Engineering Aspects of TASI

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The number of telephone circuits carried by a submarine cable system can be doubled by using the normal gaps in speech to interpolate additional conversations. TASI is a high-speed transmission and switching system that assigns a talker to a channel as soon as he starts to talk and disconnects him when he pauses, if someone else needs the channel. Switching from channel to channel may occur many times during a typical call, but the effect on transmission quality is negligible because the switching time is fast compared with the syllabic rate.

For many years telephone people have been intrigued with the idea of making use of the idle time during a telephone call. TASI, an abbreviation for Time Assignment Speech Interpolation, is a high-speed transmission and switching system based on the principle of using the free channel time to interpolate additional talkers. Although TASI requires considerable terminal equipment, it can approximately double the usefulness of long, expensive channels such as the deep sea submarine cable systems. The first speech interpolation system is expected to be placed in service during 1960 on the transatlantic telephone cable system between London and New York that was opened for service in September 1956.

The basic principles of TASI are old. An extensive investigation of the feasibility of speech interpolation systems was conducted in 1946 and 1947 by A. C. Dickieson, P. G. Edwards and others. An experimental model was demonstrated in 1950 by A. E. Melhose, and this was later extended and improved by R. L. Carbrey.

In a normal two-way conversation each talker ordinarily uses the circuit for only about half of the time. In addition, the circuit may not be used momentarily while the operator is trying to get the right people together, or while an individual comes to the phone or takes the normal pauses between sentences and even syllables. All of these gaps add up to a substantial amount of free time. Measurements on working circuits, shown in Fig. 1, indicate that the average activity (percentage of time
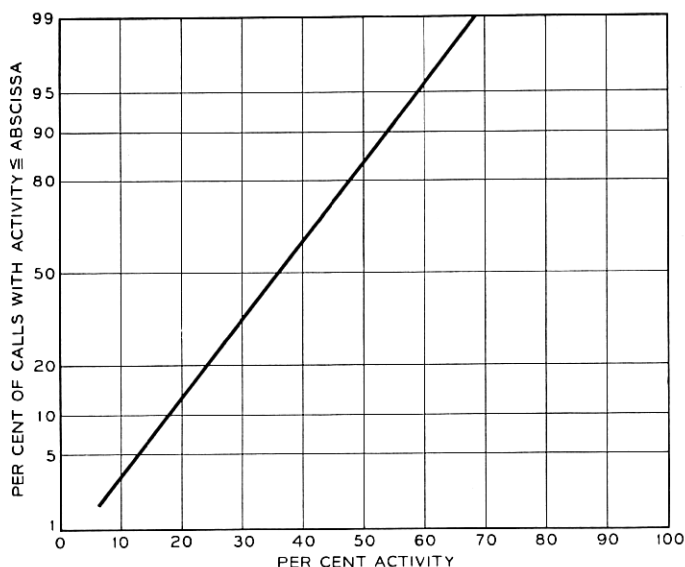
Fig. 1 —Measured activity distribution of transatlantic calls.

that energy above a very low threshold is transmitted in one direction) is no more than 35 to 40 per cent of the time that the circuit is busy at the switchboard. Since long distance circuits use separate pairs of wires or separate carrier channels for the two directions of transmission, it follows that, on the average, each one-way channel is free for 60 to 65 per cent of the time.

An attempt to interpolate two or more independent conversations on a single channel would create considerable delay and mutual interference since the probability of two talkers wanting the same channel at the same time is moderately high. However, when two or three dozen channels are operated as a group, these variations in individual activity tend to average out and the probabilities can be counted on to minimize the mutual interference to a point where there will be no noticeable effect on continuity of conversation. For example, even when all the channels are busy, at least one channel on the average is available for reassignment every L/c seconds, where L is the average talkspurt length (which is somewhat less than one second) and c is the number of channels in the group.

A simplified block diagram for a TASI system is shown in Fig. 2 for one direction of transmission. An identical but independent arrangement is used for the opposite direction. Each of the n lines from the toll switch-
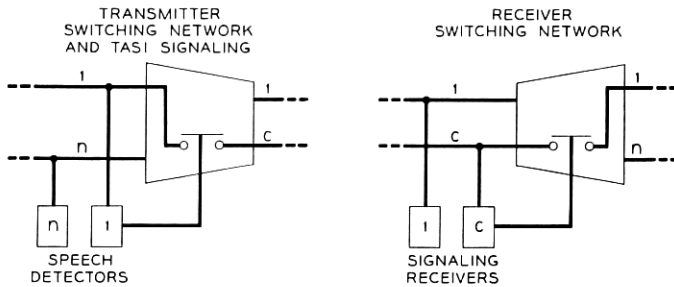
Fig. 2 — Simplified block diagram for a TASI system.

board is equipped with a speech detector which is capable of recognizing the weakest speech within 5 milliseconds or less. When the speech detector on line 1 operates, the TASI switching network connects line 1 to an idle channel, say channel c, and then sends a 10–15 millisecond coded signal on that channel which instructs the distant receiving terminal to connect that channel to listener line 1. Once a connection has been set up, it is maintained until someone else needs the channel, even though the person may stop talking in the meantime. A similar 10–15 millisecond coded signal is used for disconnect purposes but this is sent over a separate channel reserved for this purpose in order to avoid interference to the listener.

When speech appears on any of the n lines, the speech must be recognized by the speech detector, which causes some clipping during the first few milliseconds. This type of clipping can be minimized by increasing the sensitivity of the speech detector. The sensitivity cannot be too high, or it will operate too often on noise. This is undesirable because it increases the activity, and hence reduces the TASI advantage. A compromise is needed to achieve minimum activity but maintain satisfactory speech quality for even the weak talkers.

The potential impairment caused by the loss of speech energy that is below the sensitivity of the speech detector and by the time delay required to set up a connection can be made negligible by design. Another possible impairment is inherent in any line concentration arrangement, but this can be minimized to any desired degree by limiting the number of lines to be served. This factor is the possibility that the number of individuals who are talking or starting to talk at a particular instant will exceed the number of available channels. For example, telephone subscribers on a party line must share time with their neighbors on a single pair of wires leading to the central office. In addition, all trunk lines between two or more central offices may occasionally be busy and a call

coming in at that instant will experience some delay. In a similar manner, TASI may occasionally be overloaded by an unusually large number of simultaneous talkers. In this case, however, the information cannot be delayed and any failure to make an almost instantaneous connection results in a loss of speech transmission (called a freezeout) until a channel becomes available. It appears that the effect on transmission quality is negligible as long as the percentage of lost speech (freezeout fraction) is less than 0.5 per cent.

During periods of light traffic, the system's operation is essentially the same as without TASI, and hence there can be no TASI impairment. However, as the load increases, the amount of switching and possible impairment increases. The objective is to limit the number of busy lines to a point where the resulting impairment is not noticeable to the average listener and is not objectionable to the more critical listener.

The number of circuits that can be made available for service at the toll switchboard (for a freezeout fraction of 0.5 per cent) is greater than the number of physical channels by the TASI multiplying factor shown in Fig. 3. As the number of channels in the group increases, the number of potential conversations approaches a limit set by the reciprocal of the average activity. It will be noted that a 36-channel group, such as is available in present submarine cable systems, achieves a substantial TASI advantage, but that the application of TASI to only a dozen channels or less is much less attractive. For an average activity in the range of 35 to 40 per cent, it appears that the use of TASI on a 36-chan-
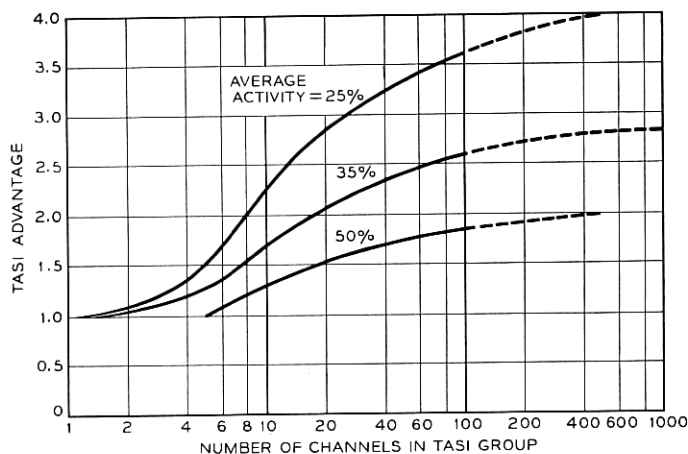

Fig. 3 — TASI multiplying factor for freezeout fraction of 0.5 per cent.

nel group can at least double the number of available circuits and still maintain good quality.

The average number of simultaneous talkers, np, is the product of the number of busy lines, n multiplied by the average activity, p. When the average number of simultaneous talkers is approximately equal to the number of channels, c, there is a 50 per cent chance that a new talker will be frozen out momentarily. This does not mean that 50 per cent of the speech is lost, but there is noticeable impairment. In order to allow for variations around the average and to achieve satisfactory quality, the average number of simultaneous talkers np should be limited to a value that will satisfy the approximate condition $np + \sqrt{np} \leqq c$. This approximate expression is based on a more exact derivation given in the Appendix. When this criterion is met, only a small percentage of the connections will experience any degree of freezeout, except for that required for the connect signaling code.

The expected freezeout fraction is shown in Fig. 4 as a function of the number of busy lines working on 36 physical channels for a talker activity of 30 to 40 per cent. Listening tests have shown that a freezeout
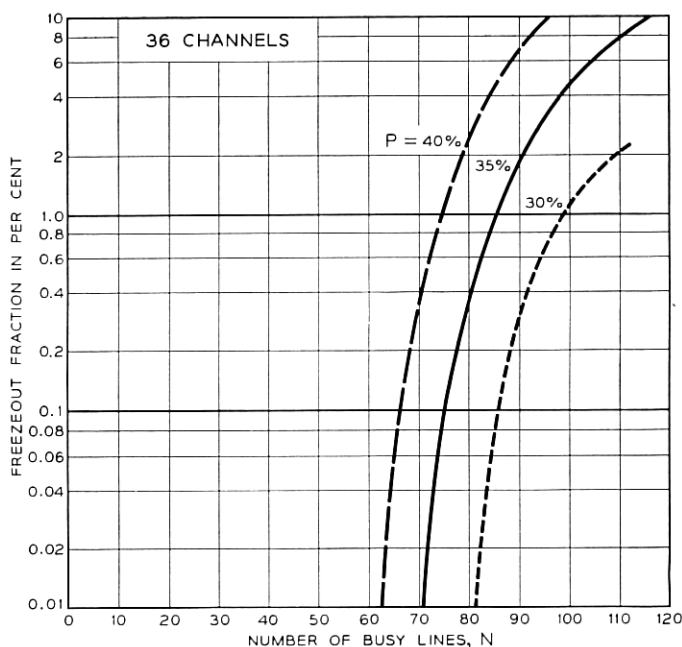

Fig. 4 — Expected TASI freezeout fraction as a function of the number of busy lines.

fraction of 0.1 per cent is barely perceptible by a critical listener. A value of 0.5 per cent is noticeable to the critical listener but not usually apparent to an average listener who is intent on understanding a message. A value of 2 per cent would be somewhat objectionable and a value of 5 to 10 per cent would be definitely objectionable.

The average length of freezeout is roughly proportional to L/c, where L is the average talkspurt length and c is the number of channels. The average talkspurt length for TASI purposes depends not only on the characteristics of speech, but also on the sensitivity, operate time and hangover of the speech detector. In addition, it depends on the number and duration of bursts of noise and echoes on the circuit. A typical measured value of effective talkspurt length is about 0.6 second. Measurements of speech alone (as given by Norwine and Murphy[1]) indicate a median talkspurt length of about 0.6 second and a mean length of 1.5–1.8 seconds.

The probability that a talkspurt will be clipped longer than any specified value is shown in Fig. 5 for a 36-channel system with an effective talkspurt length of 0.6 second. First of all, the chart shows that a 15-millisecond clip occurs for TASI signaling each time a new connection is needed. During the busy hour, this may occur on almost every talkspurt,
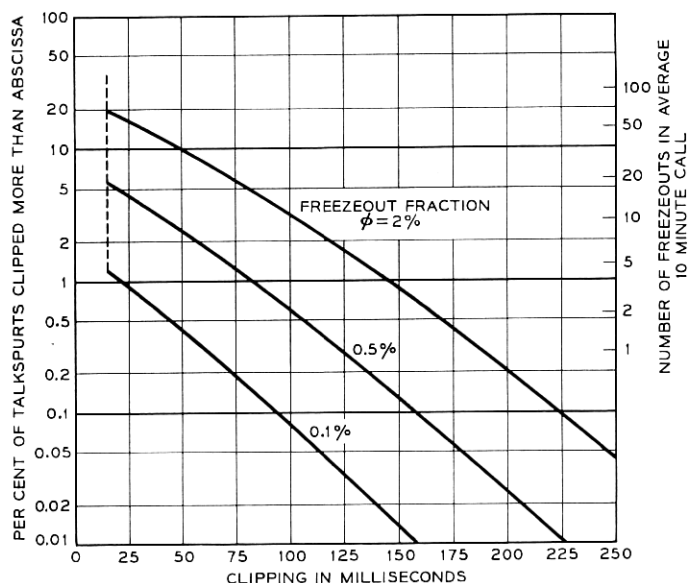

Fig. 5 — Clipping after operation of speech detector.

but the number of operations will be reduced considerably in nonbusy hours. The three lines sloping toward the right represent three different freezeout fractions. For example, the middle curve, labeled 0.5 per cent, indicates that 0.5 per cent of the talking time has been lost because a channel was not available. In this case, about 6 per cent of the talkspurts are frozen out for more than the 15-millisecond signaling time and 1 per cent of the talkspurts are frozen out for 80 milliseconds or longer. A freezeout longer than 80 milliseconds can be expected about four times during an average 10-minute call. For comparison purposes, it is worth noting that the average syllable length is about 125 to 250 milliseconds. On the average, less than one talkspurt in 10,000 will be frozen out for as long as $\frac{1}{4}$ second, and this will occur only once in about 30 calls during the busy hour.

As mentioned earlier, a talker holds a channel until his speech detector indicates that he is finished talking and until someone else needs his channel. This is true on all but three of the available channels. One channel is reserved full time for disconnect and other control purposes and two talking channels taken at random are disconnected when possible, in order that a channel will be instantly available for the next talker.

Switching from channel to channel during a conversation also causes some variations in circuit noise and net loss. It is expected that a little noise will be introduced in the receiving circuits in order to prevent a completely dead receiver during the silent intervals. The variations in net loss are not expected to be important as long as the plant is maintained to meet the present objectives.

TASI is designed to take advantage of the characteristics of two-way conversational speech. It requires a channel width of about 3,000 cycles in order to accommodate the tones needed for the rapid connect and disconnect signaling.

Telegraph or data systems that use frequency shift or frequency modulation will lock up the TASI speech detector 100 per cent of the time and hence be transmitted satisfactorily. On the other hand, the use of on-off telegraph or data systems will require either a means for locking the speech detector or a separate channel outside the TASI complement. The high activity of telegraph and data systems requires an essentially full-time channel, and hence reduces the number of conversations that TASI can yield.

TASI will be located in the four-wire part of the telephone plant, as shown in Fig. 6. It requires that split-type echo suppressors be used to insure that echoes cannot seize an outgoing circuit at either end. Com-
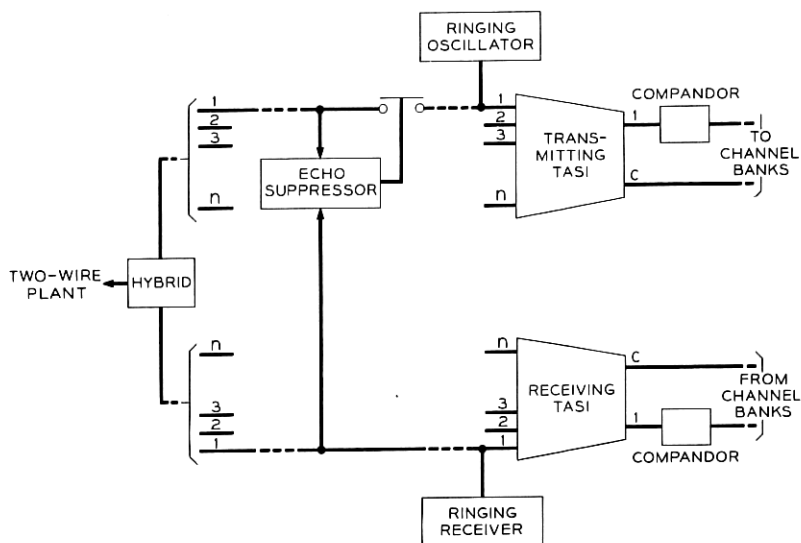
Fig. 6 — TASI location in the four-wire plant.

pandors, which are to be added to deep sea submarine cable systems on a channel-by-channel basis as required by noise conditions, are also compatible with TASI.

Provision will be made to switch out TASI for testing purposes. In order not to affect service, circuits will be removed as they become idle until the number of circuits available to the switchboard is no greater than the number of physical channels before TASI is removed.

Because TASI is a time-sharing device, there are problems involved in transmitting supervisory and dialing pulses. TASI can work satisfactorily with the present ringdown manual arrangement, but it is obvious that continuous supervision by means of a steady tone during the idle time cannot be used. Likewise, dial pulses cannot compete for a TASI channel on the same basis as a talker, because TASI clipping would cause signaling errors. Various schemes using spurt signaling are being investigated for use when dialing over TASI is required.

APPENDIX

The TASI principle has been recognized for many years, and several individuals, including R. I. Wilkinson, have contributed to the mathematic analysis of speech interpolation. The following summary is based on a more complete analysis given in an unpublished 1953 memorandum by H. Cravis.

Assume that there are n independent talkers, each of whom has an average activity p, competing with an individual test call (total number of talkers $= n + 1$). At any particular instant, the probability that the number of simultaneous talkers will equal or exceed c (where c is less than n) is given by the cumulative binomial distribution, $B_{(c,n,p)}$:

$$B_{(c,n,p)} = \sum_{x=c}^{n} \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x}. \tag{1}$$

The probability of a freezeout lasting longer than t seconds is given by $B_{(c,n,\theta)}$, where $\theta = pe^{-t/L}$ for an exponential talkspurt distribution [or $\theta = p(1 - t/L)$ for a constant talkspurt length].* In this expression, L is the average talkspurt length.

It can be shown that the average freezeout length (for an exponential talkspurt distribution) is

$$t_F = L \sum_{k=c}^{n} \frac{1}{k} \frac{B_{(k,n,p)}}{B_{(c,n,p)}} \tag{2}$$

$$= \frac{L}{c} M, \tag{3}$$

where

$$M = \left[1 + \frac{c}{c+1} \frac{B_{(c+1,n,p)}}{B_{(c,n,p)}} + \frac{c}{c+2} \frac{B_{(c+2,n,p)}}{B_{(c,n,p)}} + \cdots \right]. \tag{4}$$

This series converges rapidly, so only a few terms are needed for sufficiently accurate results.

The fraction of the speech that is frozen out is

$$\Phi = \frac{t_F B_{(c,n,p)}}{L} = \frac{M}{c} B_{(c,n,p)} = \sum_{k=c}^{n} \frac{1}{k} B_{(k,n,p)}. \tag{5}$$

Tables of the binomial distribution are available for accurate computations. However, in the range of interest to TASI, this function is almost identical with the cumulative normal probability law, that is,

$$B_{(c,n,p)} \approx \frac{1}{\sqrt{2\pi}} \int_{u=y}^{\infty} e^{-u^2/2} \, du, \tag{6}$$

where

$$y = \frac{c - np - \frac{1}{2}}{\sqrt{np(1-p)}}.$$

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* The assumption of an exponential distribution of talkspurt lengths is the best simple approximation to the experimental data. The use of a constant talkspurt length does not change the over-all result significantly.
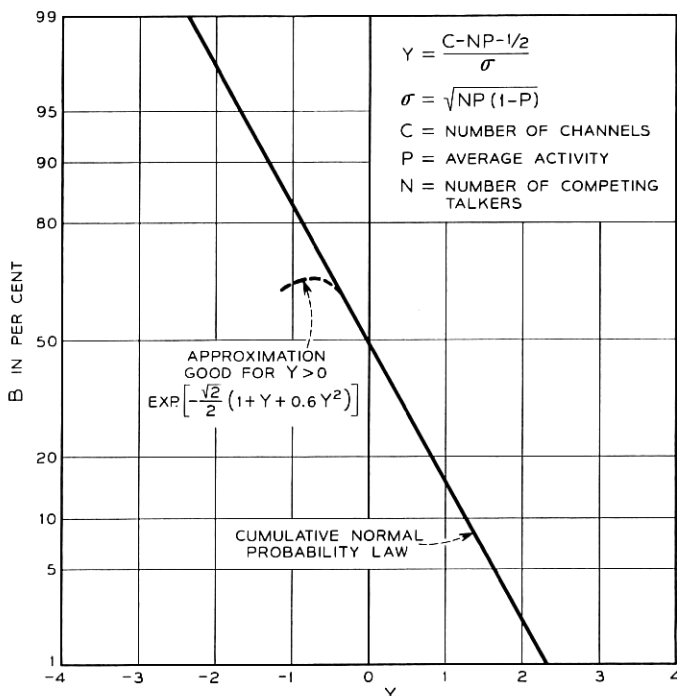
Fig. 7 — Probability of freezeout, $B_{(c,n,p)}$.

In this expression the mean value is $np + \frac{1}{2}$ and the standard deviation $\sigma = \sqrt{np(1 - p)}$.

The probability that a given talkspurt will be frozen out can be obtained from either (1) or (6) and is shown as a solid line on Fig. 7. For example, when $y = 1$, 16 per cent of the talkspurts will experience some degree of freezeout, because there are more talkers than channels. Most of these freezeouts will last only a few milliseconds, so the percentage of speech that is lost is less than 16 per cent by the ratio t_F/L.

By substituting $\theta = pe^{-t/L}$ for p in Fig. 7, it is possible to obtain the probability of a freezeout lasting longer than t/L. Typical values for a 36-channel system are shown in Fig. 5, for various values of the freezeout fraction Φ.

In all practical cases the probability of freezeout is less than 50 per cent and the cumulative binomial distribution and its approximation, the cumulative normal probability law, can be further approximated by the dashed line in Fig. 7; that is,

$$B_{(k,n,p)} \approx \exp\left[- \frac{\sqrt{2}}{2} (1 + y_k + 0.6y_k^2) \right] \qquad (7)$$

for $B < 0.5$, where

$$y_k = \frac{k - np - \frac{1}{2}}{\sigma} = y_c + \frac{k - c}{\sigma}.$$

This approximation, together with the omission in (4) of the factors $c/(c + 1)$, $c/(c + 2)$ etc. (which are less than but close to unity), leads to the following approximate expression for the factor M:

$$M \approx \sum_{k=c}^{\infty} \exp\left[-\frac{\sqrt{2}}{2} \frac{k - c}{\sigma} \left(1 + 1.2y_c + 0.6 \frac{k - c}{\sigma} \right) \right]. \tag{8}$$

The magnitude of M varies from about 1.5 to 3 or more, as shown in Fig. 8. This chart, together with (3), indicates that the average freezeout, when it occurs, is only about 1/10 to 1/20 of the average talkspurt length in a 36-channel system.

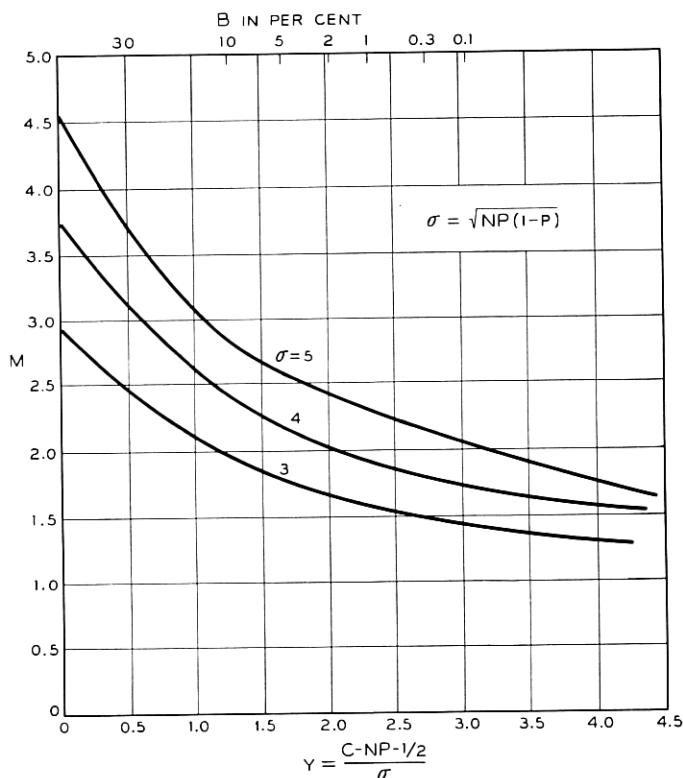By the use of (5) and Figs. 7 and 8, Fig. 4 can be constructed and sim-

Fig. 8 — Mean freezeout length.

ilar charts for other values of c can be obtained. A cross plot of such data for a constant value of Φ yields curves of TASI advantage like Fig. 3. The TASI advantage is $(n + 1)/c$, since there must be $n + 1$ potential talkers in order to have n competing talkers.

In order to achieve a value of Φ less than 1 per cent, it is necessary for $y > 1$; that is,

$$y = \frac{c - np - \frac{1}{2}}{\sqrt{np(1 - p)}} > 1,$$

or

$$c > np + \sqrt{np} - \sqrt{np}\,(1 - \sqrt{1 - p}) + \tfrac{1}{2}.$$

The last two terms are opposite in sign and each is small compared with the first two terms. This leads to the simple approximate relation that a practical TASI should be limited to the following condition:

$$np + \sqrt{np} < c.$$

REFERENCE

1. Norwine, A. C. and Murphy, O. J., Characteristic Time Intervals in Telephone Conversation, B.S.T.J., **17,** April 1938, p. 281.