INTRODUCTION

The Northwestern Bell Traffic Rating System is a real-time audio response dual computer system which must be on-line continuously. The system allows any Northwestern Bell long-distance operator to interrogate a remotely located computer system for a long-distance toll rate. The 3000 operators are widely scattered over an area covering 10% of the country. The toll message response consists of an amount, plus a word denoting whether the rate is for a "station-to-station" or "person-to-person" call. These conditions are ideal for using audio response for the remote display of information, rather than any of the commonly used hardware terminals.

The Traffic Rating System concentrates an operation that was formerly done by widely dispersed Rate Operators. This concentration has a disadvantage in that the operation is now vulnerable to the single failure of any part of the computer system. To keep the operation going continuously, a Systems Monitor is necessary to 1) detect failure of the on-line operation, and 2) transfer the operation to a standby computer system. In this way the system "heals itself" without recourse to human intervention. The necessity for such a capability is becoming widespread as more computer systems are installed which must be on-line all the time.

The building and installation of a real-time system requires special procedures to deal with the unique problems involved. Some of the problems in putting together the Traffic Rating System were:

1. Liaison between the customer and the manufacturer over a distance of half the country.
2. Development of two completely new units for the system—one from a subcontractor who was also a great distance from the manufacturer.
3. The system had to be in operation less than a year after the contract was signed, resulting in the parallel debugging of new hardware along with the software.
4. Once on-line, the system had to operate continuously. It could not be taken off-line for any reason, and so no long shakedown of the system was possible.

These and many other problems had to be solved, through close liaison, careful planning, and tight scheduling. The successful installation of the system was the one purpose of the project. Of potentially greater value was the gaining of experience which will provide the capability to meet the growing demand for this type of system.

PURPOSE AND OPERATION OF THE TRAFFIC RATING SYSTEM

Manual Rate Quotation

When a long-distance call is made from a telephone booth, the operator must determine the ini-
tial deposit—the rate for the first three minutes. To do this, she calls a Rate Operator and gives her the first six digits of each of the two 10-digit telephone numbers involved. The Rate Operator then goes through the following procedure:

1. Using the six digits, she looks up in a table the Vertical and Horizontal Coordinates for the call's origin and terminal points. These are grid coordinates, similar to latitude and longitude.
2. She then calculates the differences between the two Vertical Coordinates, and the difference between the two Horizontal Coordinates. This gives her a measure of the two legs of the right triangle whose hypotenuse connects the two locations.
3. Another table enables her to find the airline distance between the two locations.
4. Finally she enters the appropriate rate table with the distance, and gets the initial rate, which she relays back to the operator handling the call.

The above process occupies two operators, their positions and the connecting circuit for an average of 45 seconds. Times as long as two minutes have been recorded. In an effort to improve the service while at the same time reducing the costs involved, telephone companies are investigating ways of automating the rate quoting process.

Automatic Rate Quotation

The Northwestern Bell Telephone Company serves an area in the Upper Midwest that covers approximately 10% of the United States (Fig. 1). Late in 1964, the company requested bids on a real-time computer system which would:

1. Be accessible to any of the 3,000 operators in the Northwestern Bell territory who handle calls requiring an initial rate quotation;
2. Accept rate inquiry digits from an operator;
3. Calculate the rates, using information previously put in memory, such as Vertical and Horizontal Coordinates, location time zones, rate tables, etc.;
4. Inform the operator of the resultant rate;
5. Operate continuously without fail; and
6. Handle the peak hour load of 5,000 inquiries over 24 trunks with less than 60% of the total central processor capacity.

System Input

Input to the automatic system would come from keysets which were already an integral feature of the operators' positions. These keysets send digits in a form which are received and decoded by a Multi-Frequency Receiver. The computer system would interface with 24 trunks, each having a Multi-Frequency Receiver. (See Fig. 2).

System Output

The answer to an inquiry would consist of an amount in nickel increments from $0.00 to $3.00 and/or control or information words. In all, the replies could be made up from less than twenty different words.

The possible output devices were cathode-ray tubes, teleprinters, or audio response units. Each device had certain advantages, as shown by Table 1. The slight disadvantages of limited vocabulary and low speed of the Audio Response Unit were more than offset by its negligible cost and minimum maintenance requirements. With audio response, the system responsibility of the computer system manufacturer would be concentrated in one location, and not be spread among 3000 remote sites.
"NEVER-FAIL" AUDIO RESPONSE SYSTEM

TO/FROM TOLL CALL OPERATORS

TELEPHONE COMPANY EQUIPMENT: MULTI-FREQUENCY RECEIVERS

AUDIO RESPONSE UNIT AND PHRASE SELECTION MATRICES #1 - #24

COMMUNICATION ADAPTER UNITS

COMMUNICATION CONTROL UNIT A

COMMUNICATION CONTROL UNIT B

CENTRAL PROCESSOR

RANDOM ACCESS DRUM

SYSTEM MONITOR

RANDOM ACCESS DRUM

CENTRAL PROCESSOR

Figure 2. Diagram of Traffic Rating System.

Table 1. Ratings of Terminal Output Devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost</th>
<th>Vocabulary</th>
<th>Speed</th>
<th>Installation</th>
<th>Maintenance</th>
<th>Human Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode-Ray Tube</td>
<td>High</td>
<td>Unlimited</td>
<td>High</td>
<td>Difficult</td>
<td>Moderate</td>
<td>Excellent</td>
</tr>
<tr>
<td>Teleprinter</td>
<td>Medium</td>
<td>Unlimited</td>
<td>Medium</td>
<td>Difficult</td>
<td>Moderate</td>
<td>Poor</td>
</tr>
<tr>
<td>Audio Response Unit</td>
<td>Very low*</td>
<td>Limited</td>
<td>Low</td>
<td>None</td>
<td>None</td>
<td>Good</td>
</tr>
</tbody>
</table>

*Cost is that of central site audio equipment divided by 3000.

Traffic Rating System Operation

In November of 1964, Honeywell proposed a Traffic Rating System to meet the requirements set forth by the Northwestern Bell Telephone Company in their bid request.

To obtain an initial rate from the proposed system, an operator performs the following steps.

1. She keys in a three-digit access code, thus tying her position to one of the 24 trunks in Omaha.

The system recognizes that the trunk has been "seized," and returns a "beep-beep" tone from the Audio Response Unit to the operator.

2. Upon hearing the beep-beep tone, she keys in the 12 digits, plus a 13th digit to signify whether the call is station-to-station or person-to-person. The system calculates the rate in less than 0.1 second—a procedure that took a Rate Operator 45 seconds. The Central Processor then sends the audio track addresses for the reply to the trunk's Phrase Selection Matrixes.
tion Matrix. At intervals of 0.5 seconds, the matrix directs the chosen words to the output trunk, and the reply goes to the operator.

3. The operator hears the reply, such as “eight-five-station-eight-five.” The reply states the requested rate, confirms the rate through repetition in case the operator did not understand it the first time, and confirms that the rate is for a station-to-station call. This form of reply reduces the chance of operator error or misunderstanding.

Benefits of the Traffic Rating System

A comparison between the manual quotation procedure and the automated system shows the following advantages of the Traffic Rating System:

1. **Service.** The customer waits 15 seconds or less instead of 45 seconds.

2. **Cost.** The Rate Operators and their positions are available for other tasks. This saving is partially offset by the Traffic Rating System rental, and by the cost of equipment to handle the additional long-distance traffic coming to Omaha.

3. **Accuracy.** The chances for error in determining the rate are greatly diminished.

On the cost basis alone, the system will justify itself many times over. While the other advantages are difficult to assess quantitatively, they are highly significant to an organization which must answer to the general public in its function as a public utility.

The basic advantage of the Traffic Rating System is the concentration of the widespread manual rate quotation operation into an efficient centralized activity. Efficiency implies the reduction of redundancy. A system without redundancy becomes extremely vulnerable to failure. A single mishap to the Traffic Rating System destroys the rate-quoting capability for the entire Northwestern Bell area. Such an event must be guarded against at all cost. The Traffic Rating System must “never fail.”

"NEVER-FAIL" SYSTEM REQUIREMENT

The Traffic Rating System requires the functioning of all four major components: Communications Control Unit, Central Processor, Random Access Drum, and Audio Response Unit. The Phrase Selection Matrices, Communication Adapter Units, and associated telephone company equipment are all modular—one unit for each of the 24 trunks served. A malfunction in a modular unit affects only one trunk, while a malfunction in a major component cripples the entire system. Therefore each of the major components is duplexed. Switches enable any component to be switched into or out of the system almost instantly. This capability protects the system from failing from any single malfunction.

This capability solves one problem, but brings in more problems. Now that the switches are available, these questions arise:

- *When* should a switch be thrown?
- *Which* switch is thrown?
- *Who* (or what) throws the switch?

Obviously a switch is thrown when the system comes to an unprogrammed halt. Still, the system could be running when only a portion of the system malfunctioned. Numerous transient errors could occur which, while individually correctable, collectively indicate an incipient malfunction. Therefore the running of the system is not the only criterion which determines when a switch should be thrown.

Which switch is thrown depends on which of the major components malfunctioned. If this is not immediately apparent by a control panel display, then additional time must be spent in either finding the bad unit, or trying each switch in turn to see if the system resumes operation. As an alternative to these procedures, all switches may be thrown for any malfunction, thus replacing all major units in an effort to get the system back on the air as quickly as possible. Should another malfunction occur before the first one is remedied, then which units are malfunctioning must be determined.

The Traffic Rating System operates in an unattended environment, since none of the usual data processing personnel are necessary for its operation. Other personnel are located too far from the system to be of timely assistance. Therefore, the throwing of the switch must be done automatically, acting upon information as to the status of the major units of the system.

Neither of the Central Processors are used to perform the status evaluation and activate the switch, since they are part of the system which could fail. An independent judgment is necessary to determine...
whether a system has failed. This requirement is fulfilled by the System Monitor, which also has the capability of activating the switch to bring in all the standby components.

Design of the System Monitor

The primary purpose of the System Monitor (Fig. 3) is to detect malfunctions. The degree of monitoring could be as simple as the detection of a system halt, to the complex sensing of all circuits of a unit (as on the engine of a Saturn rocket). The more complex a System Monitor becomes, the greater the probability that: 1) the System Monitor interferes with the efficiency of the system that it monitors; and 2) the System Monitor itself malfunctions. Considering also the high cost of increasing monitor complexity, the development concentrated on the simpler design concepts.

The design was also affected by the purpose and operation of the Traffic Rating System. These were considered in finding answers to the following questions:

- Does all information in the system have to be saved or transferred from the on-line Central Processor when it is switched to off-line?
- How are malfunctions detected which do not halt the system?
- What is the allowable interval between the occurrence of the malfunction, and detection? Does the detection have to be instantaneous?

When a system requires that all information that has entered the system be saved, the usual procedure is to have two computers receive and operate on all
incoming data. An example of this operation is the New York Racing Association Tote System, where both Honeywell computers receive real-time information on every bet made at the Aqueduct, Belmont, and Saratoga Tracks. However, in the Traffic Rating System each inquiry is independent and complete—it has no connection with any other inquiry before or after it, and the receipt of the reply completes all processing for that inquiry. If an operator does not get a reply within seconds after keying her input, or if she does not understand the reply for any reason, all she has to do is disconnect, and re-initiate the inquiry. Since only one computer is necessary for input to the Traffic Rating System, the back-up computer could be used for regular data processing.

Malfunctions which do not halt the system could be found while running dummy inquiries through the system, testing all possible program loops, and ascertaining the correctness of the replies. This check should not be run too frequently, since it might degrade the system’s capability to handle live inquiries. Transient errors sometimes indicate that the system is close to a marginal condition, and should be “peaked up.” A cumulative record of such events as correctable drum read errors will provide for the detection of incipient malfunctions.

The interval between the occurrence and detection of a malfunction was balanced against the time required to execute the switching procedure. This time was variable over a small range, since it depended upon the state of the system which was to go on-line. Since instantaneous detection of a malfunction was not required, a query-response scheme rather than a continuous signal method was advocated. This required the system being monitored to send a periodic response in reply to an outside query, rather than passively send a continuous signal.

**System Monitor Operation**

The System Monitor is designed to perform the following functions:

1. It sends a Check character to both Central Processors at regular time intervals.
2. It expects to receive an OK character in return, before a new Check character is due to be sent.
3. If the System Monitor does not receive the OK character from a system in time, it sounds the visual and audio alarms. It may initiate the switching procedure, depending on whether the on-line or back-up system has the malfunction.
4. If the back-up system is to be brought on-line, the System Monitor sends a message to that system, so that it may be prepared to accept the trunks when they are switched. After a short time interval, it switches the trunks.

A Monitor program in each of the Central Processors works with the System Monitor. This program returns the OK character within the allotted time span, unless it is blocked from doing so by a system malfunction or through its own intent. Optional variations to improve the quick detection and remedy of malfunctions are listed below:

1. The program does not return the OK character immediately, but holds it up until nearly the end of the interval. Should a malfunction occur during this time, the System Monitor detects the nonreturn of this OK character rather than the next one. With this variation, the detection time is 50% of what it would be otherwise.
2. The Monitor program runs a dummy inquiry through the system, testing all the major components except the Audio Response Unit. If the result differs from that previously computed, the program blocks the return of the OK character. The frequency of the dummy inquiry check is either a function of the current traffic load or a constant. In either case, care is taken to make sure that the system capability is not affected by running the dummy inquiry too frequently.
3. The Monitor program ascertains that the System Monitor is sending the Check characters periodically. This closes the loop to make sure that the System Monitor is functioning correctly. If a Check character is not received, the Monitor program displays this information on the teleprinter attached to the system.
4. When an OK character is deliberately blocked from being sent to the System Monitor, the Monitor program displays the reason for its action on the teleprinter. This enables the malfunction to be more readily identified.
5. The program causes a time signal to be printed on the teleprinter periodically. This evidence of operation is reassurance that the system has not somehow malfunctioned without giving any alarm. Should a malfunction occur, the printed record gives the most recent time at which the system can be presumed to have been operating correctly.
The Monitor program in each Central Processor thus provides a great amount of flexibility in the detection and identification of malfunctions. This flexibility would be difficult and expensive to achieve with additional System Monitor hardware.

Secondary System Capabilities

The primary back-up capabilities are handled by the System Monitor when it switches all off-line major components to the on-line system in case of any malfunction. During the period while the malfunction is being repaired, a second malfunction could occur in the (new) on-line system. There are manual switches which allow a functioning Traffic Rating System to be assembled, assuming that the malfunctioning components can be identified and the two components are not identical. These switches are located on the System Monitor Control Panel. The Panel also displays the current status of all components—which system it is that controls each component.

Audio Response Unit Monitor and Switch

The output on each of the 20 tracks of the two Audio Response Units is continuously monitored. If a track output falls below a given threshold, audible and visual alarms on the System Monitor are activated. If the malfunctioning unit is on-line, the back-up unit is automatically cross-switched with it.

Power

The one element that affects every portion of the Traffic Rating System is the power supply. The threat of power failure is eliminated through the following steps:

1. A motor-generator unit is installed to assure uninterrupted power to the Traffic Rating System in case of outside power failure.
2. The power supplies within the system are either duplexed and automatically switched, or else they can be switched manually. That portion of the system which must always be available is fed by two pairs of automatically-switched power supplies (one pair for the Audio Response Units and the Phrase Selection Matrices, and the other pair for the remainder of the modular units, plus the System Monitor and the switches). A regular power supply is normally connected to each of the two groups of major components, each group consisting of a Communications Control Unit, a Central Processor, and a Random Access Drum.

3. A power switch allows any identical pair of major components to be cross-switched between the two regular power supplies. With this switch, two nonidentical malfunctioning major units from different groups can be fed from one power supply, while the other supply handles the functioning system. A power supply is handled as a major component, being able to be switched back and forth between systems as the need indicates.
4. Each cabinet in the system, and each of the drawers in the cabinet is provided with interlocks to enable them to be isolated from the rest of the system when undergoing repairs.

Other modifications are made to break up the system so that the effect of any malfunction is isolated, and not propagated throughout the power supply network.

Future Applications

The computer state-of-the-art is heading toward a level of sophistication in which large electronic systems will monitor their own operation, detecting malfunctioning components and replacing them without human intervention. The System Monitor and duplexed components of the Traffic Rating System makes it one of the systems which is leading the way toward this goal.

IMPLEMENTATION OF THE TRAFFIC RATING SYSTEM

Planning

Immediately after Honeywell signed the contract for the Traffic Rating System, an organization was created to handle the project. An Engineering Project Director was appointed to coordinate all the activities relating to the subcontracting, building, and testing of the complete system. Coordination between the customer and the Engineering Project Director was the responsibility of the Project Manager, who was appointed from the marketing home office. The Project Manager was the center of a network of communication lines. It was his job to collect and interpret the needs of the customer, examine the effects of different system approaches, expedite the paperwork, issue progress reports to interested parties, and in general be informed on all aspects of the project.

Scheduling

The initial phase of the project included the setting up of a master schedule, which would end at the
cut-over date. Progress toward determining that date was made from three directions simultaneously—merging the requirements of the Northwestern Bell management with the capability of their programming staff and of Honeywell's Engineering Department. The software was PERT-charted, the hardware development was scheduled in detail, and a cut-over date was agreed upon. This date was less than a year after the contract for the Traffic Rating System was signed.

Design and Test of New Equipment

When the project started, the Audio Response Unit and the System Monitor had been functionally specified. The responsibility for any additional design work necessary for the Audio Response Unit was given to the subcontractor. The System Monitor was designed and built by Honeywell.

When each equipment prototype was ready, a series of component tests were run on the individual units. Only when these were passed was the unit connected to other components for system test.

The recording for the Audio Response Unit presented a unique problem. There was no quantitative way to determine whether the quality of the voice recording was satisfactory. Can a high voice be understood better than a low voice? Should the voice be that of a telephone operator, or that of a professional voice specialist? Should the phrases be spoken in a flat voice or with a rising or falling inflection? Even spectral contour plots were used to determine the solution to such dilemmas as these.

The System Monitor also had its share of problems. A complex program was written to test the effect of all possible inputs to the System Monitor. Timing intervals were measured, changed, and measured again. Concurrent with this test, the Monitor program was being written and debugged. Through close cooperation among the two programmers and the engineers, the final checkout of the System Monitor hardware and software was done in parallel.

System Test

The complete traffic Rating System was assembled and tested at the Honeywell plant. The system was arranged in exactly the same way that it would be installed at Northwestern Bell. Twelve of the 24 trunks were installed to test the interface of the system, and to allow live multiple input and output. By setting up the complete system at the Honeywell plant, there was little chance of an oversight occurring at a place and time in the future which could be more difficult to handle by Honeywell engineers.

As quickly as possible, one of the two systems was made available to the Northwestern Bell programming staff, who used it to debug their programs. They had planned their program writing so as to parallel the engineering schedule—working from the "inside out" by first doing that portion of the inquiry program involving only the central processor, and ending with the complex control program which handles a variety of inputs and outputs to the central processor. Thus, through detailed program planning and some extra effort at a time when it could be spared, the final operating program was completely debugged on the entire system only a week after the system itself had been debugged.

Acceptance

A total of 12 Multi-Frequency Receivers were connected to the system. Each receiver was connected to a keyset, and the 12 keysets became 12 telephone operator positions. (Actually, each Multi-Frequency Receiver could simulate two trunks to the computer—so the complete environment could be simulated.)

After the system was turned over to the Northwestern Bell programming staff for their final debugging, an extensive series of tests commenced for checking both hardware and software. These consisted of 2 million rate computations that had already been calculated as part of a regular batch process run on a computer. This was followed by a series of inquiries which were put in simultaneously on the 12 keysets, with the results being checked against precalculated answers. When both tests were completed to the satisfaction of NWB management, the system was shipped and reassembled on site in Omaha, where the same tests were run through the system again.

SUMMARY

Despite the difficulties imposed by distance, time, and new equipment, the Northwestern Bell Traffic Rating System began operating on schedule on November 15, 1965. It has been in continuous operation since that time, 24 hours a day, 7 days a week.