	84	
	838		41	11	19	
If no forced display, go to(T)	839		20	8	56	
	840	7	42	13		
Store message type forcing display.	841	2	49	17	50	
	842	7	42	13	1	
Store t_1 of message forcing display.	843	2	49	17	51	
	844		42	11	96	
	845		43	11	58	
Increment no. forced displays to do	846		49	11	96	
Increment #2-Go to (N).	847	2	76	8	48	
(N)	848		42	11	78	
	849		43	11	53	
Increment no. Regular's in Cycle looked at.	850		49	11	78	
	851		41	11	93	
If no. Regular's looked at=no. in cycle, Go to (B).	[illegible]		23	8	[illegible]5	
Increment #7. Look at next message. Go to (S).	[illegible]	7	76	[illegible]	28	
	854	7	70			
Go to (S)	[illegible]	7	77	3	28	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
(T) OUTPUT REGULAR MESSAGE	856		42	11	40	
	857		41	11	58	
Decrement no. Regular's left in cycle.	858		49	11	40	
	859	7	42	13		
Transfer message type.	860		49	11	68	
	861	7	42	13	1	
Transfer t_1 of message	862		49	11	69	
Go to (T^3)	863		22	17	82	
Go to (N)	864		22	8	48	
(B) Reset no. Regular's looked at.	865		49	11	78	
Reset Forced display Register-#2.	866	2	70			
(P)	867		42	11	96	
If no Force Display, go to (M)	868		23	8	20	
	869		8	11	84	
Enter Data Pres. for forced display - Go to (TE)	870		26	10	53	
	871		42	11	7	
Store time processing started for ith forced display.	872		49	11	61	
	873		42	11	17	
Store μ for display processing.	874		49	11	71	
	875		8	11	84	
Convert to time to process forced display. Go to (EX)	876		26	9	85	
	877		42	11	40	
	878		41	11	58	
Decrement no. Reg. left in cycle.	879		49	11	40	
	880	2	42	17	50	
	881		43	11	58	

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NOTES	Location	K	OP CODE	Address		(A) or (AA)
Transfer message type with Forced Display Indicator.	882		49	11	09	
	883	2	42	17	51	
Transfer message t_1.	884		49	11	69	
	885		42	11	96	
	886		41	11	58	
Decrement no. Forced Displays.	887		49	11	96	
Go to (T^3) for output.	888		28	17	32	
Go to (P) for next forced display	889	2	76	8	67	
(C)	890		42	11	58	
Set Ready for Flight Plan Ind.	891		49	11	81	
Go to (K+2)	892		29	7	21	
(C')	893		42	11	87	
Transfer no. Flight Plans. FP	894		49	11	99	
If no FP, go to (J)	895		23	7	30	
	896		41	11	58	
Decrement no. FP	897		49	11	87	
	898		40	11	20	
Store 7/μ to process FP.	899		49	11	71	
	900		8	11	84	
Convert to time to process FP. Go to (EX).	901		29	9	85	
	902		8	11	84	
Determine Message Type	903		49	11	74	
	904	6	70			
	905		42	11	58	
Set message type counter to 001.	906		49	11	67	
Go to L + 4	907		29	9	11	

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NOTES	Location	K	OP CODE	Address		(A) or (AA)
	908		42	11	67	
	909		43	11	11	
Increment message type counter by 100.	910		49	11	67	
	911	6	42	11	42	
	912		41	11	74	
If message type not reached, go to L+10.	913		22	9	23	
	914		42	11	67	
Store Message Type	915		49	11	68	
	916		41	11	58	
If Flash, go to (AF)	917		23	9	24	
	918		41	11	11	
If Display Request, go to (AS)	919		23	9	57	
	920		41	11	11	
If Flight Plan, go to (FP)	921		23	9	77	
Regular. Go to (AR)	922		29	9	33	
Go to L-15	923	6	76	9	8	
(AF)	924		8	11	84	
Convert to Flash Process Time. Go to (T_{FL}).	925		28	17	75	
	926		43	11	75	
Type Output Time for Flash	927		33	21	1	
Type Message Type	928		33	11	68	
Type t_{FL}	929		38	11	75	
	930		30		1	
Go to (E)	931		29	7	8	
	932					
(AR)	933		42	11	68	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
	934	1	49	13		
	935		42	11	5	
	936	1	49	13	1	
	937		42	11	88	
If no Regulars, go to L+2	938		23	9	40	
L+4	939		29	9	43	
	940	1	42	13	1	
	941		43	11	92	
Set T_{c2}	942		49	11	29	
L+3	943	1	76	9	46	
	944	1	70			
L+1	945	1	77	9	46	
	946		42	11	88	
	947		43	11	58	
Increment Regular Counter	948		49	11	88	
	949		41	11	94	
If $N_{RB} < F_1$ - Go to (E)	950		22	7	8	
Type t_1	951		33	11	05	
Type no. in Regular Counter	952		38	11	88	
	953		30	00	01	
(Q)	954		42	11	58	
	955		49	11	23	
Go to (E)	956		29	7	8	
(A_S)	957		42	11	5	
	958	3	49	17		
	959		42	11	89	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
L + 2	960		23	9	62	
L + 4	961		29	9	65	
	962	3	42	17		
	963		43	11	91	
Set T_{c1}	964		49	11	27	
L + 3	965	3	76	9	68	
	966	3	70			
L + 1	967	3	77	9	[illegible]	
	968		42	11	89	
	969		43	11	53	
Increment Disp. Req. Counter	970		49	11	89	
	971		41	11	95	
If $N_S \measuredangle F_2$, Go to (E)	972		24	7	[illegible]	
Type t_s	973		[illegible]	11	05	
Type no. in Disp. Req. Counter	974		35	11	89	
	975		30	00	01	
Go to (Q)	976		29	9	54	
(FP)	977		42	11	[illegible]	
	978	4	49	18	[illegible]	
	979		42	11	37	
	980		43	11	58	
Increment (Fp) Counter	981		49	11	87	
Increment #4, Go to (E)	982	4	76	7	8	
Reset #4	983	4	70			
Go to (E)	984		29	7	8	
(EX) Exp. Distribution	985		49	11	74	

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PROBLEM: DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
	986		41	10	04	
	987		47	11	74	
	988		49	11	74	
	989		44	21	01	
	990		49	09	32	
	991		44	11	12	
	992		43	10	06	
	993		44	09	32	
	994		43	10	05	
	995		44	09	32	
	996		43	10	04	
	997		44	09	32	
	998		43	10	03	
	999		44	11	74	
	1000		48	11	71	
$\Delta t = -\frac{\ln(1-P)}{\mu}$	1001		49	11	75	
Go to (U) routine following select T.	1002		29	10	56	
	1003					
	1004					
	1005					
	1006					
Second part of (T') routine.	1007	5	49	12	1	
	1008		42	11	69	
Type t_1 for message.	1009		33	21	1	
	1010	5	49	12	2	
	1011		42	11	7	

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NOTES	Location	K	OP CODE	Address		(A) or (AA)
	1012		41	11	69	
Type t_{TOT} for mes[illegible].	1013		3[illegible]	21	1	
	1014	5	49	12	3	
	1015		43	11	1	
Store total t_{TOT} for all messages in class.	1016		49	11	1	
	1017		42	11	2	
	1018		43	11	58	
Store total processed in class	1019		49	11	2	
	1020		47	11	1	
Type t_{TOT} (AVG)	1021		38	21	1	
	1022	5	49	12	4	
	1023		42	11	61	
	1024		41	11	69	
Type t_w	1025		3[illegible]	21	1	
	1026	5	49	12	5	
	1027		43	11	3	
Store total t_w for all messages in class.	1028		49	11	3	
	1029		48	11	2	
Type t_w (AVG)	1030		33	21	1	
	1031	5	49	12	6	
	1032		16			
(T")	1033		42	11	87	
Type N_{FP}	1034		3[illegible]	21	1	
	1035	5	49	12	7	
	1036		42	11	89	
	1037		43	11	39	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Type N_S	1038		33	21	1	
	1039	5	49	12	8	
	1040		42	11	88	
	1041		43	11	40	
Type N_R	1042		33	21	1	
	1043	5	49	12	9	
	1044	5	43	12	8	
	1045	5	43	12	7	
Type $N_{TOT} = N_R + N_S + N_{FP}$	1046		33	21	1	
	1047		30		2	
	1048	5	49	12	10	
	1049	5	76	10	52	
	1050	5	70			
Punch stored output.	1051		3[illegible]	12	99	
	1052		16			
Task entry (TE)	1053		44	11	14	
PΔ + lower limit	1054		43	11	10	
Store ◄t	1055		49	11	75	
(U) IA indicator.	1056		42	11	31	
	1057		41	11	58	
If not an IA select, Go to L+4.	1058		22	10	62	
	1059		41	21	1	
Reset IA Indicator.	1060		49	11	31	
	1061		18			
(U') ◄t is for processing, not	1062		42	11	75	
for IA TIME	1063		43	11	7	

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PROBLEM: DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Store new t_s	1064		49	11	7	
Go to (K)	1065		29	7	19	
Remainder of test routine,	1066		41	11	29	
Go to "Cycle request set" if $t_s > T_{c2}$	1067		20	7	26	
	1068		42	11	99	
If =0, not doing FP, Go to (J)	1069		23	17	70	
Go to output of FP	1070		28	10	82	
Go to (C')	1071		29	8	93	
	1072		*			
	1073		*			
	1074		*			
	1075		*			
	1076		*			
	1077		*			
	1078		*			
	1079		*			
(FP?) if>o, doing FP, Go to L+2	1080		42	11	99	
	1081		23	10	61	
Type t_s	1082		33	11	7	
Type FP code	1083		33	11	98	
Type t inp t_i	1084	9	38	18	50	
Increment #9. Go to L+2	1085	9	76	10	87	
	1086	9	70			
Go to (OUTPUT FP)	1087		29	17	67	
(T_{DP})	1088		44	11	15	
	1089		43	11	16	

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PROBLEM: DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
Δt = PΔ + lower limit	1090		49	11	75	
Go to (U')	1091		29	10	62	
(T_{PR})	1092		44	11	72	
	1093		43	11	73	
Δt = PΔ + lower limit	1094		49	11	75	
Go to (U')	1095		29	10	62	
	1096		*			
Working Storage	1097					
	1098		*			
	1099		*			

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NOTES	Location	K	OP CODE	Address		(A) or (AA)
(OUTPUT FP)	1767		30	2	1	
	1768		26	10	33	
	1769		18			
	1770		42	11	81	
If not ready for FP and not in FP, go to (J).	1771		23	7	33	
	1772		41	21	1	
Reset "Ready for FP" Indicator	1773		49	11	81	
If not in FP but ready to start go to (C')	1774		29	8	93	
(T_{FL})	1775		44	11	21	
	1776		43	11	18	
T_{FL}= PA + lower limit	1777		49	11	75	
	1778		43	11	7	
t_s new = t_s old + T_{FL}	1779		49	11	7	
	1780		42	11	5	
	1781		18			
(T^3)	1782		42	11	77	
Total t_{TOT} for Reg. since t_s=0	1783		49	11	1	
	1784		42	11	36	
Total Reg. done since t_s = 0	1785		49	11	2	
	1786		42	11	79	
Total t_w for Reg. since t_s =0	1787		49	11	3	
Go to (T')	1788		26	7	2	
	1789		42	11	1	
New total t_{TOT}	1790		49	11	77	
	1791		42	11	2	
New total no. Reg. processed.	1792		49	11	36	

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PROBLEM DPC SIMULATION

NOTES	Location	K	OP CODE	Address		(A) or (AA)
	1793		42	11	3	
New total t_w	1794		49	11	79	
Go to (T")	1795		26	10	33	
	1796		18			

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PROBLEM Index Register Settings

NOTES	Location	K	OP CODE	Address		(A) or (AA)
		1	70	00	00	
		1	71	00	02	
		1	72	00	99	
		1	73	00	00	
		1	74	01	00	
		1	75	03	00	
		2	70	00	00	
		2	71	00	02	
		2	72	00	65	
		2	73	00	00	
		3	70	00	00	
		3	71	00	01	
		3	72	00	49	
		3	73	00	00	
		3	74	01	00	
		3	75	01	00	
		4	70	00	00	
		4	71	00	01	
		4	72	00	49	
		4	73	00	00	
		5	70	00	00	
		5	72	00	98	
		5	73	00	00	
		6	70	00	00	
		6	71	00	01	
		6	72	00	16	

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PROBLEM: Index Register Settings Line: ______

NOTES	Location	K	OP CODE	Address	(A) or (AA)
		6	73	00 00	
		7	70	00 00	
		7	71	00 02	
		7	72	00 99	
		7	73	00 00	
		7	74	01 00	
		7	75	03 00	
		8	70	00 00	
		8	71	00 01	
		8	72	00 49	
		8	73	00 00	
		8	74	01 00	
		8	75	01 00	
		9	70	00 00	
		9	71	00 01	
		9	72	00 49	
		9	73	00 00	

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G-15D PROGRAM PROBLEM CHANNEL BASE ASSIGNMENT

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Line 10

0	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	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
100	101	102	103
104	105	106	

L	P	T or L_k	N	C	S	D	BP	NOTES
72		U1	73	3	13	28		Clear and subtract CH base of index register 7 to AR (accumulator)
73		74	75	1	10	29		Add constant in 1074 to the AR.
74	<	00	00	0	20	>		Constant = (.0000020)
75		77	77	0	22	31		Test if sign of AR negative? If yes, go to 1078. If no, go to 1077.
76		U1	96	0	28	13		Store AR in CH base of index register 7.
77		U1	96	0	29	13		Store ZERO in CH base of index register 7.
78		79	96	0	10	28		Transfer contents of address 1079 to the AR.
79	<	00	00	0	40	>		Constant = (.0000040)
96		98	98	0	29	31		Test the overflow indicator? If yes, go to 1099. If no, go to 1098.
98	W	00	87	0	21	31		Return to Intercom.
99	W	00	87	0	21	31		Return to Intercom.
					NOTE:			Contents of the CH base of index register 7 is stored in address 13 U1.

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G-15D PROGRAM PROBLEM: Random Number Generator $X_{n+1} = (2^7+1)\, X_n + \mu$ MOD (2^{28})

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Line 11

0	1	2	3	L	P	T or L_k	N	C	S-	D	BP	NOTES
4	5	6	7	84		85	90	0	19	21		BEGIN: $X_n \rightarrow 2101$
8	9	10	11	85	<	7Z	ZZ	Z	ZZ	>		$\langle X_r \rangle$
12	13	14	15	90		93	00	0	20	23		$2001 \rightarrow 2301$
16	17	18	19	00		03	04	0	23	31		Clear 2 word registers
20	21	22	23	04		05	06	1	21	28		$X_n \xrightarrow{+} AR$
24	25	26	27	06		07	09	0	28	24		$X_n \longrightarrow MQ_1$
28	29	30	31	09		14	22	0	26	31		$2^7 X_n$
32	33	34	35	22		23	24	1	24	29		$(2^7+1)\, X_n$
36	37	38	39	24		25	26	1	19	29		$(2^7+1)\, X_n + \mu = X_{n+1}$
40	41	42	43	25	<	X8	VO	W	XV	>		$\langle \mu \rangle$
44	45	46	47	26		27	28	2	28	28		$\lvert X_{n+1} \rvert$
48	49	50	51	28		29	30	1	28	21		$\lvert X_{n+1} \rvert \longrightarrow 2101$
52	53	54	55	30		33	34	0	19	20		Extractor $\rightarrow$ 2001
56	57	58	59	33	<	ZZ	WO	0	00	>		$\langle$ Extractor $\rangle$
60	61	62	63	34		37	38	0	31	24		EXTRACT $(X_{n+1}) \longrightarrow MQ_1$
64	65	66	67	38		39	41	0	29	28		SET AR = 0
68	69	70	71	41		V2	60	0	27	31		Normalize MQ_1
72	73	74	75	60		61	64	0	21	22		$2101 \longrightarrow 2201$
76	77	78	79	64		65	66	1	19	29		ADD exponent
80	81	82	83	65	<	00	00	0	80	>		$\langle$ exponent $\rangle$
84	85	86	87	66		69	70	1	24	29		Floating point Nbr. (X_{n+1})
88	89	90	91	70		73	76	0	23	20		Reset 2001
92	93	94	95	76		77	80	1	28	21		$X_{n+1} \longrightarrow 2101$
96	97	98	99	80		82	82	0	29	31		Reset overflow indicator
U0	U1	U2	U3	82		85	86	0	22	11		$X_{n+1} \longrightarrow 1985$
U4	U5	U6		83		85	86	0	22	11		$X_{n+1} \longrightarrow 1985$

SDC

G-15D

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Prepared by ___

PROGRAM PROBLEM: Random Number Generator $X_{n+1} = (2^7+1) X_n + \mu$ MOD (2^{28})

				L	P	T or L_k	N	C	S	D	BP	NOTES
0	1	2	3									
4	5	6	7	86	W	00	87	0	21	31		Return to Intercom
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	33	34	35									
36	37	38	39									
40	41	42	43									
44	45	46	47									
48	49	50	51									
52	53	54	55									
56	57	58	59									
60	61	62	63									
64	65	66	67									
68	69	70	71									
72	73	74	75									
76	77	78	79									
80	81	82	83									
84	85	86	87									
88	89	90	91									
92	93	94	95									
96	97	98	99									
u0	u1	u2	u3									
u4	u5	u6										

DESCRIPTION OF STORAGE LOCATIONS

LOCATION	ITEM
0932	Working Storage
1003	2
1004	.66667
1005	.4
1006	.28571
1101	OUTPUT Total Time in System
1102	OUTPUT Total Messages of that Kind Processed
1103	OUTPUT Total Waiting Time
1104	*
1105	t_1
1106	*
1107	t_s
1108	In Cycle Indicator
1109	*
+ 1110	Lower Limit (Enter Task)
1111	100
1112	.22222
+ 1113	μ (IA TIME)
+ 1114	Δ (Enter Task)
+ 1115	Δ (Execute Data Preparation)
+ 1116	Lower Limit (Execute Data Preparation)
+ 1117	μ (Data Presentation)

+ 1118	Lower Limit (Process Flash)
+ 1119	P (Probability that message forces display)
+ 1120	 (Process Flight Plan)
+ 1121	∆ (Process Flash)
1122	*
1123	Cycle Request Indicator
1124	*
1125	*
1126	*
1127	T_{c1}
1128	*
1129	T_{c2}
1130	*
1131	IA Indicator
1132	200
1133	*
1134	*
1135	OUTPUT No. Display Requests Processed
1136	OUTPUT No. Regular Processed
1137	Task No. (Regular) = Task Identification
1138	*
1139	Total Display Requests in Processing Batch
1140	Total Regular's left in Processing Batch
	*

+ 1142	N_1
+ 1143	N_2
+ 1144	N_3
+ 1145	N_4
+ 1146	N_5
+ 1147	N_6
+ 1148	N_7
+ 1149	N_8
+ 1150	N_9
+ 1151	N_{10}
+ 1152	N_{11}
+ 1153	N_{12}
+ 1154	N_{13}
+ 1155	N_{14}
+ 1156	N_{15}
+ 1157	N_{16}
1158	1
1159	10^{10}
1160	*
1161	Processing Start Time
1162	Total Time in System - Display Request
1163	Total Waiting Time - Display Request
1164	*
1165	*
1166	*

	1167	Message Type Counter
	1168	Message Type
	1169	OUTPUT Message T_1
	1170	*
	1171	μ (in EX)
+	1172	Δ (Process Regular)
+	1173	Lower Limit (Process Regular)
	1174	P from Random No. (in EX)
	1175	Δ t, OUTPUT from "Convert to Time" routine
	1176	*
	1177	Total Time in System - all Regular's
	1178	No. Regular's looked at
	1179	Total Waiting Time - all Regular's
	1180	*
	1181	"Ready for Flight Plan" Indicator
	1182	*
	1182	*
	1184	*
	1185	*
	1186	*
	1187	No. Flight Plans in System
	1188	No. of Regular's in Collection Batch
	1189	No. of Display Requests in Collection Batch
	1190	*
+	1191	T_1

+ 1192	T_2	
1193	No. Regular's originally in Processing Batch	
+ 1194	F_1	
+ 1195	F_2	
1196	No. Forced displays left to do	
1197	Display Request Code - 101	
1198	Flight Plan Code - 201	
1199	Flight Plans in Process Indicator	
LOCATION		INDEX REGISTER
1300-1499	Regular's Batch 1	1,7
1500-1699	Regular's Batch 2	1,7
1760-1789	Forced Displays	2
1700-1749	Display Requests Batch 1	3,8
1800-1849	Display Requests Batch 2	3,8
1850-1899	Flight Plans	4,9
1200-1298	Output	5
	Message Type	6

NOTES:

1. * Location is used in random number generator subroutine.
2. + Item is input parameter.
3. Locations 1142-1157 are for probabilities of message types

   N_1-0 = Flash

   N_2-N_1 = Display Request

   N_3-N_2 = Flight Plan

$N_4 - N_3$ = Regular Task 1

⋮ ⋮

$1 - N_{16}$ = Regular Task 14.