Pacific objects to this interrogatory on the grounds that it is overbroad, vague and ambiguous, and unduly burdensome. Without waiving such objections, Pacific responds as follows.

Documents responsive to this interrogatory are contained in Exhibit 15. As these documents show, Northern Telecom, Inc. ("NTI") first notified Pacific in March, 1988 of a phenomenon NTI called "the synchronization effect" (also called "the harmonic effect") which NTI predicted could reduce the effective capacity of a DMS-200 switch by 5-7% from its stated central processor capacity. (The problem appeared to be generic to all DMS-200 switches, not the San Diego DMS-200.) Because Pacific's plans never called for the San Diego DMS-200 to operate at its full stated capacity, the "synchronization effect" should not have impaired Pacific's operation of the access tandem. In addition, NTI performed an on-site inspection of the San Diego DMS-200 on July 11, 1988 which concluded that the switch was not experiencing the "harmonic effect." Nonetheless, Pacific took preventative measures to ensure that the San Diego DMS-200 would continue to operate without impairment. These measures, directed at either reducing the number of calls to be handled by the switch or increasing the switch's operating capacity, included: turning off the EADAS-DC (Engineering and Administration Data Acquisition System-Data Collection) feature; activating the deferred AMA feature, which deferred the creation of AMA records until the least busy traffic periods each day; deloading 1,509 intraLATA trunks; rehoming "high volume call-in" and 811 traffic to the 4ESS access tandem; moving intraLATA cellular traffic to the 4ESS; having NTI install a "bleed patch," a software change designed to cure the "synchronization effect"; and installing a total of 1195 interLATA direct trunks (for US Sprint, TMC, and ExpressTel) during March, 1989. Documents showing interLATA direct trunks installed for other carriers are contained in Exhibits 2, 7, and 8.

INTERROGATORY 24

Identify the number of voice grade analog lines used for FGD direct trunking in LATA No. 732 from 1985 to the present; list the carriers that use or used such lines for direct trunking access service during this same time frame, including the dates of such use by carrier; indicate whether the use of such lines requires routing through the Tandem, and, if not, why not; provide the rates applicable to such lines; and provide all documents relating to any of the foregoing, and all persons and participants involved with the use of such lines and their sale to IXCs on behalf of PacBell.

Pacific objects to this interrogatory on the grounds that it is overbroad, vague and ambiguous, and unduly burdensome. At the status conference held on July 28, 1989, TMC agreed to repropound this interrogatory as follows: "Could FGD direct trunking have been provided to TMC using voice grade analog lines?" Without waiving its objections, Pacific responds as follows.

An accurate response to this interrogatory requires information in TMC's sole possession and control, e.g., the characteristics, capabilities, features, and functions of TMC's entrance facilities and switch. For TMC to be provided with voice grade analog lines, TMC's switch must either have analog port capacity sufficient to handle the number of voice grade analog lines ordered, or interface equipment (such as a channel bank) capable of converting an analog signal to digital. Pacific is informed, and on that basis believes, that TMC has a digital switch. Pacific is also informed, and on that basis believes, that the port capacity of TMC's switch is limited. Therefore, it appears that in the absence of an upgrade to TMC's switch as it existed in 1986 and 1987, this interrogatory would have to be answered in the negative.

Defendant notes that defendant, his legal counsel, and the staff of legal counsel for defendant are continuing the investigation and inquiry into the facts surrounding the accident which is the subject matter of this litigation and on this basis defendant reserves the right to present any further and additional facts as such become known to defendant in the process of this investigation and inquiry. The responses set forth herein, subject to inadvertent or undiscovered errors, are based on and necessarily limited by the records and information still in existence, presently recollected and thus far discovered in the course of preparing these responses.

Respectfully submitted,

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Date: September 8, 1989

CERTIFICATE OF SERVICE

I, Suzan B. Ard, hereby certify that a copy of the foregoing document was served to the parties listed below on September 8, 1989 by first class United States mail, postage prepaid.

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C

ATTACHMENT
PARA 30 (A)

THE EFFECTS OF CHANGING POST-DIALING DELAY ON CUSTOMER ABANDONMENTS AND PERCEPTIONS OF SERVICE

PART 1:

A SEMI-MARKOV MODEL AND A SURVEY OF EXISTING LITERATURE

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I. Introduction

This report represents Part I of an analysis being performed by Drs. Mercer, Edwards and Chang on the impact of increasing the post-dialing delay (PDD) experienced by customers of Pacific Bell services. Post-dialing delay refers to the period after a customer (or "caller") completes dialing and is waiting for an identifiable response by the network indicating the disposition of the call, such as ringing, busy tone, no circuit/reorder tone, or recorded announcement. The motivation for the study is that with the onset of new services in which call progress through the network is temporarily suspended while a data base is queried, customers of these services may experience an increase in PDD. The results of such a change in delay may be to increase the rate of customer abandonments and/or to cause customer annoyance over a perceived degradation in service quality.

Specifically, we are addressing three questions about the effect of an increase in PDD, as requested by Mr. R.B. Griffiths:

1) To what extent are customer abandonment rates, irritation, and/or perception of trouble during the post-dialing period likely to change if additional network delay is introduced?

2) Will any such changes be transitional or are they of long-term effect? That is, do customers acclimate their behavior to the conditions that exist in the network? If so, how quickly?

3) Would call-progress tones help to reduce customer abandonments during the post-dialing period?

In establishing the methodology for the project, we identified three sources of data that are useful in analyzing the above questions. The first is the regular service evaluation process conducted in Pacific Bell using the Service Evaluation System II (SES II), which can provide data on actual network response and customer abandonment time distributions. As outlined herein, such data are of use in addressing the part of question 1 dealing with changes in abandonment rates, and to a limited extent, question 2. The second data source is TELSAM, in which customers are interviewed about their perceptions of service quality. TELSAM data provide insights into the remainder of question 1. The third source is a Human Factors experiment. Such an experiment, if properly structured to obtain the desired information, can address both the customer perception part of question 1, and questions 2 and 3.

As agreed with Mr. Griffiths we are conducting the project in two major phases. In the first phase, we analyzed existing service evaluation data in conjunction with a mathematical/statistical model to predict the likely effect of an increase in PDD on customer abandonment rates. Also during phase I, we have conducted a literature search to acquire and analyze all existing information on the above questions. Phase II, planning for which is now underway, will consist of a Human Factors experiment to provide additional insights into the problem and its possible solutions.

This report contains the results of the phase 1 analysis. It also includes a definition of what is to be accomplished in the phase II Human Factors experiment, should Pacific Bell choose to proceed with that phase.

II. Analysis of the Effect of Post-dialing Delay on User Abandonment Rates.

A. Methodology

The major activity in phase 1 has been to use service evaluation data to determine the network response and customer abandonment patterns existing in Pacific Bell territory today; and based on those patterns, to model the likely effect of increased PDD on customer abandonment rates. Service evaluation data is collected routinely in Pacific Bell using SES II. SES II is a mechanized process by which call attempts are monitored from the time the customer goes off-hook until the attempt is either completed or abandoned [1]. The time sequence of several events during the attempt is recorded, including end of dialing, first network response, answer by called party, and customer abandonment on unsuccessful attempts. The dialed digits are also recorded, and the attempt is classified into Intra-LATA, Inter-LATA/Intra-State, and Inter-LATA/Inter-State. Dial prefixes (0 and 1) and Interexchange Carrier Access codes are recorded as well. Finally SES II has a sophisticated and accurate ability to recognize network tones and speech, and is thus able to record the call disposition as well. Pacific Bell and other companies use SES II data on a routine basis to monitor and try to correct situations where high rates of Equipment Blockage and Failure dispositions are occurring. With the wealth of data recorded by SES II, however, it is possible to study many more aspects of call attempts, notably disposition probabilities and the time distributions of various events that take place during a call attempt. As discussed subsequently, the basic data obtained for the PDD analysis were the relative probabilities of network response versus customer abandonment following dialing, and the distributions of response and abandonment times relative to end of dialing. These were obtained for the three classes of calls identified above and for the following additional classes: INWATS (800) calls, all seven-digit calls, and all ten-digit calls.

In Pacific Bell, SES II data is being collected in 500 end offices. With a bogey of 500 dial line observations per office per month, in excess of 250,000 observations per month are recorded. We obtained roughly a one-month sample of SES II data. This data was collected during the months of March and April, 1987. In total, over 280,000 observations were included in the sample.

The model which uses the call attempt data to predict the effects of changing the PDD is mathematically fairly complex [2]. It models a call attempt as a semi-Markov process in which an attempt, having reached a state such as completion of dialing, makes its next transition to a subsequent state, and after a holding time, which are determined by the rules of such a probabilistic process. The formal mathematical model will be presented in our next report, including a formal presentation of the convergence of the distributions. However, the fundamental model is presented in the Appendix.

Intuitively, the model, referred to as the "competing process" model, works as follows as it pertains to the PDD period. Following completion of dialing by a customer, one of two major events occurs in the call attempt after some time has elapsed: either the network responds with a progress signal -- ringing, busy, No Circuit/Reorder ("fast busy"), recorded announcement, etc. – or the customer abandons the attempt by hanging up prior to a response. There is thus, in effect, a "competition" between the network and the customer as to which event will occur first. Should the network always take an extended time to respond, for instance, almost all attempts will be abandoned by the customer first; on the other hand, should the customers be very patient, almost all attempts will result in a network response, except for those few cases where a "high and dry" condition has occurred in which the network will never respond. Under normal circumstances, a collection of call attempts exhibits a mixture of these two events, although a large majority of attempts (more than 95%) reaches one of the various network responses.

A customer's abandonment behavior is presumably shaped by his/her past experience with network response time. It thus has some degree of "memory" associated with it; that is, customers will not instantaneously change their abandonment behavior if the network response time distribution changes. The degree to which this is true is critical to the issue of how significant is a change in PDD. To the degree that customer abandonment and network response distributions overlap, and instantaneous changes in abandonment behavior don't take place, an increase in the network response time -- that is, a shift in the network response distribution to greater times -- will result in more customers abandoning their attempts. As discussed in the section on the results of the literature search, this tends to lower the efficiency of the network by generating more retrials, and to increase customer dissatisfaction.

Because of the competition between responses and abandonments, predicting the effect of a change in the network response time is not easy -- both the observed abandonment and response distributions and their associated probabilities will generally change as a result. To see this with an extreme example, suppose all network responses happen at five seconds, whereas customers will not abandon call attempts before eight seconds. Then no abandonments will be observed because the network always responds first. Suppose, however, that the network response time increases to 10 seconds. Then one would observe some calls being abandoned, by those customers whose abandonment time falls in the range of eight to ten seconds. In other words, the change in network response time changes the distributions and probabilities of both the observed response and abandonment events -- the latter from a null set of events to one having a potentially significant number of occurrences.

The model provides an algorithm and associated formulae for determining the changes in customer abandonment rates and distribution as the result of a change in network response time distribution. Qualitatively, the algorithm works as follows:

- determine the existing probabilities and time distributions of network responses and customer abandonments, under the condition that network responses and customer abandonments compete with each other (the SES II data is used to make this determination);

- from these "empirical" distributions, determine the "pure" response and abandonment distributions that would pertain separately if the other competing result was not possible. This is done according to formulas developed in the model;

- hypothesize a change in the network response distribution, based on the phenomenon being analyzed. In the case of this project, this requires some knowledge or estimate of what the data base access process will do to the network response time distribution;

- with this modified pure distribution, use the appropriate formulas contained in the reference to calculate new distributions and probabilities that would pertain when their was competition between the two processes;

- compare the resulting abandonment probability with the empirical abandonment probability observed in the data to see the effect of the modified network response distribution.

To summarize the use of the model, then, it is possible to predict if, and by how much, customer abandonment rates will increase due to a given change in the network response distribution. What is needed are the distributions and probabilities that currently hold, as determined from the SES II data, and an estimate of how the data base access process will affect the network response time distribution. Again, the caveat must be stated here that the predictions pertain to the time during which the customers' inherent abandonment behavior has not yet changed in response to the network change. Determination of how fast the customers' memories change is addressed subsequently.

B. Results of the Data Analysis

Data has been analyzed for the following three classes of calls:

1) Intra-LATA [LATA]

2) Inter-LATA [IEX]

3) INWATS (800) calls [800]

For ease of subsequent reference, each class of call is abbreviated according to the designation in the square brackets above. Initially two additional classes of calls were considered, namely 7-digit and 10-digit calls. These strongly overlap the LATA and IEX classes, respectively, but they are not identical because the LATA and NPA boundaries are not contiguous. We had thought to analyze them separately to be thorough since it was suspected that even now, customers tend to more differentiate between 7-digit versus 10-digit calls than between LATA versus IEX calls. In fact, however, we found the respective distributions to be so similar as to obviate the need for the separate analysis.

Table 1 presents basic call disposition probabilities for each class of calls. The last two lines restate the probabilities of the key dispositions relevant to the PDD analysis: customer abandonment prior to network response (pAB), and all network responses taken together (pRE). By definition, pAB + pRE = 1. As is typically observed in studies of call attempts, the completion probability for all classes of attempts is within a few percent of 70, although in this case the IEX calls are somewhat lower due to a higher abandonment rate. Most unsuccessful attempts have a disposition of either No Answer or Busy. All network failures (EB&F) together account for only 2-4 percent of the attempts. The EB&F rate is somewhat higher for IEX and 800 calls; very low for LATA calls. Customer abandonments typically occur on a small fraction of the attempts as well, more on IEX calls than on LATA, where the abandonment rate is very low.

INSERT TABLE 1 HERE

Figure 1 shows the (normalized) time distributions of customer abandonments and network responses for LATA calls; Figure 2 does the same for IEX calls, and Figure 3 for 800 calls. Table 2 summarizes the characteristics of all the distributions by showing the mean and standard deviations. Three key conclusions can be drawn from these characteristics. First, not surprisingly, the network response time distributions clearly shift to higher time values for IEX versus LATA calls, and to a lesser extent, for 800 versus IEX. Second, the 800 network distribution has a slighter higher mean. Third, the customer abandonment time distribution means show no particular pattern compared to the response time means. This suggests that customers are relatively insensitive to the response time distribution, hence that they will not respond to a change in the network. This reflects on the answer to question 2, suggesting that any increase in abandonment rates is likely to be more than a transitory effect, although it is not conclusive. Should this insensitivity be verified in the Human

Factors experiment to be discussed later, it indicates grounds for more concern by Pacific Bell than would be the case if customers showed a faster adaptability to network response time.

INSERT TABLE 2 and FIGURES 1, 2 and 3 HERE

Consider now the effect of changing the network response time distribution due to the onset of services requiring database access through a Service Switching Point. There exists virtually no data on the expected effect of such access on response time. Nor apparently does there exist a good model of the effect, at Bellcore or elsewhere. The best information we have been able to obtain suggests that the likely shift in the mean response time is 2-6 seconds.

We have used the "competing process" model described previously to predict the rate of customer abandonments as a function of the change in the network response time distribution, parameterizing the function in terms of the shift in the mean of the distribution. This has been done for the LATA, IEX, and 800 classes of calls, for a range of changes in the mean response time of 0-6 seconds. The results are summarized in Table 3.

INSERT TABLE 3 HERE

What is clear from this analysis is that depending on the change in mean response time, there may be a significant increase in the absolute percentage of calls abandoned; more significantly, the increase as a fraction of the original abandonment rate is as much as 300% (for the LATA calls). **This means that more than twice as many customers will abandon attempts than with the current network response distribution. This is a significant**

increase, whose impact on Pacific Bell depends on the degree of customer annoyance associated with such abandonments, on the increased network utilization that follows from increased abandonments, and on the potential lost revenue due to abandonments. These associations are considered in the following section dealing with the results of the literature search we have conducted and in the discussion of the proposed Human Factors experiment in Section IV.

III. Results of the Search of Relevant Literature.

From the outset of the project, it has been understood that while the analysis presented in Section II provides a great deal of insight into the potential PDD problem, it does not address all aspects of the problem. In particular, it does not deal with the issue of customer annoyance or trouble perception, with the rate at which customers adapt to changes in the network response distribution, or with the value of providing call progress tones to the network. Therefore, we have undertaken a search of human factors literature to see what insights we could provide in any of those areas. This section reports the result of that search.

We can deal with the subject of call progress tones rather quickly: there is virtually no data on the effect of such tones. While all people consulted who are familiar with human factors issues in telecommunications are in general agreement that call progress tones should decrease the probability of customer abandonments, none knew of any quantitative data on the subject. Only one paper we found dealt with the subject at all, and it was a dated paper by a researcher in the British Post Office who had found that "comfort tones" (CCITT terminology for call progress tones) were of help in reducing abandonments [3]. This thus becomes a prime subject for study in the Human Factors experiment. Pacific Bell should be aware that there are CCITT standards for the tone frequencies and power levels that should be used if new tones are added; these are also summarized in the LSSGR.

Regarding the issue of the rate of customer adaptation to changes in the network response time distribution, there is only slightly more insight, which comes mainly from the analysis in Section II. There it is concluded that customers are relatively insensitive to such changes even in the long-term view provided by the SES II "snapshot"; this implies that they certainly don't adapt to such changes quickly. One paper, again from Britain and of older vintage (1980), suggests that in fact customers get less tolerant as they make additional attempts, and actually reduce their waiting time before abandonment [4]. Again, then, this subject is a prime one for study in the Human Factors experiment.

Considerably more data exists on the subject of customer perceptions of delay and its effect on service quality. All of the sources agree that PDD has a significant effect on customer perceptions, although they differ as to the strength of the effect. Two papers are illustrative of the data. The first [5] presents a Grade of Service model for call set-up impairments analogous to the more familiar transmission grade of service models developed in the past by AT&T Bell Laboratories. Using this model, it shows that for a short-duration call (call completion grade of service is dependent on call duration), a five second increase in PDD will reduce the percent of customers who rate Grade of Service as good or better by 2-5%. To calibrate this number somewhat, an equivalent drop in transmission grade of service is shown in the paper to increase the number of operator trouble reports by 8 to 30 per 10,000 calls, or nearly double the existing trouble report rate.

The other paper [6] deals with the result of a special TELSAM study done in 1976. It reports a greater impact of PDD on customer opinion. Two examples suffice. First, of all interviewees who rated overall quality of service poor or fair, which are the two lowest categories of rating, 30 percent indicated "nothing happened after dialing" as the reason for that rating, more than any other factor including poor transmission. Second, of those interviewees who indicated they needed operator assistance at some time during the previous month, "nothing happened after dialing" was given as the reason more than twice as often as the next most common reason, which was "got busy", and three times more often than "bad transmission." The paper concludes that "...'nothing happened after dialing' is the most serious single aspect of service troubling customers in the entities sampled." While these results are somewhat outdated, recent TELSAM data from Pacific Bell indicates that "trouble getting through" rates with "poor transmission" as the predominant reason for being dissatisfied with overall service. It should be noted, however, that this category may include more than the "nothing happened after dialing" -- the normal TELSAM questionnaire used by Pacific Bell does not provide the same level of detailed discrimination that was used by AT&T Bell Laboratories during its special study. This issue is addressed further in Section IV.

One additional study is of particular interest here. An AT&T Bell Laboratories study [7] of customer retrials after unsuccessful attempts indicated that after an initial attempt resulting in no network response, only 66% of customers made another attempt, only 54% of the desired connections were ultimately established over the following 24 hour period observed in the study, and that on the average, each initially unsuccessful attempt generated one additional attempt prior to ultimate completion or abandonment. These results suggest that the lack of a network response generates additional traffic and results in lost revenue.

These and other data we discovered suggest strongly that PDD is a significant factor in determining customer-perceived service quality, increases the frequency with which customers seek operator assistance, increases the number of attempts per completed call, and may be a source of lost revenue due to abandoned calls. Combined with the results of Section II showing that moderate increases in PDD will apparently cause a significant increase in customer abandonments, **these data indicate that Pacific Bell has grounds for concern over the likely increase in PDD due to database access services.**

IV. A Proposed Human Factors Experiment

With Phase 1 of the project now complete, one of the three major sources of data identified in the introduction remains to be tapped; that is, a properly-designed Human Factors experiment. Such an experiment could fill in the gaps remaining after all the foregoing analysis, as well as updating and augmenting the insights gained to date. Specifically, the experiment should address the following questions:

1) How accurately do customers perceive PDD, and how important is it in determining customers' opinion of service quality? This would update the literature reviewed during phase 1.

2) How quickly, and to what extent, do customers adapt to changes in PDD, both in terms of their abandonment behavior and their perception of service quality?

3) What impact would the addition of call progress signals have on abandonment behavior and perception of service quality? What form should such signals take -- volume, tone sequences, repetition rate, etc?

As the first step of Phase II of the project, we will define this experiment in more detail, and then either conduct it or manage its execution by another organization. This definition is to be completed in early May. Tentatively, we believe these questions are amenable to a "classical" human factors experiment in telecommunications, in which test subjects are asked to perform a task requiring the use of a telephone, while simulated network conditions they experience are varied. During the performance of the task, the subjects' behavior is observed; upon completion of the task, they are asked to rate the service quality they have experienced. Question 2 is apparently the most difficult to address in this fashion as it requires an analysis of time variation; however, we envision a period of subject "conditioning" followed by a change in the simulated network performance.

We also believe, subject to further analysis of other alternatives, that Bellcore has the best combination of experience and facilities to conduct the experiment in a timely fashion. Should that turn out to be the case, we propose that we monitor the design and execution of the experiment to insure Pacific Bell's needs are adequately accommodated, and then interpret the results in light of the network performance and customer behavior characteristics that pertain to Pacific Bell. Should Bellcore prove untimely in meeting Pacific Bell's needs, then we are prepared to do the Human Factors experiment internally.

Associated with the Human Factors experiment, we recommend that Pacific Bell consider modifying its normal TELSAM questionnaire along the lines done in the AT&T Bell Laboratories study in the 1970s. This would permit a more detailed and up-to-date examination of how customers perceive and respond to PDD, which would help to validate the Human Factors experiment.

V. Conclusion

To summarize, we have conducted two activities in this phase of the project. First, we have analyzed call attempt data from the SES II running in Pacific Bell to determine how an increase in PDD may affect the rate of customer abandonments while waiting for a network response. **We have found that for the three key classes of calls – Intra-LATA, Inter-LATA, and INWATS –**

the number of abandonments may increase significantly for PDD changes in the range estimated to result from database access services. Second, we have conducted a thorough search of relevant literature to gain additional insight into the possible transitory nature of these effects, customer annoyance and/or perception of trouble associated with PDD, and the possible value of providing call progress tones during the PDD period. We have found the literature to be sketchy at best, particularly in the area of call progress tones. The best data exists on the subject of customer annoyance, and suggests that PDD is a major factor in determining customer perception of service quality. **Therefore, to the degree to which the data exists, we believe Pacific Bell should be concerned with the potential increases in PDD.**

Several subjects have not been adequately addressed by either the call attempt analysis or the existing literature. Key among these is the value of adding call progress tones, and the proper format for those tones. As envisioned when the project started, we recommend that Pacific Bell undertake a Human Factors experiment to gain the necessary additional insights. There are several options for doing so; key are for Pacific Bell to do the study itself or for Bellcore to do it. We tentatively believe that Bellcore has the experience and expertise to do the study best, and we understand that plans are already underway there to study the PDD issue. **Therefore we would encourage Pacific Bell to pursue with our assistance the Bellcore analysis, insuring that its interests are covered by the planned study. In parallel with the human factors experiment, we recommend that Pacific Bell consider the use of a modified TELSAM questionnaire which focusses specifically on the reaction of those interviewed to PDD.**

Acknowledgements

The authors are greatly indebted to various Pacific Bell employees for their support during this phase of the study: Ms. Clarice Davis, Ms. Dana Martin, Mr. Steve Simon, Mr. Danh Lai, Mr. W.S. Burgers and Mr. R.M. Douglas. Your help, suggestions, and patience are greatly appreciated. Thank you!

Footnotes and References

1. This description pertains to the Dial Line Service Evaluation (DLSE) component of SES II. SES II also collects Incoming Trunk Service Evaluation data, in which call attempts are picked up at the point they are incoming to a terminating tandem switch, and followed from there to their final disposition.

2. See R. A. Mercer, "Connection Availability Study: A Theoretical Model of Call Attempts", Bell Laboratories Technical Memorandum TM-74-3433-16, October 10, 1974.

3. S. P. Szlichcinski, "The Effect of Post-Sending Delays on the Behavior and Attitude of Telephone Users", Post Office Research Centre, Post Office Telecommunications Research Department Report #710, 1978.

4. R. B. Archbold, "Methods of Determining Telephone Users' Difficulties Arising from Pre- and Post-Dialing Delays and Understanding of Tones", U. K. Post Office Research Department, appearing in the Ninth International Symposium on Human Factors in Telecommunications Proceedings, 1980, Red Bank, New Jersey.

5. B. W. Kort, "Models and Methods for Evaluating Customer Acceptance of Telephone Connections", Proceedings of the IEEE GLOBECOM Conference, San Diego, California, December 1983.

6. D. J. Mehan, "TELSAM - Switching Entity Performance Study; Report 1 - Questionnaire and First Pass Analysis of TELSAM Data", Bell Laboratories Technical Memorandum TM-76-3431-1.

7. K. S. Liu, "Direct Distance Dialing: Call Completion and Customer Retrial Behavior", BSTJ 59 (1980), p. 295.

The Competing Process Model

Customer abandonments tend to reduce the probability of completion by terminating attempts that might have been successful. On the other hand, they also tend to reduce the network setup load by terminating attempts that otherwise might have taken a long time to complete, if at all. A consideration of alternative ways to improve the completion ratio by changing some aspects of network or customer behavior requires an understanding of the effect of change on the completion probability and the average attempt time. The primary purpose of the Call Attempt model is to provide this type of predictive capability.

The model introduces a set of independent random variables $\{X_{ij}\}$ with distribution functions $\{G_{ij}(t) = p(X_{ij} \le t)\}$. Intuitively X_{ij} represents the holding time in state i if the only exit from state i is to state j, and therefore identified with a particular transition in the state diagram.

Because the random variables $\{X_{ij}\}$ are independent, a hypothesized change in the characteristics of a particular transition can be formulated as a modification in a single member of the set $\{G_{ij}(\bullet)\}$. Using the relationships between the sets $\{Q_{ij}(\bullet)\}$ and $\{G_{ij}(\bullet)\}$ that are developed below, it is then possible to predict the effect of the change on the transition probabilities and conditional holding time distributions.

The Competing Process Model is formally defined as follows: if state i is entered then the next state is determined by comparing the values of N independent random variables $\{X_{ij}, j = 1, 2, ..., N\}$ whose distribution functions are $\{G_{ij}(t), j = 1, 2, ..., N\}$ (if a branch from i to r is impossible $G_{ir} = 0$ for finite t). If X_{ik} is the smallest of these and has the value Z_i ($Z_i = \min_{1 \le j \le N} X_{ij}$), then the next transition will be to state k after a holding time Z_i in state i. It is this "competition" between the possible transitions from a state that leads to the term "competing process". The competing process formulation can be made equivalent to the formulation in terms of the functions $\{Q_{ij}(\bullet)\}$ by choosing the functions $\{G_{ij}(\bullet)\}$ such that

$$Q_{ij}(t) = \int_0^t dG_{ij}(x) \prod_{k=1, k \ne j}^{N} \left[1 - G_{ik}(x) \right], \qquad i, j = 1, 2, ..., N.$$

Also derived is the inverse relationship:

$$G_{ij}(t) = 1 - \exp\left[-\int_0^t \frac{dQ_{ij}(x)}{1 - U_i(x)} \right], \qquad i, j = 1, 2, \cdots N,$$

where $U_i(\bullet)$ is the unconditional holding time distribution in state i:

$$U_i(t) = P\left\{ X_m \le t \mid J_{m-1} = i \right\} = \sum_{k=1}^{N} Q_{ik}(t)$$