errors detected by this means will be directed to the computer supervisor's console printer for manual handling.

The specifications under which the FLIDEN equipment is being developed require that transmission of flight-plan messages be made over standard teletypewriter code. However, the logical design of its internal circuitry has been planned that transmission at higher speeds using six or seven-level code will be possible with minor modifications in the final equipment.

With the advent of this type of equipment in the field, on-line filing of flight plans directly into the computer system for flights originating in the center-control area will be possible. This will ultimately reduce the quantity of flight plans which are received by interphone in the center area and manually prepared for insertion into the computer.

Reducing the clerical workload of controllers in the CAA air-traffic control system is only the first step. Anyone who is familiar with the background of thinking on air-traffic-control systems and the great volumes of studies, papers, programs, and system configurations produced during the past ten years may well ask, "What about pictorial displays, radar inputs, data links, automatic position reports, etc.?" This introduction of computers into what is presently a completely manual operation should speed the day when these very desirable features will be included. With the formation of the Airways Modernization Board and the rapid progress that is being made in their data-processing and display program, it is anticipated that air-traffic control operations will soon be provided with powerful tools commensurate with the jet-age traffic-control problem.

Design Techniques for Multiple Interconnected On-Line Data Processors

F. J. GAFFNEY† AND S. LEVINE†

Introduction

THE application of data-processing techniques to large-scale nation wide industries, such as the transportation industry, has resulted in the need for remoting of subscribers and for multiple data processors regionally located. These equipments form elements of a complete integrated data-processing system or network of systems to solve such problems as reservations control on a complete system basis for railroads and airlines. Early applications of digital data-processing equipment to solve the reservation problem were concerned with limited area problems.[1] The improvement and extension of these systems to integrate the entire reservation-space problem has been a logical evolution.

System Considerations

In a reservations system, large numbers of inquiries as to availability of space as well as actual transactions involving sales, cancellations, and waitlisting must be processed each minute. Responses to these inquiries from agents all over the country must be in the order of seconds, so that minimum delay is introduced in handling a customer inquiry over the telephone; further, these inquiries may occur at almost any time of day, particularly in systems for nationwide carriers.

System analysis of these traffic, speed, and operational requirements has led to the design of integrated systems for airlines and railroads which include a number of data processors, each of which provides access to agents using specially designed input-output devices, either in the large reservation offices adjacent to the data processor, or in remotely located offices using specially designed communications equipment. The individual data processors are interconnected by means of high-speed data links so that updating of regional processors by a central data processor can be accomplished rapidly. These systems must be capable of continuous operation for at least 22 hours a day so that reliability considerations are important factors in the design of the system.

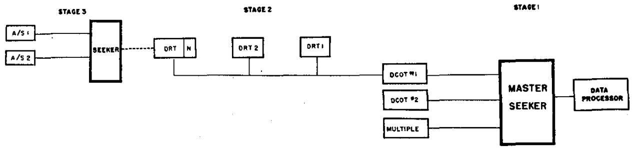
The shutdown of a data processor for maintenance failure for more than a few minutes during peak traffic periods can result in large queues, with resulting loss in business. Requirements for uptime (*i.e.*, the ratio of time the system is actually available to the scheduled time) for systems of this type are in the order of 99.5 per cent.

Remoting of Input-Output Devices

One of the first extensions of the Reservisor concept was that of providing facilities for the connection of remote agents to the central information store. One method

† Teleregister Corp., Stamford, Conn.

[1] M. L. Haselton and E. L. Schmidt, "Automatic inventory system for air travel reservations," *Elec. Eng.*, vol. 73, pp. 641-646; July, 1954.



T = mean processing time by DCOT.

V = transmission time per message.

C = call rate.

S_1 = mean roll call time of calls delayed.

S_2 = mean roll call time of calls not delayed.

P = proportion of calls delayed.

H = mean service time (DCOT processing plus roll call and transmission times).

E = effective load factor of server (DCOT together with communication links).

(1) $H = T + V + PS_1 + (I - P)S_2$

(2) $E = CH$

(3) Mean Response Time $R = H + D$

(4) $P = E$

(5) Mean Delay Time $D = \frac{1}{2}\,\frac{EH}{1-E}$

(6) Mean Response Time $R = \frac{1}{2}H\left[\frac{2-E}{1-E}\right]$

Fig. 1—Queueing analysis.

for accomplishing this utilized an editor for ordinary teletype messages arranged in a standard format. Space sales or cancellations can then be routed to the data processor by existing communications facilities such as the 81-D-1 system of A. T. & T. Automatic broadcasting of stop and resume-sale messages can be accomplished by the data processor when indicated by the inventory level of a given flight. This type of system has been installed recently for Braniff Airways and is currently in use.

There exists, however, the requirement for direct connection of agent sets and the data processor to serve locations which generate appreciable traffic in order to minimize time delays between sales of space and their effect on the central inventory.

One obvious solution to this problem is to connect each remotely located group of agent sets to the data processor by means of individual teletype lines. This procedure, while economically applicable to centers of high-traffic generation, is uneconomical of line costs for many remote locations. It is necessary, therefore, to arrange for common utilization of a transmission line by a number of remote locations along its length. This can be done on a time-sharing basis.

In order to minimize transmission delays it is necessary to provide way-station selection and roll-calling equipment which operates in minimum time consistent with the bandwidth of the communication facility utilized. Such equipment has been developed in a joint Teleregister-Western Union development program.

Fig. 1 shows a typical arrangement of remote locations and central processor. The central processor is sequentially connected, by means of a master seeker, to a number of remote line terminations called Distant Central Office Transceivers, and to multiples which serve local groups of keysets. Each of these inputs is served in turn and remains connected to the processor until a reply has been generated and transmitted .

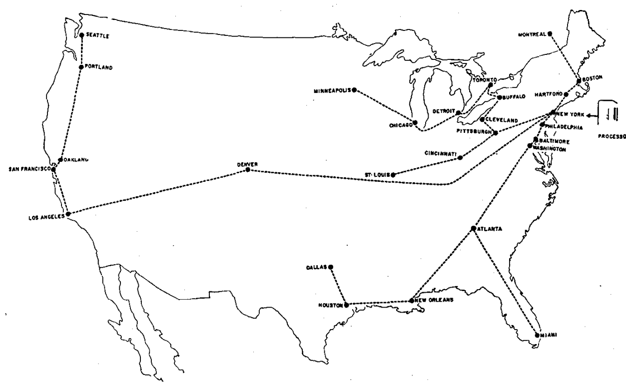


Fig. 2—Pan American Airways reservisor network.

Each Distant Central Office Transceiver (DCOT) is the termination of a teletype line along which are located remote stations, each equipped with a Distant Remote Transceiver (DRT). Each DRT, in turn, connects sequentially through a seeker to a number of agent sets at its location.

In the sequence of operations, a remote agent set bids for access to its DRT. The DRT then bids, by means of a roll-call procedure to be described presently, for access to its DCOT. The DCOT, in turn, bids for access to the data processor. When this chain of events has been completed, the agent set sends its message over the line and receives its reply from the processor. It is then automatically disconnected from the line and another transaction from a different agent set proceeds in the same way. Fig. 1 also shows representative equations for queueing time for a DRT under such a set of conditions. Eq. (6) shows mean response time at a DRT for an idealized system. Actual response time for any given fraction of the calls for consant holding time at the processor is obtained from charts. It is possible to predict, for example, the fraction of calls which will be delayed one holding time or five holding times. In actual practice with current equipment utilizing a 75-word-per-minute teletype line, the mean response time is of the order of several seconds.

The roll-call operation which connects the DRT's successively to the DCOT is of the Round Robin type, that is, each DRT not having traffic when queried generates the call letter of the following DRT. Single letter addresses are utilized for economy of line time. Parity check of all messages is provided.

A remoting system utilizing these techniques was installed early this year for Pan American Airways and is shown in Fig. 2. The central data storage is located in Long Island City, N.Y. The communications system serves 26 cities arranged along four transmission lines.

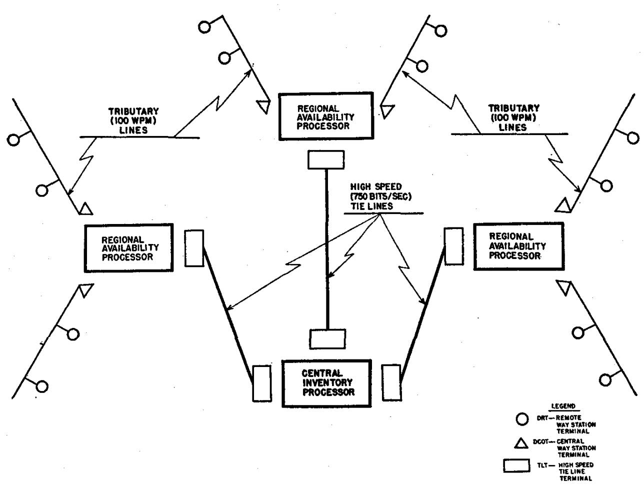


Fig. 3—Integrated airline reservation system.

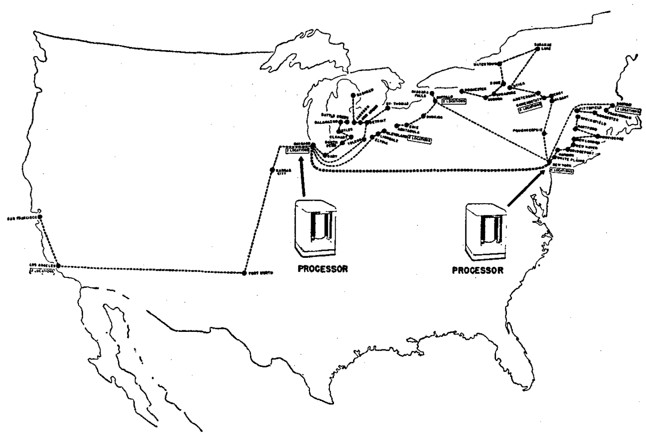


Fig. 4—Railroad Reservisor transmission network.

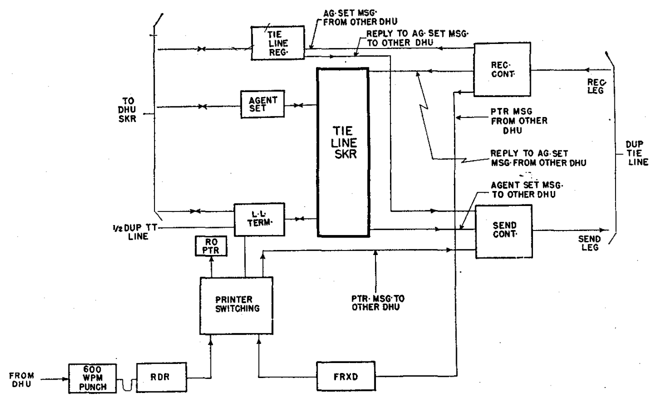


Fig. 5—Railroad Reservisor tie-line terminal.

Integrated Airlines Reservation System

Where traffic volumes in regional areas are high, greater economy can be served by the use of regional data processors connected together to form an integrated system. Such a system is shown in Fig. 3. The regional availability processors, in this system, do not store an actual seat-count type of inventory, but do store several levels of availability status (such as available, not available, in cushion, etc.) for each flight or flight segment. Automatic provision is made for routing sell-cancel calls over the tie line to the central processor which does store the actual inventory on all flights and flight segments. Since there are several availability requests for each sell-cancel transaction, the availability processors act as filters to reduce the tie-line traffic. The availability processors are updated automatically by the central inventory processor whenever the inventory level of a given flight segment reaches a value which dictates a different availability status.

The tie lines utilize voice channels which are capable of transmission at the rate of 750 bits per second. Tie-line terminal equipment incorporates buffer stores of the magnetic-core type to permit optimum-line loading.

Each of the availability processors serves local keysets as well as a number of remote lines which feed traffic from cities in its regional area.

Integrated Railroad Reservation System

The requirements of a railroad reservation system differ considerably from those of an airline system, due principally to the requirements for storage of information on a large number of types of reserved space. The economies of regional storage of data can still be effected, however, since sales of space on certain trains will predominate in the region from which the trains depart.

In the Teleregister system designed to serve the New Haven, the New York Central, and the Atchison, Topeka, and Santa Fe Railroads, two identical data processors are located in New York City and Chicago, respectively. These processors are connected by a 75-word-per-minute tie line. This tie line enables either center to direct an agent set message to the other center and receive a reply, to receive a message and send a reply, to receive a printer message, and to send a printer message. The total inventory is split between the two processors in such a way as to minimize tie-line traffic. Agent set calls are automatically addressed to the appropriate data processor as determined by the particular space involved in the transaction.

A map of this system is shown in Fig. 4. As in the case of the airline system, each processor serves a number of remote lines along each of which are located cities having a group of agent sets. Each processor also serves agent sets in its local reservation rooms and ticket offices.

A block diagram of the tie-line equipment is shown in Fig. 5. A data-processing center has local agent sets and long-line terminals serving agent sets at remote cities. Any of the local agent sets or long-line terminals has access to either the local Data-Handling Unit or the remote Data-Handling Unit. The determination of which Data-Handling Unit is to be used is automatic, and is determined by the addressing code generated by the request for specific train routes when a particular plate is inserted into an agent set. When the remote Data-Handling Unit is required, the agent set or long-line terminal bids through the tie-line seeker for the send selector. When an input is connected, this seeker bids against the printer-switching equipment and the tie-line register for the use of the send control. When this unit is available, it controls the pulsing out of the message in 5-element, 7.42 unit code to the remote tie-line terminal. A distinctive character precedes the message to identify it as an agent set query. The receiving control at the remote central station recognizes the character and causes the receive selector to steer the incoming message to the tie-line register where it is stored in relays. Upon completion of the outpulsing, the send control in the originating station becomes available for inputs from the printer-switching equipment or from its own tie-line register. The receive control at the terminal station is now available for printer messages or a reply to one of its own agent-set queries.

Upon completion of the message the remote central station tie-line register bids against the local agent sets and long-line terminals for the Data-Handling Unit. When it has received and stored its reply, it bids against the tie-line seeker and printer-switching equipment for the use of the send control. When connected, the send control pulses out the reply preceded by a distinctive character to identify it as such. The receiving control at the original station recognizes this switching character and thereupon switches the reply through the tie-line seeker to the original agent set or long-line terminal.

Certain agent set calls and some Data-Handling Unit operations cause printer messages to be perforated by the Data-Handling Unit 600-wpm, 5-unit punches. These printer messages can be directed to local Receive-Only printers, printers on the long lines connected to the center, or to local or remote printers associated with the remote Data-Handling Unit. The perforated messages have sufficient addressing characters to select system, line, station and printer. When the printer-switching equipment sees an address associated with the remote Data-Handling Unit, it bids against the tie-line seeker and tie-line register for the send control. When given access, it pulses out its message preceded by an appropriate switching character. This switching character directs the receiving control to feed the incoming message into the FRXD. This FRXD or RT is a receiving reperforator and a transmitter distributor. The machine is built so that a loop of tape can be stored between the punch and distributor. This loop forms as the message comes in. When the message is complete, the FRXD is connected to the printer-switching equipment which selects the designated local printer or long-line terminal associated with a remote printer and completes the routing of the message. The tie-line equipment is designed such that two agent set messages, one from each end, can be simultaneously in progress. By the same token a printer message from one end can be in progress at the same time as an agent set query from the other end.

The tie-line equipment is equipped with odd parity checking and various time outs to prevent service delays.

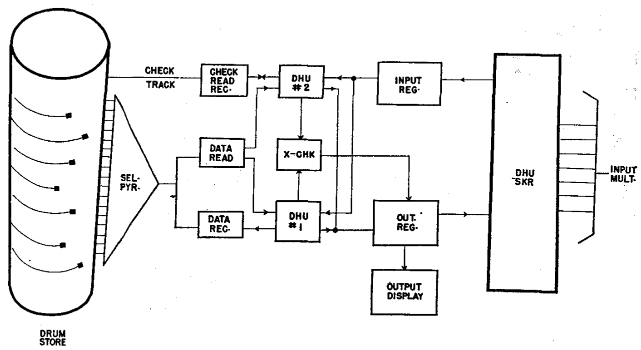


Fig. 6—Dual data processor operation.

Reliability Considerations

In an on-line system of interconnected Data-Handling Units, reliability of the various components of the over-all system becomes a prime consideration. The system must be designed and maintained so as to secure long periods of trouble-free operation and rapid correction of failures which do occur. Means must be provided wherever possible to permit independent operation of the various units, so that the system may be operated with somewhat reduced performance characteristics, even when one of the component subsystems has failed.

Of great importance, of course, in maintaining this reliability is the use of carefully chosen electronic and electromechanical components of high quality. To effect this requires an active standards program and careful life testing of components intended to be added to the standard list. In the equipment described, for example, vacuum tubes expressly designed for long life have been chosen. These tubes, when operated under derated conditions in the equipment, have demonstrated average lifetimes of well over 50,000 hours. Bifurcated contact relays of the telephone type are used for electromechanical switching and are capable of several million operations before any need for adjustment.

To further assure reliability of the central Data-Handling Units, portions of the equipment such as the electronic data processor are duplicated. Reliability can be increased by a large factor through the use of this technique. For example, if the probability of failure of a given unit in a specific time interval is one part in a thousand, the probability of failure of both of two identical such units during the same specific time interval is of the order of one part in a million.

A block diagram of such a duplicate processor is shown in Fig. 6. Calls coming in to the Data-Handling Unit seeker shown at the right-hand side of the diagram are stored in an input register and fed simultaneously to two Data-Handling Units. The process of a given call as it progresses through each of the units is checked by means of a cross-checking circuit, and the call rejected, should a check not be obtained. Where the call is one which requires writing on the drum to change the stored information, this is done simultaneously on a check track fed by one of the

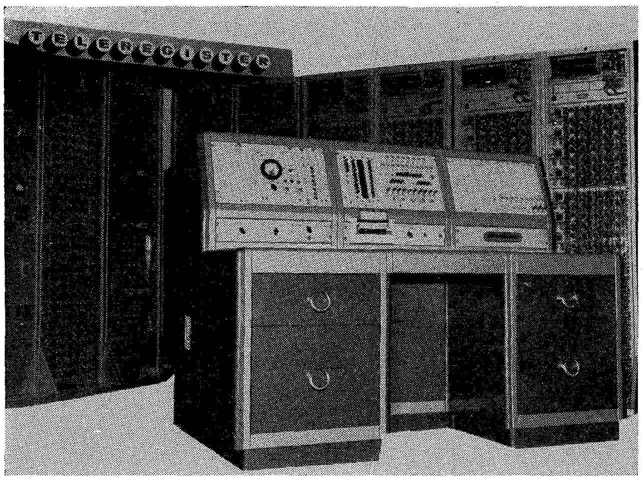


Fig. 7.

Data-Handling Units and on the appropriate inventory track fed by the other Data-Handling Unit and selected by a track-selection pyramid. The changed information is then read back from both tracks through the Data-Handling Units and compared by the checking circuit for certification. Should verification not be obtained, the call is printed out so that corrective action may be taken.

In the design of some systems of this type, facilities are provided for automatic switchover in case of failure of one of the systems to the remaining system, which can operate alone. Indication of this type of operation is provided to maintenance personnel.

To provide further reliability, the Data-Handling Units are operated in a temperature-controlled environment and with fully attended maintenance. Maintenance and adjustment periods of approximately two hours per day provide opportunity for the employment of marginal-checking techniques for weeding out components for which failure is incipient.

Open rack type of construction is used for the equipment to enable access to all of the components, in order that repair time may be minimized. The equipment is provided with a maintenance console which indicates to maintenance personnel the progress of calls through the Data-Handling Unit and which provides a facility for the introduction of test calls in order that failures may rapidly be located. A typical system arrangement is shown in Fig. 7.

Of equal importance in the over-all problem of system reliability is the minimization of human error by operators who have access to the system and the facility to change the stored information. It is of paramount importance that agent sets be well designed from the human engineering standpoint, with a view to simplicity, ease of operation and protection against human error. Fig. 8 shows an agent set designed for airlines use in accordance with these principles. The use of a plate inserted into the agent set provides an almost fool-proof method of addressing to a particular location on the magnetic drum. It provides the

Fig. 8.

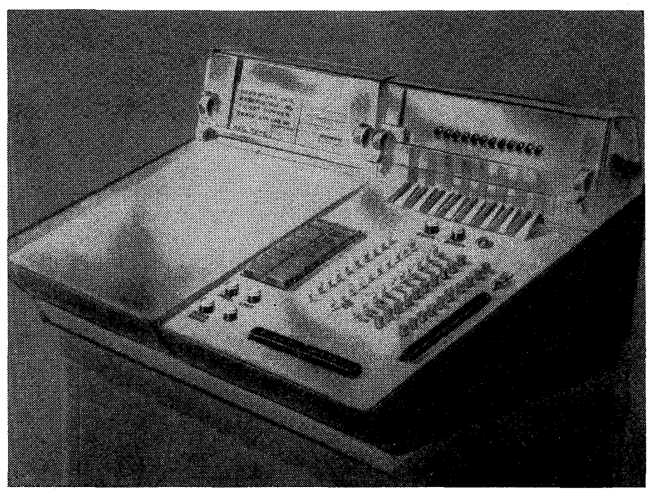


Fig. 9.

facility for automatically coding information which would otherwise require a number of button depressions. The addresses to which the plate directs the inquiry are clearly shown in printed English on the plate itself, which can also be used to display other information, such as fares. The insertion of the plate in one position together with the use of eight matching keys located immediately below the lower edge of the plate enables simultaneous access to the store for availability information on each of eight flights, legs, or flight segments. Depression of the appropriate button then restricts sell or cancel action to the particular flight or leg involved.

Facilities for inserting, by means of clearly marked buttons, information on the number of seats required, the data and the action required (such as sell, cancel, waitlist, etc.,) are provided. This design has been shown by experience to require very little operator training and to result in few operator errors.

The same general approach was employed in the design of a similar set for use with the Railroad Reservisor system. This is shown in Fig. 9. Here it is necessary to provide additional buttons due to the requirement for listing a number of types of space, such as seats, bedrooms, etc., but the design of the equipment is basically similar to that of the airlines agent set. In the case of the Railroad Reservisor, the reply-back information from the central data processor is also somewhat more complex, and it has been found best to display this information in printed form rather than with lights, as in the case of the airline set. In the illustration shown, the printer is shown mounted adjacent to the agent set. The reply-back information is ejected from the printer on prepared forms, one copy of which can be given to the customer.

It is believed that the systems described above represent tangible forward steps in the development of on-line data-processing systems, which enable these systems to be greatly extended geographically, with consequent increased utility.

Discussion

W. A. Morgan (International Business Machines, Owego, N.Y.): Do you buffer your inputs and outputs or allow each agent set to tie up the data-handling unit during processing time?

Mr. Gaffney: Each agent set contains its own buffer register. The call is set up in the agent set by the operator and a master seeker permits each agent set to have access to the data-handling unit in turn. The data-handling unit has its own input-output buffer and processes agent calls at its own high-speed rate.

E. Ziolkowski (Datamatic): In interrogating the system, how is the problem handled when two requests are made simultaneously for only one available reservation? Can conflict occur?

Mr. Gaffney: There is no conflict. The data-handling unit processes the calls sequentially so that only the first one having access to the equipment will obtain the reservation; the second call will be rejected.

Claude Kagan (Western Electric Co.): What error detection and correction facilities are provided in the Railroad Reservisor tie-line system?

Mr. Levine: In this system, the primary error detection facility is an odd-even parity check on each character. In addition, there is an over-all message character count. Error detection facilities are available on the data-handling unit so that nonallowable codes will be rejected. Error correction facilities are not provided; however, in the event of a detected error, the agent set receives an error signal and no change in the inventory is made. The call is then repeated.

Mr. Harris (Stromberg Carlson): Please describe the physical facilities over which your high-speed—750 bits a second—transmission takes place. For example, carrier, long-distance telephone, leased wire.

Mr. Levine: The physical plant facility to be used for transmission of 750 bits per second data will be a private wire, leased, telephone quality voice channel. The terminating device will be a data modulator-demodulator unit to be furnished by the communications common carriers. Our data terminal equipment will include necessary buffer registers and will serialize the data in the form of a series of dc pulses fed to the data modulator-demodulator.

Mr. Harris: How many stations does the Pan-Am system serve? By station, I mean one group of individual agents' equipment.

Mr. Levine: In the Pan-Am system at present we have 26 cities served by the system, and a total of 120 agent sets.

P. F. Radue (Automatic Electric Co.): What technique is used to assure correct transmission of information where parity check leaves gaps?

Mr. Levine: The technique for error detection that we expect to use will include both vertical and horizontal parity checks. The vertical parity check is a single parity check on each character while the horizontal check is performed on the entire message. This technique is expected to reduce the number of undetected errors to a negligible value. In addition, as discussed above with reference to the railroad system tie line, the data processor will reject any nonallowed codes. The message will be retained in a buffer register at the transmitting end until an acknowledgment signal is received. The message will be repeated if errors are detected. If the acknowledgment is not received, a print-out will occur after a suitable time out.

F. A. Reynolds: What is the effect of errors on increasing the traffic on the lines? How do errors break down between operator errors and facility errors?

Mr. Levine: Both of these questions are difficult to answer precisely in that systems of the type discussed have not been in operation long enough to provide a good statistical sample. The first part, on the effect of errors on increasing traffic, may be answered as follows. With proper operation and maintenance of both lines and terminal equipment, the number of retransmissions due to error should not exceed approximately 1 per cent. This type of performance has been achieved. However, during initial breaking periods this rate has been somewhat higher. The retransmissions are not expected to increase traffic sufficiently to cause difficulty. The second part of the question concerning distribution of operator and facility errors may be answered as follows. Error checking facilities are included in the operator's equipment to reject improper input data; however, certain operator errors will be undetected except through audit procedures. The number of undetected operator errors should be low.

B. Hasbrouck (Atlantic Refining Co.): If space is sold out, can all interested regional processors reject such requests locally? If space is still available, can any requests be answered on the regional level or must each such request go individually to the proper central for servicing?

Mr. Levine: Yes, the regional processor rejects requests locally if space is sold out or permits acceptance of sales if space is available. Agent sets receive their answers directly from the regional processor which forwards the transaction to the central processor.