Some Transmission Characteristics of Bell System Toll Connections

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A systemwide survey of the transmission performance of built-up toll connections was undertaken in 1966. The sampling plan underlying this survey is discussed briefly. The results are presented in terms of distributions of background noise levels, 1000 Hz loss, phase jitter, time to connect, and airline distance between end offices. The measurement results are broken down by mileage categories. Comparisons are made with the results from the 1962 connection survey. It is found that noise performance has improved since 1962 while loss performance is virtually unchanged.

I. INTRODUCTION

Many systems engineering studies require detailed knowledge about transmission performance and transmission capabilities of the Bell System plant. The need for such information exists both for specific parts or building blocks of the network and for built-up connections between subscribers. A system-wide survey of noise and loss on toll connections was undertaken in 1962.[1] The results of this survey found an important application in the setting of new over-all objectives for background noise.[2]

A similar survey was undertaken in the summer of 1966. It is our purpose to describe this connection survey and to give its results. Present transmission performance of built-up toll connections is given in terms of distributions of noise, loss, and phase jitter. Furthermore, the results include distributions of time to connect, and the distribution of airline distances between end offices of toll calls as presently established by customers.

Connection results discussed in this paper describe the toll plant contribution to the transmission performance on built-up toll connections. In considering complete toll connections from subscriber to subscriber, the influence of the loop plant must also be taken into account. Some of its characteristics have been described by Hinderliter.[3]

II. TARGET POPULATION

The target population is the population about which information is desired. It was defined as the set of all toll calls made in the Bell System during the busy period (9 a.m. to 5 p.m.) of an ordinary business day. A call was considered a toll call if it satisfied the following two conditions: (*i*) the customer received a bill which included a separate charge for the call, and (*ii*) the originating and terminating central offices did not home on the same toll office. The first criterion assures us that the population contains only completed messages rather than call attempts, while the second criterion means that with some minor exceptions the toll calls included in the population require at least one intertoll trunk for their completion.

The main difference between the population defined here and the population defined for the 1962 survey lies in the extension from the busy hour used in 1962 to the busy period. This extension provides for a more satisfactory reflection in the population of the traffic patterns generated by telephone subscribers. For example, cross-continental calls originating on the U. S. east coast were under-represented in the 1962 survey because of the different time zones on east and west coasts. Such under-representation does not exist in the 1966 survey.

III. SAMPLING PLAN AND SAMPLE SIZE

The sampling plan can be described as a two-stage plan with primary stratification and substratification and with the primary units selected with probabilities proportional to measures of size.[4, 5] The primary units were identified with Bell System end-office buildings. Two primary strata were defined, based on the size of the primary units. One of these strata contains those buildings in which at least 400,000 toll messages originate annually; the other contains the remaining smaller buildings.

The first-stage sample contains 40 end-office buildings. Twenty-five of these were selected from the stratum with large offices, and fifteen from the small offices stratum. The sample units in the two strata were selected independently from lists that contained the total of 9052 Bell System end-office buildings that were in service on January 1, 1964.

For each of the selected primary units, information was acquired about the outgoing toll traffic during the busy period of an ordinary business day. This information consisted of lists of terminating endpoints of toll calls originating in the sample office during the indicated time period. Every call in each of these lists was assigned to one of three substrata. The substratification was based on the airline distance between originating and terminating end offices. Toll calls shorter than about 180 miles were assigned to substratum one, while calls longer than about 725 miles were assigned to substratum three.

Independent selections of sample elements were made in each of the substrata for each sampled primary unit. The aim of the substratification was to achieve a sample size that would give acceptable precision in the estimation of transmission performance for toll calls in each of a number of mileage categories. The success of this endeavor is demonstrated by the confidence interval widths listed in the various tables of Section V.

An approximately equal number of toll calls was selected into the sample in each sample office. The resulting sample is not self-weighting. This means that different sample toll calls in general carry different weights in the estimation of population characteristics. The sample contains a total of 1463 calls. Of these, 476 have an airline distance between end offices up to 180 miles, while 554 are between 180 and 725 miles long, and 433 calls are longer than 725 miles.

IV. METHOD OF MEASUREMENT

The measurement procedure in the survey was similar to that used in 1962. Thus, the aim of the measurement phase was to duplicate the calls included in the sample and make transmission measurements in the receive direction on the established connections. In addition, the time required to establish the connection was noted.

All survey connections were established from an ordinary telephone set connected via a test set to a zero loop in the originating central office. The test set consisted of coils and switches and allowed the telephone set to be switched out of the connection and be conveniently replaced by a suitable measurement instrument. This test set and the transmission measuring equipment used in the survey are manufactured by the Western Electric Company for Bell System use only.

Two separate connections were established for each call included in the sample. One of them was made to the balanced (quiet) termination in the distant central office, and the other was made to the far-end milliwatt supply. The first one allowed the measurement of noise on the connection. The 3A noise measuring set[6] was used, and two readings were taken: one with C-message weighting and the other with 3 kHz flat weighting. As in the 1962 connection survey, no information about the physical routing of the call was acquired, and the measured noise levels did not include the subjective penalty due to the possible presence of compandored carrier facilities in the connection.

The second connection was established to record the 1000 Hz loss. The received level was measured with a transmission measuring set and recorded to the nearest tenth of one dB. The peak-to-peak phase jitter of the received signal was measured on the same connection with a voiceband phase jitter meter. The calls to the milliwatt supplies were also used to acquire information about time to connect. This time was measured as the time elapsed after the last digit had been dialed or after the conversation with the operator was finished until the test tone or a ringback signal was heard.

All of the terminating end offices for the sample calls were not equipped with balanced terminations or milliwatt supplies. In order to allow measurements to be made, such sample calls were replaced by calls that terminated in an end office geographically close to the desired one, and equipped with proper test lines. Replacements of this type were made on somewhat less than 10 per cent of the sample calls.

V. SURVEY RESULTS

The survey results presented here have all been evaluated by computer programs based on sample survey evaluation formulas contained in Ref. 4. The transmission results give noise, loss, and phase jitter as measured across a 900Ω termination on a zero length loop.

5.1 *3A Noise with C-Message Weighting*

A scatter diagram showing observed 3A noise levels with C-message weighting as a function of the airline distance between end offices is contained in Fig. 1. The previously observed[1] general trends of increasing mean and decreasing standard deviation as the call distance is increased is visible from this figure. These trends are ex-

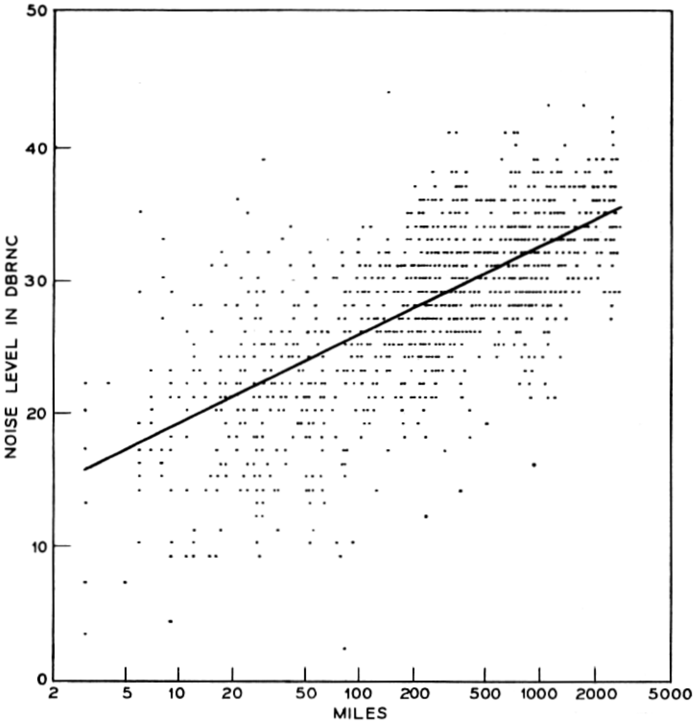

Fig. 1 — Scatter diagram of 3A noise level (C-message weighting) vs airline distance.

plained qualitatively by reference to the theory of power sums of random variables. The noise level on a toll connection can be regarded as the power sum of noise levels from a number of different noise sources, and with the number of noise sources increasing with call distance. Recent results by Marlow[7] and Nåsell[8] show that the mean of a power sum increases with the number of components, while the standard deviation of the power sum decreases as the number of components is increased, in line with the trends observed in Fig. 1.

The regression line in Fig. 1 gives an estimate of the mean noise level under the assumption that the mean noise level is linearly related to the logarithm of the airline distance between end offices. The equation for the regression line is

$$N = 12.6 + 2.0 \log_2 D \tag{1}$$

where D is the airline distance between end offices in miles, and N is the average 3A noise level. This equation shows that the average noise level increases by 2.0 dB for each doubling of the airline distance between end offices. The fact that the variance changes with distance has been accounted for in the regression analysis; weights were applied in inverse proportion to the variance about the regression line.

A summary of the results for 3A noise levels with C-message weighting is contained in Table I. As in most tables in this section, estimates are given of the mean and the standard deviation of the population distribution, and the mean is equipped with its 90 per cent confidence interval. Table I gives such results for each of eight mileage categories. These categories (except the first) are one double distance wide. The first four taken together correspond to the category referred to as "short" (0–180 miles) by D. A. Lewinski,[2] the next two cover the "medium" length and the last two contain the "long" calls (longer than 725 miles). The tendency for the mean to increase, and the standard deviation to decrease with distance is clearly demonstrated in this table.

The noise distributions discussed here are all very close to normal. No significant difference was found between mean noise levels on operator-handled calls and mean noise levels on direct-dialed calls.

A comparison between noise level distributions observed in the 1962 and the 1966 connection surveys is made in Table II. The table indicates improved noise performance of the toll plant in the intervening period; both means and standard deviations show generally lower values in 1966, and the difference between means in the long category is statistically significant. The results given for the 1962

Table I—Summary of Results for 3A Noise Levels with C-Message Weighting

Airline distance (miles)	Mean dBrnC	Std. dev. (dB)
0–23	19.8 ± 1.0	6.2
23–45	21.9 ± 1.7	6.5
45–90	22.4 ± 1.6	6.1
90–180	25.3 ± 1.4	5.3
180–360	28.9 ± 1.0	4.3
360–725	31.0 ± 0.8	3.6
725–1450	31.1 ± 1.3	4.2
1450–2900	34.6 ± 0.9	3.1

TABLE II — COMPARISON OF RESULTS FOR 3A NOISE WITH C-MESSAGE WEIGHTING FROM THE 1962 AND 1966 SURVEYS

Airline distance (miles)	1962 Survey		1966 Survey	
	Mean dBrnC	Std. dev. (dB)	Mean dBrnC	Std. dev. (dB)
0–180	23.4 ± 2.6	7.4	21.6 ± 0.8	6.4
180–725	31.0 ± 1.2	5.3	29.6 ± 0.7	4.2
725–2900	35.8 ± 1.5	4.0	32.5 ± 1.0	4.1

survey deviate slightly from those quoted by Lewinski.[2] The reason is that Lewinski's numbers are based on a sub-sample, while the results in Table II are not. The differences are well within the confidence intervals.

Table II also illustrates the improved precision achieved in the 1966 survey compared with the precision of the 1962 survey.

5.2 *3A Noise with 3 kHz Flat Weighting*

A scatter diagram of 3A noise levels with 3 kHz flat weighting as a function of the airline distance between end offices is shown in Fig. 2. It indicates much less of a distance dependence of the observed noise levels than that shown in Fig. 1. This is to be expected since flat weighted noise readings are predominantly caused by low-frequency noise components that fall below the lower cutoff frequency of most carrier facilities used in the toll plant.

A summary of the results for 3A noise with 3 kHz flat weighting is given in Table III. The table reinforces the impression that the distance dependence of both mean and standard deviation is very slight. It does, however, bring out the fact that both means and standard deviations of operator-handled calls are larger than those for direct-dialed calls. This fact is believed to be related to differences in local trunking arrangements. All of the distributions of flat weighted noise levels have a moderate amount of positive skewness.

5.3 *1000 Hz Loss*

The end-office to end-office loss at 1000 Hz is shown as a function of distance in the scatter diagram of Fig. 3. Just as was the case in the 1962 survey, we find the distance dependence of the loss to be only moderate. Table IV summarizes the results for each of the eight mileage categories discussed above. A small trend for both mean and standard deviation to increase with distance is seen to exist.

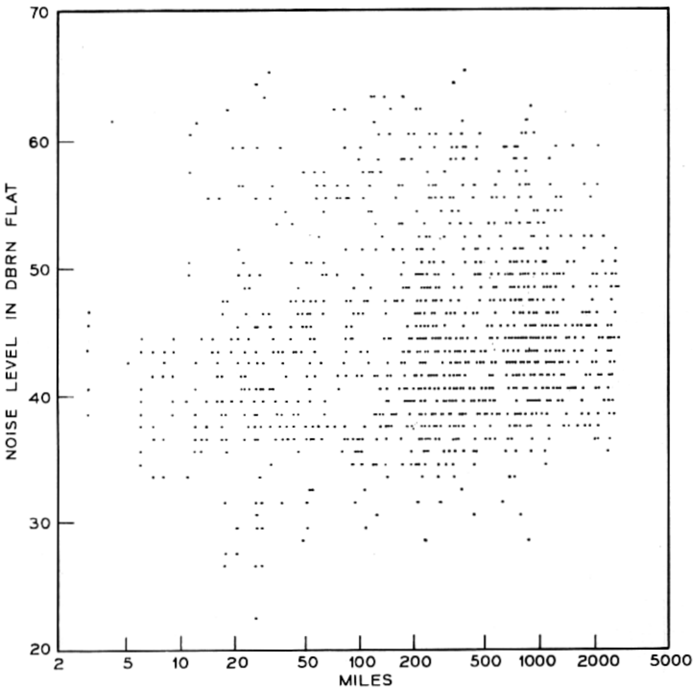

Fig. 2 — Scatter diagram of 3A noise level (3 kHz flat weighting) vs airline distance.

This is related to the higher probability of encountering more than one intertoll trunk in tandem for the longer connections. All the loss distributions deviate somewhat from normality through a moderate amount of positive skewness. Loss values exceeding 20 dB were found both on operator-handled and on direct-dialed calls.

Operator-handled calls will in general require one more trunk for

Table III — Summary of Results for 3A Noise with 3kHz Flat Weighting

Airline distance (miles)	Over-all		Operator		DDD	
	Mean dBrn (3kHz flat)	Std. dev. (dB)	Mean dBrn (3kHz flat)	Std. dev. (dB)	Mean dBrn (3kHz flat)	Std. dev. (dB)
0–180	43.9 ± 1.6	7.4	46.7 ± 3.1	9.1	42.5 ± 1.5	5.8
180–725	45.9 ± 2.4	7.6	47.8 ± 4.0	8.8	43.6 ± 1.4	5.2
725–2900	45.2 ± 1.5	6.0	46.5 ± 2.5	7.0	43.9 ± 1.1	4.2

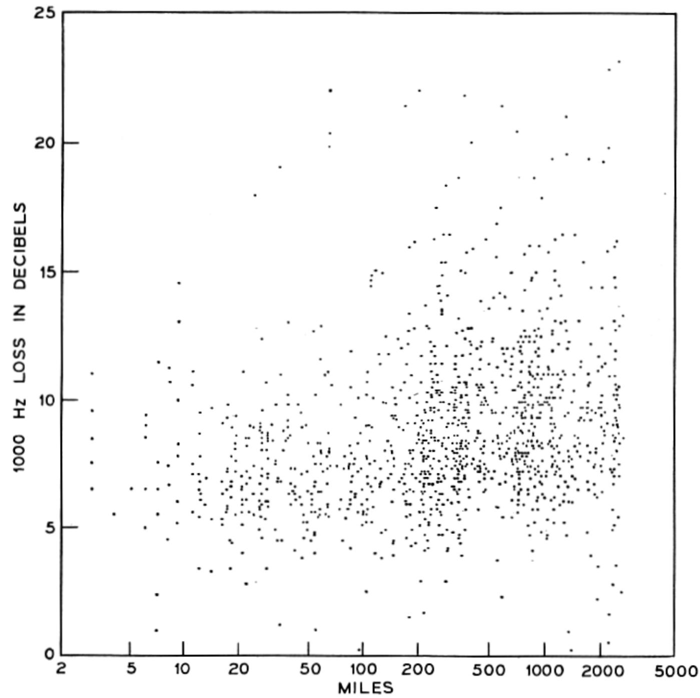

Fig. 3 — Scatter diagram of 1000 Hz loss vs airline distance.

TABLE IV—SUMMARY OF RESULTS FOR END-OFFICE TO END-OFFICE LOSS AT 1000 Hz

Airline distance (miles)	Mean (dB)	Std. dev. (dB)
0–23	6.8 ± 0.6	2.4
23–45	7.7 ± 0.5	2.6
45–90	7.1 ± 0.7	2.6
90–180	7.4 ± 0.6	2.8
180–360	8.7 ± 0.6	2.8
360–725	9.4 ± 1.0	2.9
725–1450	9.5 ± 0.4	2.9
1450–2900	9.7 ± 0.8	3.0

TABLE V — COMPARISON OF LOSS DISTRIBUTIONS FOR OPERATOR-HANDLED AND DIRECT-DIALED CALLS

Airline distance (miles)	Operator		DDD	
	Mean (dB)	Std. dev. (dB)	Mean (dB)	Std. dev. (dB)
0–180	7.5 ± 0.6	3.0	7.0 ± 0.4	2.3
180–725	9.3 ± 0.8	3.1	8.5 ± 0.6	2.5
725–2900	10.2 ± 0.6	2.7	8.9 ± 0.6	3.0

their completion than direct-dialed calls. The total loss on the connection is, therefore, expected to be somewhat higher on operator-handled than on direct-dialed calls. A comparison between the loss distribution parameters on the two types of calls is made in Table V. The table shows a lower mean loss on DDD calls in each of the three mileage categories, and in the third category the difference is significant. The mean loss difference is seen to range from 0.5 dB for short calls to 1.3 dB for long calls. No rationale is known for a distance dependence of this loss difference.

A comparison of means and standard deviations of loss distributions observed in the 1962 and 1966 surveys is made in Table VI. No large changes in the intervening time period are indicated.

5.4 *Phase Jitter*

The phase jitter measurements in the survey reveal the amount of phase modulation that an unmodulated sinusoidal carrier of 1000 Hz is subjected to on a toll connection. These measurements were included since certain types of data transmission are susceptible to phase modulation of transmitted signals. The measurements give the peak-to-peak phase jitter in degrees for jitter components between 10 Hz and 120 Hz on the signal transmitted by the far-end

TABLE VI — COMPARISON OF LOSS DISTRIBUTIONS FROM THE 1962 AND 1966 SURVEYS

	1962 Survey		1966 Survey	
Airline distance (miles)	Mean (dB)	Std. dev. (dB)	Mean (dB)	Std. dev. (dB)
0–180	7.3 ± 0.6	2.8	7.2 ± 0.4	2.6
180–725	8.9 ± 0.7	3.0	8.9 ± 0.7	2.9
725–2900	9.3 ± 1.4	3.8	9.6 ± 0.5	2.9

1000 Hz milliwatt supply. A scatter diagram of observed phase jitter versus connection distance is contained in Fig. 4. The connections for which a phase jitter of 21 degrees is indicated are connections where the phase jitter measurement was larger than or equal to 21 degrees. A trend for the average phase jitter to increase with mileage is indicated by the figure. The phase jitter distributions are definitely not normal with a high amount of positive skewness. Because of this, the summary data in Table VII give 10-, 50-, and 90-percent points of the phase jitter distributions rather than means and standard deviations.

Operator-handled calls that are of short and medium length show a significantly higher median phase jitter than direct-dialed calls of

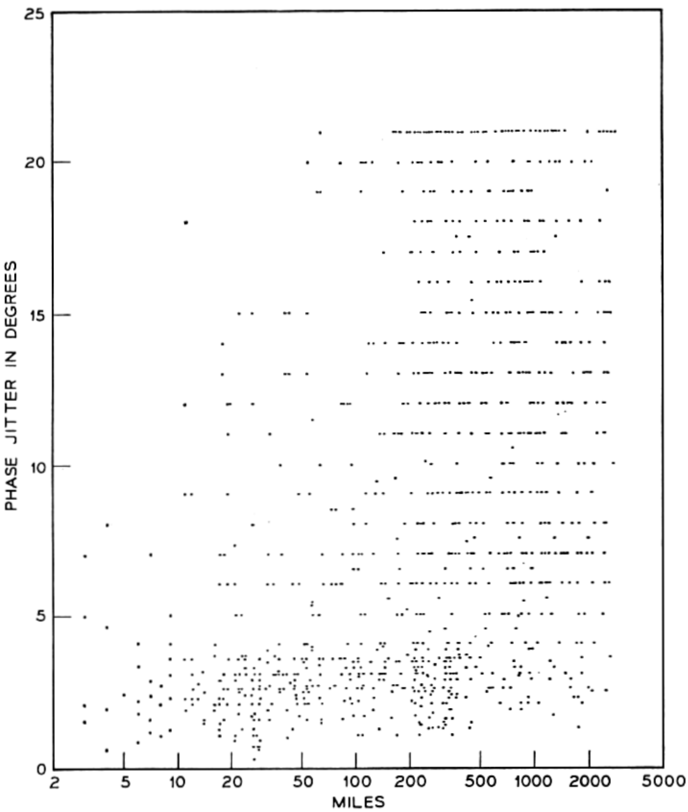

Fig. 4 — Scatter diagram of phase jitter vs airline distance.

TABLE VII—SUMMARY OF RESULTS FOR PEAK-TO-PEAK PHASE JITTER*

Airline distance (miles)	Phase jitter (degrees)		
	10%	50%	90%
0–23	1	3	7
23–45	1	3	7
45–90	2	4	15
90–180	2	7	14
180–360	2	7	20
360–725	2	11	21
725–1450	4	12	20
1450–2900	3	12	21

* The table gives the 10-, 50-, and 90-per-cent points (in degrees) of the phase jitter distributions in each mileage category.

corresponding length, while no apparent difference exists for long calls. A numerical comparison is made in Table VIII.

5.5 *Time to Connect*

The time to connect is shown versus distance in the scatter diagram of Fig. 5. A range up to 100 seconds is used to cover some operator-handled calls that suffered long delays. The scatter diagram shows a tendency for the average time to connect to increase with distance. This is a reflection of the higher average number of intertoll trunks in tandem for the longer connections, which in turn means that a larger number of switching offices is involved in establishing the longer connections.

A separation of operator-handled calls from direct-dialed calls is made in Table IX. It shows that the average time to connect is longer for operator-handled calls than for direct-dialed calls. It also

TABLE VIII—PEAK-TO-PEAK PHASE JITTER FOR OPERATOR-HANDLED AND DIRECT-DIALED CALLS*

Airline distance (miles)	Phase jitter (degrees)					
	Operator			DDD		
	10%	50%	90%	10%	50%	90%
0–180	2	4	11	1	2	9
180–725	3	11	21	2	6	18
725–2900	5	11	20	3	12	21

* The table gives the 10-, 50-, and 90-per-cent points (in degrees) of the phase jitter distributions in each mileage category.

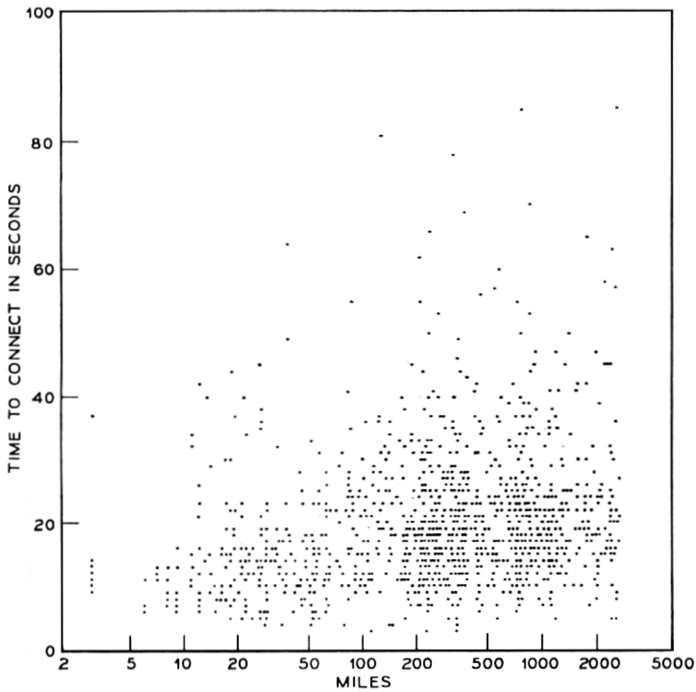

Fig. 5 — Scatter diagram of time to connect vs airline distance.

shows that the average time to connect is virtually independent of distance for operator-handled calls, while a definite trend exists for direct-dialed calls. Finally, we notice that the standard deviations are considerably higher for the operator-handled calls than for those that are direct-dialed. For these reasons, a detailed study of the time to connect for direct-dialed calls is of interest.

Table IX — Comparison of Distributions of Time to Connect for Operator-Handled and DDD Calls

Airline distance (miles)	Time (seconds)			
	Operator		DDD	
	Mean	Std. dev.	Mean	Std. dev.
0–180	24.7 ± 4.2	21.1	11.1 ± 0.9	4.6
180–725	27.0 ± 4.5	20.5	15.6 ± 1.0	5.0
725–2900	24.8 ± 2.4	11.1	17.6 ± 2.1	6.6

A scatter diagram of time to connect versus distance is given for DDD calls in Fig. 6. The regression line shown has the equation

$$T = 7.6 + 0.9 \log_2 D \tag{2}$$

where D is the airline distance between end offices in miles, and T is the average time to connect in seconds. The regression equation shows that the average time to connect increases by 0.9 seconds for each doubling of the airline distance between end-offices.

A summary of the parameters of time to connect distributions for DDD calls is given in Table X. The table indicates that the regression assumption of a linear relation between the mean time to connect and the logarithm of the airline distance may be an oversimplification; the mean time to connect is virtually constant in the first three and in the last two mileage categories; in between it increases by more than 0.9 seconds per double distance.

The distributions of time to connect over all calls have a high positive skewness as indicated by the scatter diagram in Fig. 5. On the other hand, only a small amount of skewness is present in the

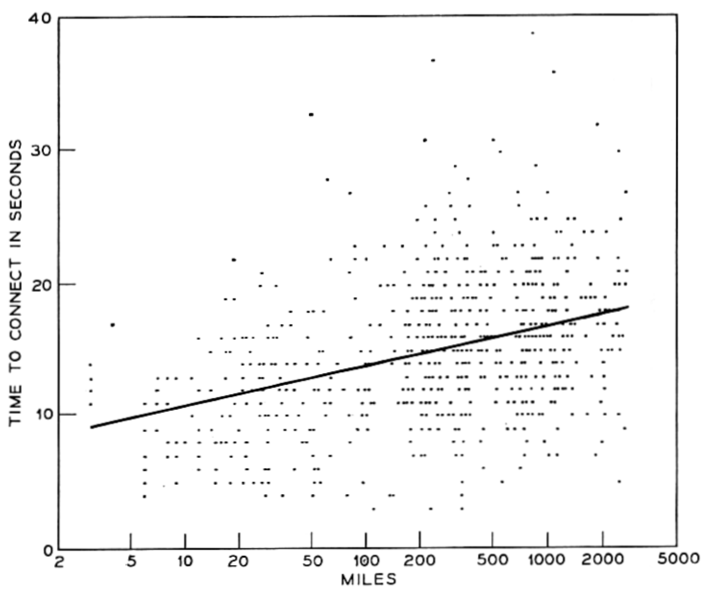

Fig. 6 — Scatter diagram of time to connect on direct-dialed calls vs airline distance.

TABLE X—SUMMARY OF RESULTS FOR TIME TO CONNECT ON DDD CALLS

Airline distance (miles)	Time (seconds)	
	Mean	Std. dev.
0–23	10.7 ± 1.2	4.6
23–45	11.6 ± 1.2	4.2
45–90	11.2 ± 1.8	4.8
90–180	12.3 ± 3.0	5.2
180–360	15.0 ± 1.0	4.6
360–725	16.8 ± 1.5	5.5
725–1450	17.8 ± 3.1	7.6
1450–2900	17.4 ± 1.1	4.4

distributions for DDD calls, as seen from the scatter diagram in Fig. 6.

5.6 *Distance Distribution*

The distribution of airline distances between end offices of toll calls is given in Fig. 7. The distribution is seen to deviate somewhat from a log-normal distribution, and it is virtually truncated at 2500 miles. Table XI gives estimated percentages of toll calls that fall in each of the eight mileage categories. A comparison with the results from the 1962 survey shows no important changes. The fact that only about four per cent of all toll calls are longer than 725 miles illustrates a problem for the design of the sampling plan. Unstratified sampling would tend to give a sample in which only about four per cent of the sample calls exceed 725 miles in length. In contrast to this, precision requirements dictate approximately equal sample size for short, medium, and long calls. The problem was solved, as mentioned before, by the use of substratification based on the airline distance between end offices of toll calls.

VI. CONCLUDING REMARKS

The 1966 connection survey represents an improvement over the 1962 survey in terms of precision. It also represents a small extension of the measurement program, to include measurements of such entities as phase jitter and time to connect. It does, however, suffer from certain limitations, which it shares with the 1962 survey. Most important is the fact that a number of important transmission parameters, such as frequency response, delay distortion, and impulse noise, were not measured. An additional limitation is that the milliwatt

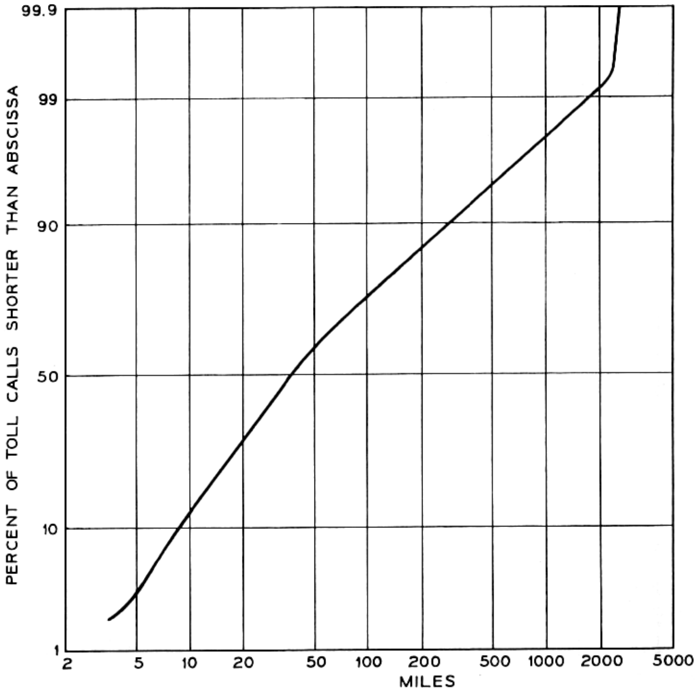

Fig. 7 — Distance distribution of toll calls.

TABLE XI — DISTANCE DISTRIBUTION OF TOLL CALLS

Airline distance (miles)	Percent of calls in distance class		
	1966 Survey		1962 Survey
0–23	33.7	83.7	85.0
23–45	20.0		
45–90	18.2		
90–180	11.8		
180–360	8.0	12.4	11.0
360–725	4.4		
725–1450	2.3	3.9	4.0
1450–2900	1.6		

signal source at the far end of each call could not be calibrated.

The use of specially-equipped test teams at both ends of the connections would alleviate both of these limitations. Studies are, therefore, under way to investigate the feasibility of using a 3-stage sampling plan in place of the 2-stage plan that was used in the 1966 survey. The main accomplishment of the 3-stage plan would be to limit the number of far-end end offices involved in the sample connections, thereby reducing the total traveling cost.

A toll connection appraisal program has recently been introduced in the Operating Companies of the Bell System. The procedures of this program are similar to those used in the connection survey described here. However, the main purpose of this appraisal program is to provide data to aid in the location of weak spots and also to aid in managerial decisions affecting the transmission performance of the present plant. In contrast to this, the data collected in the connection survey will find its main application in systems engineering studies conducted at Bell Laboratories and elsewhere in the Bell System.

It might be surprising that a sample of only 1463 calls originating in 40 end offices suffices to estimate the transmission performance of the 15 million toll calls that originate each day in one of more than 9000 end-office buildings. The results presented here show, however, that the achieved precision is indeed acceptable for a number of engineering applications. This fact demonstrates very concretely what can be achieved for data-acquisition purposes by a judicious application of the powerful methods of modern sample survey theory.

VII. ACKNOWLEDGEMENTS

The survey whose results are reported here was executed through the combined efforts of a large number of people. D. T. Osgood of the American Telephone and Telegraph Company served as coordinator between Bell Laboratories and the Operating Companies. Engineering coordinators and plant personnel in each Operating Company represented in the sample contributed to the planning and measuring. The actual measurements were carried out by more than 20 Bell Laboratories employees. Data handling was planned by F. P. Duffy and executed by Mrs. C. A. McFaul. Computer programs for data analysis were written by Miss M. L. Chubb and F. P. Duffy. The inclusion of measurements of time to connect were suggested by C. R. Ellison. I thank them all for their contributions.

REFERENCES

1. Nåsell, I., "The 1962 Survey of Noise and Loss on Toll Connections," B.S.T.J., *43,* No. 2 (March 1964), pp. 697–718.
2. Lewinski, D. A., "A New Objective for Message Circuit Noise," B.S.T.J., *43,* No. 2 (March 1964), pp. 719–740.
3. Hinderliter, R. G., "Transmission Characteristics of Bell System Subscriber Loop Plant," I.E.E.E. Trans. Commun. Elec., *82* (September 1963), pp. 464–470.
4. Hansen, M. H., Hurwitz, W. N., and Madow, W. G., *Sample Survey Methods Theory,* Vols. I and II, New York: John Wiley and Sons, 1953.
5. Cochran, W. G., *Sampling Techniques,* New York: John Wiley and Sons, 1963.
6. Cochran, W. T., and Lewinski, D. A., "A New Measuring Set for Message Circuit Noise," B.S.T.J., *39,* No. 4 (July 1960), pp. 911–931.
7. Marlow, N. A., "A Normal Limit Theorem for Power Sums of Independent Random Variables," B.S.T.J., *46,* No. 9 (November 1967), pp. 2081–2089.
8. Nåsell, I., "Some Properties of Power Sums of Truncated Normal Random Variables," B.S.T.J., *46,* No. 9 (November 1967), pp. 2091–2110.