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Performance of MARS 105 Seat Reservation System

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A summarized history of JNR's seat reservation system MARS is described. The results of performance evaluation made on the phase I system of MARS-105 which has been enhanced into the phass II are followed. The behavior of the system during the rush period is analyzed. A new figure of merit is defined: from the viewpoint of the figure, some proposals to better the system performance are made.

1. Introduction

1.1 *Seat Reservation in JNR*

Seat reservation services are thought to be brought forth with the advent of limited express trains and berth trains in JNR. In 1950 centralized management of the seat allocation was put into operation at the two ticketing centers located in Tokyo and Osaka. However transactions were handlep by telephone between the clerk at a ticket office and the one at the center and by manual updating of the seat inventory files. By these means, congestion at the ticket windows would be inevitable when the demand for seat reservation increased. Studies on introduction of electronics which then were drastically developing to the seat reservation services had been started since 1957. A small scale tentative machine was devised for reservation of the limited express trains on Tokaido Line in 1959 which named MARS 1. The machine was capable of handling 2,100 reservation seats of four trains a day, and communicating with ten sets of agent terminals. The functions were minimized and inalterable because of fixed program control, but it attained a full success with good operating results.

Studies on a nation-wide system began in 1960 with encouragement at the success of the prototype machine. Analysis of the services, research of the requirements and studies on communication subsystem were made: along with them, development of the large capacity magnetic drums and terminal equipment and data transmission experiments on the microwave channels were continued to realyze the system. The nation-wide system called MARS 101 was completed to build in 1964, which had capacity of 30,000 reservation seats per day and became the first one of the large scale on-line real-time systems in this country.

A year after the opening of Tokaido SHINKANSEN, MARS 102 central processors were added to the system to alleviate congestion at the ticket windows caused by a larger demand for the superexpress trains than expected. At the same time there were established a few hundred ticket windows at the selected large stations which served reservation exclusively. They were called " Green Windows " and were equiped with the MARS terminals. In 1968, in accordance with the transportation improvement project, MARS 103 was scheduled to build. A couple of large-scale, general-purpose, stored-program computers were first applied to it, enabling the total system to handle 330 thousand reserved seats a day which amounted to over ninety percent of reservation at that time.

In parallel with the enhancement, construction of MARS 201 was being under way. Its initial target lay in computerization of seat allocating operation for group travellers, while it had much advanced functions such as earlier reservation, linking more than one trip and passenger information file on the random access devices. They laid the technological foundations for the forthcoming Integrated Travel Service System.

In later sixties intensive discussion was made on management information system in JNR, wherein 100-series MARS was given its position as a core file system which would manage the massive seat inventory file and sale simple trips efficiently.

System design of MARS 105 was undertaken according to this concept. In September 1972 phase I system was completed. After several times of conversion from the preceding systems as deliberately scheduled, it was put into full operation. The capacity being of 700 thousand seats per day, would have to be increased when SHINKANSEN would have been extended to Hakata. Two sets of computers added, communication control ones and separate file control ones were connected in tandem which formed the phase II system of a capacity of 1.4 million reservation seats per day.

A system analysis on telephone reservation service was undertaken in 1968. The alternatives discussed were one in which the center operators intervened the reservation and the other in which accepting inquiries and issueing tickets were fully automated. Both were on the assumption of the use of an audio-response system. A tentative system was devised in 1969, which through the repeated experiments proved to be applicable to the telephone reservation service. Construction of the practical system started in 1971. After a long time investigation of the requirements and studies on fundamental specifications, a project team was organized in 1973 which fulfilled its task to develop MARS 150 Telephone Reservation System in 1975.

MARS 201 for group travellers reservation, on the

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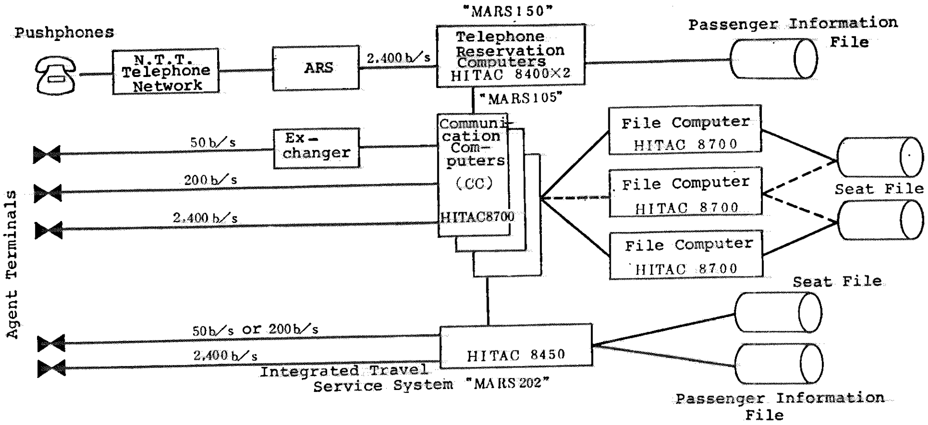
other hand, has been replaced by MARS 202 which has a larger capacity and much more advanced functions than the former.

The total sales management system today is composed of as shown in Fig. 1. Fig. 2 illustrates development of the system in connection with the numbers of reserved seats to be handled and agent terminals installed.



N.T.T.: Nippon Telegraph and Telephone public corporation

ARS : Audio-response system

Fig. 1 Total sales management system

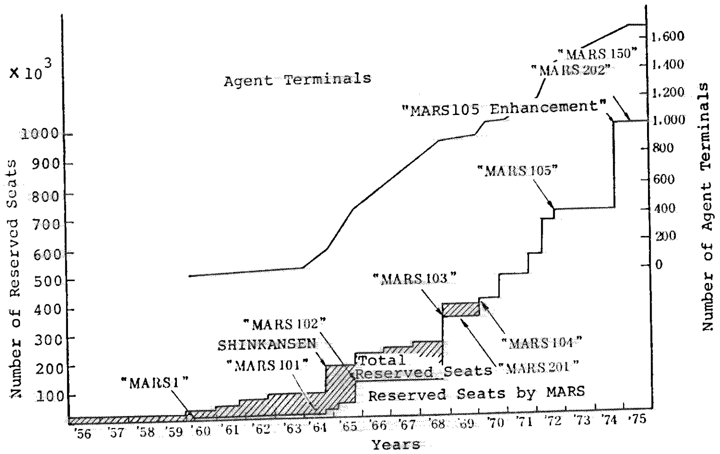


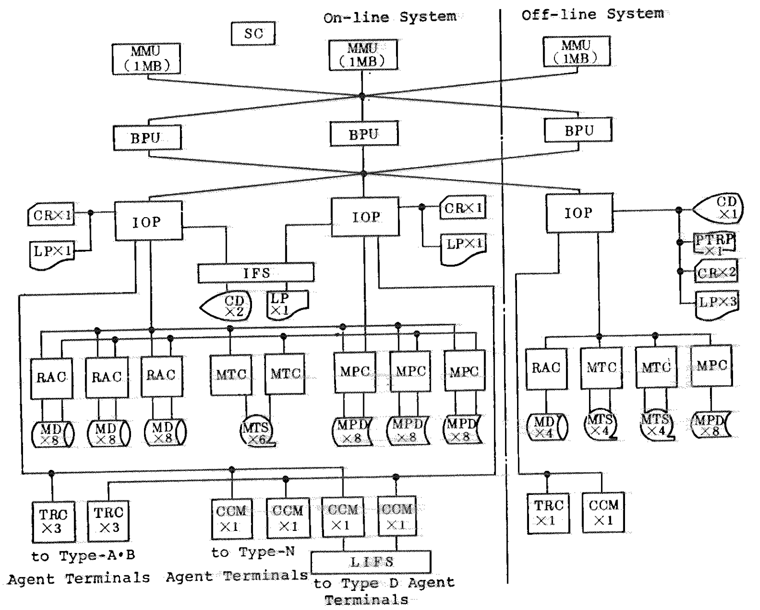
Fig. 2 Development of seat reservation systems

1.2 *Background of the study*

Congestion of message traffic is a great concern in the on-line systems in which frequent input and output are made between a large number of terminals and the central computer through communication lines. As phase I MARS 105, dimensions of which are shown in Table 1, must accept a huge volume of message traffic, analysis of its behavior and evaluation of its performance during

Table 1 Dimensions of MARS 105 (Phase I) system

Number of Trains to be handled	1,900
Number of Reserved Seats per Day	700,000
Reservation Period	one week up to two months
Number of Agent Terminals Type A·B Type N	 1,000 2,000



Note

Mark	Explanation
MMU	Main Memory Unit
BPU	Basic Processing Unit
IOP	Input-Output Processor
C D	Console Display
PTRP	Paper Tape Reader and Puncher
C R	Card Reader
L P	Line Printer
RAC	Random Access Controler
M D	Memory Drum
MTC	Magnetic Tape Controler
MTS	Magnetic Tape Station
MPC	Multi-pack Controler
MPD	Multi-pack Disk
TRC	Transmitting/Receiving Controler
CCM	Communication Control Multichannel
LIFS	Line Interface Switch
IFS	Interface Switch
S C	System Console

Fig. 3 Configuration of MARS 105

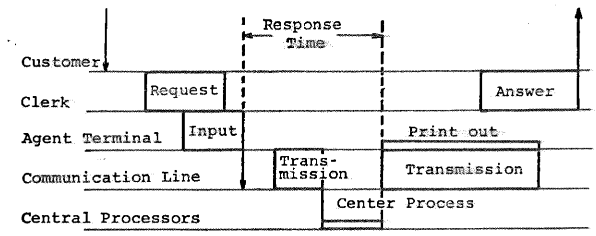


Fig. 4 Typical timing diagram

a congestion period are the prime considerations in course of all the stages of the system life.

MARS 105 consists of terminals, communication network and central processors. In these subsystems control over the traffic is made in principle on a delay system basis. A message sent from a terminal utilizes resources such as trunk lines, main memory areas in the central processors, file devices, programs and so forth to complete a reservation. During the congestion period competition among the messages will frequently occur at these resources, causing the response time to lengthen. The response time is here defined as shown in Fig. 4, and is so specified as less than 6 seconds for over ninety percent of the messages sent from the type-N agent terminals. Excessively long response time would not merely lower the service grade at the Green Windows but impair the system operation.

2. Performance Evaluation at Each Stage

2.1 *Planning and design stages*

The load to the system was supposed to be proportional to the number of seats to be reserved and 1.23 million inquiry messages were estimated to arrive to the center per day in case of 700 thousand reservation seats. Considering an hourly fluctuation, such assumption was made on the system design as an arrival rate of 42.7 messages per second at the busiest hour. In evaluating the system performance, the following were the major unknown factors:

(1) newly manufactured HITAC 8700 computers when applied to the service,

(2) real-time control program (RTCS) developed for an exclusive use to this application, and

(3) type-N agent terminals.

Among the above, (1) involved a great concern because the computers adopted a much improved computer architecture and a couple of H-8700's were composed into a multiprocessor to be applied to the on-line operation. Further, a basic processing unit (BPU) was equiped with a high-speed buffer memory where segments of program and data were brought from the main memory to be excuted. As the transfer took place in a statistical manner, the prediction of the frequency was one question under discussion. The relative capacity of a multiprocessor to a single processor was another.

The seat file which retained seat inventory had been suspected since earlier stages to form a bottleneck in the central processors. These kind of disks chosen were cheaper than drums in terms of a unit memory capacity, but they were of less throughput rate. It was therefore an economical way to allocate drums to the upper twenty percent of trains on which inquiries would concentrate and disks to the others. The file system design was done on this scheme.

2.2 *Implementation and test stages*

When a coarse configuration plan had been determined and the program construction and execution time had been made enough detailed to build into a simulation model, GPSS type simulations were carried out repeatedly to pick up potential bottle-necks and predict effectiveness of the multiprocessor configuration and its limitations of throughput as well. This kind of simulation, however, can hardly describe exactly the program behavior of the simulated computer which has a high-speed buffer memory. Thus more precise performance prediction was expected to be made in the later stages with data gathered from measurements on the actual configuration. When H-8700's had been built and the peripheral equipment had been connected to them as were in practical operation, test messages were sent to them from a testing computer to be processed by the actual program. In the course of the test, transfer frequency to the buffer memories and other items were measured by means of a hardware monitor. As the results, it was made clear that the performance of the multiprocessor was 1.4 times as large as a single processor and the firmware contributed to it by 21%.

At the heavy traffic tests which were carried out as part of the overall system tests, the behavior of the central processor was observed in terms of throughput rate and CPU and task utilization using not only hardware monitor but software monitor devised for this purpose. Estimation of the response time was also tried by observing the wave forms on the communication lines.

2.3 *Operation stage*

Performance evaluation tests of a system in operation are so planned as to grasp its response characteristics in detail to the real load and to gather necessary data to tune it up. At the same time, the validity of the assumption which the system design was based on such as message arrival rate, message length and the like, will be proved.

On the phase I system, performance evaluation tests were made several times at the busiest weeks in spring, summer and year-end. Measurement of all kind of parameters by hardware and software monitors, observation of wave forms on the communication lines and analysis of the journal records as to the message-oriented properties such as center staying time were put into practice. Besides them, a series of bench-mark tests were carried out where messages were fed to the central processors and observation was made on their behavior as the predetermined messages were processed.

Through these tests for over one and a half years since the cutover, the following facts were disclosed.

(1) There come a rush of inquiry messages to the center just after 9 a.m. when the reservation seats of trains a week ahead are set about selling. The rush is thought to be caused by message transmission made from the terminals almost simultaneously with release of line busy. The arrival rate is much higher than the average designed supposing random arrival.

(2) The central processors then advance reservation processing on the messages at the maximum throughput rate. But as the preceding messages have held the trunk lines, long queues are formed at the line concentraters. As the result, the response time of the messages transmitted at 9 a.m. will range very widely. Some of them extend to 15 seconds (type-A•B) or 20 seconds (type-N). Many terminals then consider themselves to be in failure when their guard timers go out. This state is refered to terminal lock-up.

(3) The tasks are the primary bottle-neck in the central processors. As a task uses one unit of the main memory area to process a message, it seems to be a relief to provide additional units, but it will lengthen the average holding time and impossibly increase throughput.

(4) The dominant increasing portion of the average task holding time is due to the disks used for the seat file (SF). Intensive inquiries for the specified trains would make large the message queue waiting for file processing at the related disks. And almost all the tasks would be gradually occupied by these messages. It is therefore a possible solution to rearrange the allocation of disks to trains so that the access may be made as equal as possible to the disks.

3. Analysis of Response Time during the Rush Period

3.1 *Estimation of the response time*

Design of an on-line system to meet the peak load will be by no means economical. In case of MARS, however, the rush at 9 a.m. being a rather ordinary phenomenon, the system is obliged to work fully in such an environment. Accordingly the response time during the rush period deserves discussion, while its measurement on many agent terminals widely dispersed is very difficult. An estimation using a schematic model was tried as to the messages transmitted at 9 a.m. simultaneously from a large number of agent terminals. Both types of terminals are connected to the center through the line concentraters which operate on a delay system basis. Messages which can luckily catch the trunk lines arrive first at the center. This message arrival will be denoted as mode I.

Messages from type-A•B terminals arrive at a nearly constant rate due to the bottle-neck at the telegraph exchanger, while those from type-N terminals, the number of which is restricted to that of the trunk lines, arrive in batch within a short period. Fig. 5 describes this situation schematically, reflecting the message arrival in the real world as illustrated in Fig. 6.

In the model of Fig. 5, let r the sequence number of an arriving message, then its arrival time $A(r)$ is

$$A(r) = \begin{cases} r/\lambda_N + T_0 & \text{(type-N)} \\ r/\lambda_{A\cdot B} + T_1 - L_N/\lambda_{A\cdot B} & \text{(type-A}\cdot\text{B)} \end{cases}$$

where λ_N and $\lambda_{A\cdot B}$ are the message arrival rates respectively, and T_0 and T_1 are the arrival times of each first message from the respective class of terminals.

The tasks work at the maximum throughput rate, that is, with the utilization factor of 100 percent during the rush period. On this condition, the time when the message r is given a task to process is represented with a thick line in Fig. 7. In the figure the horizontal distance between the relating point on the line and $A(r)$ is no other than the task waiting time, which is meant to be possibly a major component of the center staying time of the message. Fig. 8 illustrates the measured center staying time including the task processing time. The response time is composed of elapsed time from 9 a.m. till the task processing begins, task processing time and time for transmission of characters to turn on the answer lamps on the terminal.

Let $g(t)$, $h(t)$ and $a(t)$ be the probability density functions of the above time components respectively, then time taken to turn on the answer lamps will have the following distribution.

$$g(t) * h(t) * a(t)$$

In the expression, symbol $*$ means convolution of functions. An estimation was made on the distribution of the response time supposing each of the time components based on the above mentioned model. Fig. 9 shows the results relating to the mode I messages. The response time of the mode II messages is also studied in the same way and it was proved that there could occasionally arise extremely long response time. It was well explained that it would cause the terminal lock-up.

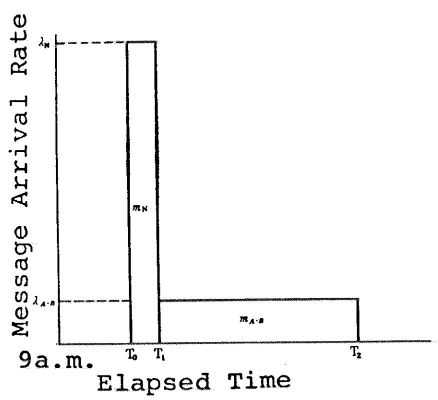


Fig. 5 Simplified model of message arrival

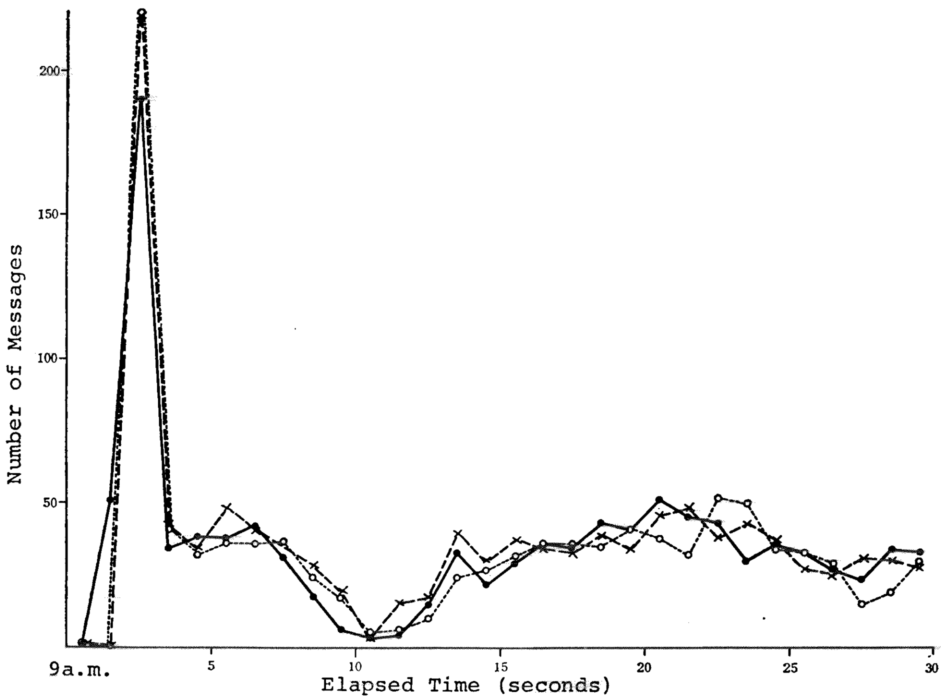


Fig. 6 Typical message arrival in the rush period

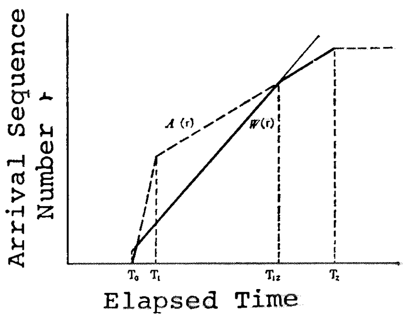


Fig. 7 Beginning time of task processing

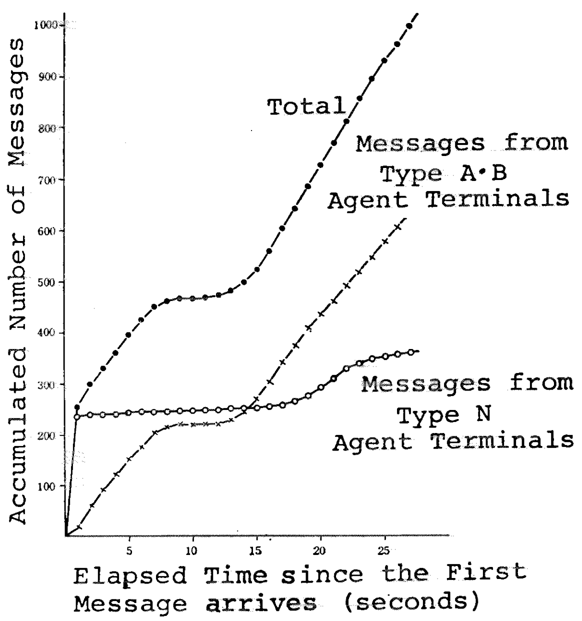
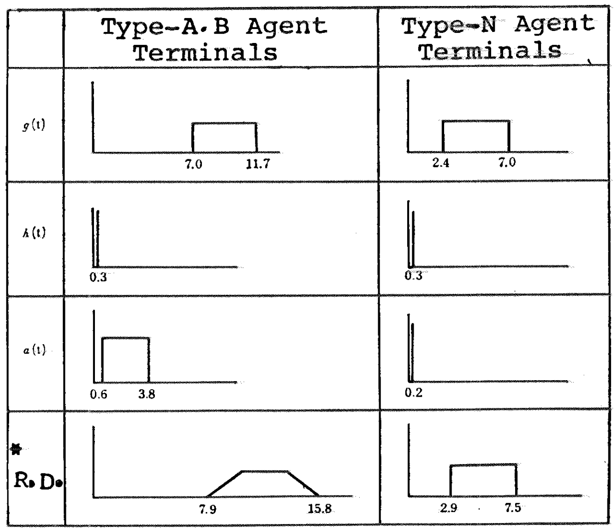


Fig. 8 Accumulated number of messages



* R.D. : Resultant Distribution

Fig. 9 Estimation of response time

3.2 *Analysis of center staying time*

As described above, the task waiting time occupies a major portion of the center staying time of a message arriving during the rush period. In order to reduce the time, improvement of the total throughput of tasks is required. The alternatives for it are reduction of the task processing (holding) time and increase of the number of tasks.

According to the co-variance analysis applied to the results of the bench-mark test, the throughput depended more on the degree of the SF file access concentration than the number of tasks. The reason is explained as below.

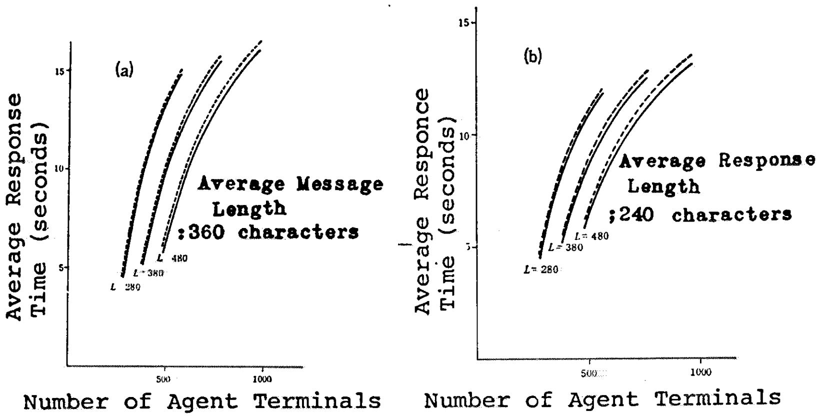


Fig. 10 Estimated response time in the rush period

Suppose $b \times 100\,\%$ of the arriving messages require to access to a single specific device, then with a large b the tasks are gradually occupied by the messages waiting in the device queue. That is, the overall throughput of the central processors is affected almost exclusively by that of SF devices, decreasing with the time elapsed to approach a constant value which depends on b.

$$\Theta_{SF}=\frac{1}{\overline{T_{TK}}}\left(\frac{a_2}{a_1}-bN\right)e^{-a_1 t}+\frac{1}{b}-\frac{1}{\overline{T_{SF}}}$$

In the expression, Θ_{SF} is the total throughput of the SF devices and N is the number of tasks. $\overline{T_{TK}}$ and $\overline{T_{SF}}$ are task and SF processing time respectively, where

$$a=b/\overline{T_{TK}},$$
$$a=bN/\overline{T_{TK}}-(1-b)/\overline{T_{SF}}$$

3.3 *Improvement of the response time*

In the system design stage, random occurrence of the inquiry messages was assumed, and the estimated throughput of each component subsystem was based on the busiest-hour steady-state load. However, in actual fact, a rush of messages takes place at the center at a specific time every day. As in this situation the terminal sites in turn will be crowded with passengers, it will then be of great importance to lessen the response time during the rush period. But it is by no means the only solution to equip every bottle-necking subsystem with additional facilities. Reasonadle trade-off of cost/performance must be considered.

As a new figure of merit, the total amount of response time is defined here to the messages which are transmitted from the prevailing type-N terminals simultaneously. The response time of each message belonging to the mode I corresponds to the arriving sequence as described adove. The rest of the messages, on the other hand, form queues at the line concentraters, grasping a trunk line as soon as any one of the mode I messages frees it to enter the center. These messages are refered to as mode II messages. While a bottle-neck does no doubt lie in the tasks till processing of all the mode I messages have been completed, after this it lies in the trunk lines till the mode II messages have been received by the central processors. During the period the utilization factor of the central processors keeps very low.

The contribution of the mode I messages to the figure of merit and the possibility of its improvement have been discussed. In order to lessen the contributing portion of the mode II messages, increase of throughput of the trunk lines is needed. It will be achieved either by increasing the number of the trunk lines or shortening their holding time. Implementing a format editing function on the terminals instead of the center to reduce the transmission characters is a feasible solution for the latter. Terminals like type-HN which apply higher data transmission speed is advisable from the view point of the total amount of the response time, though they require wider bandwidth on the communication lines. Also a kind of line multiplexers which store the incoming messages from the type-N terminals and send them at a higher bit rate to the center is favorable.

4. Concluding Remarks

Performance evaluation in each stage of the life of MARS 105 phase I system was briefly reviewed. Its response characteristics during the rush period at the operation stage were analyzed, and some practical ways were proposed to better the system performance from the point of view of a newly defined figure of merit. The author hopes that the studies may help the system adapt itself to the ever-changing environments.

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