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RECENT OBSERVATIONS OF SUBCRIBER BEHAVIOUR

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ABSTRACT

This paper presents an analysis of experimental observations of subscriber repeat attempts and subscriber patience in relation to the post-dialling delay. The analysis includes, in particular, an investigation of the influence of the interval between successive attempts and we derive estimates of the probability distributions of the subscribers' patience. The results concern local, trunk and international calls made by certain subscribers on a Paris exchange.

1 INTRODUCTION

A sound knowledge of subscriber behaviour is fundamental to the correct interpretation of the detailed traffic and quality of service measurements provided by modern telephone systems. It is also important to take account of the interactions between users and system when determining optimal network structures and dimensions. This paper is concerned with the observation of the subscribers' repeat attempt behaviour and of the reactions of the caller to long post-dialling delays.

In France, the first systematic observations of subscriber repeat attempts were undertaken in 1966, [1,2]. Further measurements, on a larger scale, were subsequently made using the purpose built equipment known as Octopus,[3,4]. These observation campaigns did not differentiate between causes of failure and it was therefore not possible to determine subscribers' reactions to given network or called party conditions. To enable this, more detailed characterization of subscriber behaviour, a new equipment called Octopus II incorporating tone detection circuits was built, [5]. The detection of tones has also made possible the large scale measurement of post-dialling delays and the observation of subscriber patience during the call setting up process.

After briefly describing certain features of the observation campaign, this paper presents the results obtained concerning these two aspects of subscriber behaviour for both national and international calls.

2 DESCRIPTION OF THE OBSERVATION CAMPAIGN

An investigation of subscriber behaviour requires a particularly large scale and difficult observation campaign comprising a lengthy period of measurements using sophisticated equipment followed by an off-line computer analysis of the recorded data. We outline the general characteristics of the present campaign before briefly discussing two special problems concerning the recognition of failure causes and the identification of repeat attempts.

2.1 GENERAL CHARACTERISTICS

The observation equipment Octopus II has been described in detail in [5]. We note here simply that the equipment is capable of recording, for each of 192 subscriber lines, the following details of all outgoing calls :

- the epochs of the start and end of the call and the start of conversation for effective calls ;
- the number dialled ;
- certain details of the tones on the line after the end of dialling ;
- the duration of certain phases, including the time from the end of dialling to the start of the busy tone or ring tone (the "post-dialling delay").

In the present campaign, 164 lines belonging to eight PBX subscribers on the Tuileries exchange (in the centre of Paris) were observed during a total of some 130 working days, between April 1977 and July 1978. The subscribers were specially chosen for their high levels of varied traffic (local, long distance, international).

The validity of the statistics derived from the analysis of the recorded data is assured by the length of the observation period and the large number of call attempts recorded (some 260 000 local, 65 000 long distance and 47 000 international calls). A comparison of the results corresponding to independent periods has confirmed the stability of the reported values.

2.2 IDENTIFICATION OF FAILURE CAUSES

The identification of effective attempts is assured by the detection of the answer signal (battery inversion). The identification of the cause of failure of ineffective attempts depends on the recognition of the tone (if any) present on the line at hang-up time. The method of tone recognition used with Octopus II is described in [5]. In real time, Octopus recognizes the start of a tone on detecting the continuous presence of a frequency in the range 380-520 Hz and then records certain details characterising the rythm of the periods of presence and absence of this frequency. During the setting up of trunk calls in France, the caller is relayed a "transfer tone" (rapid pips at 425 Hz) which is meant to reassure him that his call is being processed even in the event of long delays. In the present observation this tone is distinguished from the subsequent tone (i.e. busy tone or ring tone) or recorded announcement. An off-line analysis determines the failure cause as one of "busy" (network or called line), "no reply" or "abandon before tone" or classes the cause as "non-identified".

The principal reasons for non-identification are :

- recorded announcements ;
- tone frequencies outside the detected range or special tones (international calls) ;
- noise on the line, possibly introduced by the caller's microphone ;
- non respect of standard frequencies and rythms for busy tone and ring tone.

To ensure the validity of those statistics which depend on given causes of failure (probability of perseverance after busy tone, etc...), a rigourous selection policy has been employed in which the slightest doubt leads to the classification as non-identified.

Among call failures, the proportions of non-identified causes are : 12 % for local calls ; 22 % for trunk calls ; and 31 % for international calls. These figures reflect the more widespread use of recorded announcements in the trunk and international networks but the relatively high proportion for international calls, in particular, is also to be explained by the difficulty of recognizing tones in the presence of background noise.

The long call setting up time of international calls results in long post-dialling delays. Clearly, the longer this delay, the more probable is the occurrence of a spurious noise which will declench the tone detection procedure and lead to the recording of false rythm characteristics. In these circumstances it is particularly difficult to distinguish those calls abandoned with no tone.

2.3 THE IDENTIFICATION OF REPEAT ATTEMPTS

The method of processing the primary data provided by Octopus to identify the successive attempts of a given "call intent" is basically the same as that described in [3]. In other words, a call intent is determined by the identity of the caller and the number of the called party. Any attempt made by the same subscriber to the same number as that of a previous ineffective attempt is considered as a repeat attempt. The reappearance of the same number after an effective attempt corresponds to a new call intent. It seems necessary to note that this definition can lead to certain interpretation difficulties.

If, for instance, a called subscriber has more than one number, which is frequently the case for business subscribers in Paris, then all the attempts of a given call intent (which may therefore be made to different numbers) may not be correctly identified. Nor is it possible to differentiate between two call intents from the same PBX to the same called number when their sequences of successive attempts overlap. This coincidence of call intents is likely to occur when an observed PBX subscriber has a close relationship with another PBX subscriber (e.g. a head office in Paris and a subsidiary in the provinces). It is quite possible that two employees call the same number for quite independent reasons.

While these difficulties are unavoidable, it is felt that, since only a small proportion of calls is involved, they do not detract from the value of the present investigation which aims to show up the major characteristics of subscriber behaviour and consequent network reactions. They should perhaps be borne in mind when interpreting the finer points of the presented results.

3 SUBSCRIBER REPEAT ATTEMPT BEHAVIOUR

We first present a quite detailed description of subscriber behaviour and network reactions for calls to destinations within France before considering the important case of repeat attempts in the international network.

3.1 NATIONAL CALLS

National calls made by subscribers of the Tuileries exchange (in the centre of Paris) can be classified according to the location of the called subscriber's exchange :

- local calls to Paris and adjacent suburbs : seven digit numbers ; unique charge per call.
- regional calls to the outlying exchanges of the Paris numbering region : seven digit numbers ; calls charged according to duration ; calls routed via regional transit switching centres.
- trunk calls to the provinces : eight digit national numbers preceded by the trunk code "15" or "16" ("16" only since April 1978) ; calls charged according to duration ; trunk network accessed via one of two Paris transit centres.

During the setting up of trunk calls and of certain regional calls, the calling subscriber is relayed a "transfer tone". For other calls, the subscriber remains in silence until he hears the ringing tone or the busy tone.

To avoid unnecessary complication and above all to reduce the amount of data to be presented, only the categories of "local" and "trunk" calls will be considered in the following analysis. As in the previous studies [1-4], incompletely dialled numbers and calls to inexistant exchanges have been eliminated from the data prior to the identification and regrouping of call intents. The data analysed relates to working days (Mon-Fri) only, and to calls made between 8.30 and 18.30. To reduce the effects of truncation (i. e., possible repeat attempts after 18.30), unsuccessful call intents for which the last recorded attempt occurred after 17.30 have not been included in the analysis.

3.1.1. FAILURE RATES AND PERSEVERANCE FUNCTIONS

A concise representation of the repeat attempt phenomenon, adopted in the analyses of previous observation campaigns [1-4], consists in the expression of failure rates as a function of attempt rank and the definition of a perseverance function, $H(x)$, giving the proportion of the calls failing at the xth attempt which continue to perservere and make an $(x + 1)$ th attempt.

In the present study, the identification of the result of call attempts beyond the simple division success/failure has enabled the deduction of perseverance functions relative to given causes of failure.

Tables 1 and 2 show the results obtained for local and trunk calls, respectively. The apportionment of the results of call attempts has been made according to the following categories :

- EF - effective attempt, i.e. giving rise to the answer signal.
- BY - busy tone, i.e. busy subscriber or network congestion.
- NR - ringing tone - no reply.
- AB - abandon, i.e. caller hangs up before the end of processing after waiting for at least 5 seconds after dialling (in silence for local calls and in presence of the transfer tone for trunk calls).
- OF - other failures (recorded announcement, subscriber mishandling, tone not identified, ...).

For the class AB, the 5 seconds criterion is meant to avoid the inclusion of those calls abandoned because of subscriber mishandling so that this heading then concerns only those calls abandoned because the caller judges the setting up time to be abnormally long. This aspect of subscriber behaviour is the subject of a subsequent section of this paper.

At	Calls	Result (%)					Perseverance (%)				
		EF	BY	NR	AB	OF	BY	NR	AB	OF	All
1	204 555	77	9	9	2	4	81	55	87	55	67
2	32 308	48	28	15	3	6	86	61	86	67	76
3	12 848	36	38	16	3	7	88	67	89	73	81
4	6 632	31	45	14	3	7	90	70	93	73	84
5	3 854	25	52	13	3	7	90	71	90	78	85
6	2 478	23	54	13	3	7	91	76	94	78	87
7	1 671	22	57	12	3	6	92	81	91	86	90
8	1 171	19	61	11	3	6	92	75	95	89	89

Table 1 : Results and perserverance for local calls.

At	Calls	Result (%)					Perseverance (%)				
		EF	BY	NR	AB	OF	BY	NR	AB	OF	All
1	46 803	72	11	6	1	10	90	58	79	69	75
2	9 802	49	25	9	1	16	92	62	86	80	82
3	4 114	41	31	9	1	13	93	71	75	84	87
4	2 115	35	36	8	1	20	94	74	88	89	90
5	1 227	30	39	9	0	22	94	69	—	87	89
6	766	32	38	8	1	21	97	75	—	94	93
7	488	27	40	9	0	24	93	80	—	95	91
8	326	23	45	7	0	25	95	70	—	91	91

Table 2 : Results and perseverance for trunk calls.

The first columns of Tables 1 and 2 show that a rapid decrease in the proportion of effective calls with the attempt rank is due mainly to the increase in the number of calls encountering busy tone. Explanations of the increases in failure rates with the attempt rank are offered in section 3.1.4.

Tables 1 and 2 show that the subscriber's perseverance depends strongly on the cause of failure but also increases systematically with the attempt rank for a given cause of failure. For trunk calls the perseverance is strongest in case of busy tone ; for local calls, the absence of tone incites the most repetitions. Note that the class AB is not strictly comparable for local and trunk calls since, for the latter, the subscriber hears the transfer tone during the call setting up process. The presence of the transfer tone probably persuades the caller that the network is working correctly even in the event of long delays.

The perseverance is apparently stronger for trunk calls than for local calls but this is not necessarily a manifestation of a real difference in subscriber behaviour. In Paris, the called (PBX) subscriber often has more than one number and, in the event of a call failure, a caller will probably repeat his call forming an alternative number.

The increase in the perseverance probability with the attempt rank can be explained by what has been termed, "the selection effect" [6]. Simply by persevering once, the subscribers identify themselves as having the greatest need to place their call intents, either because of the urgency of the call or because of the absence of other means of communication (other number, telex,...). It is only natural that, in the event of a subsequent failure, a greater proportion of these subscribers make another repeat attempt.

The perseverance functions in Tables 1 and 2 are convenient for the global description of the repeat attempt phenomenon but it will be noted that they make no distinction between rapid repetitions and repeat attempts which are perhaps made more than an hour after the original rejection. It is clear however, that the interval which separates successive attempts has considerable influence on the network reaction.

3.1.2 REPETITION INTERVALS

For present purposes, the "repetition interval" is defined as the period of time lapsing between the start of one unsuccessful attempt and the start of the subsequent repetition. The interval between the end of one call and the start of the next is more directly dependant on the subscribers' behaviour but it is the time between successive arrivals which determines the network reaction.

Tables 3 and 4 present the observed distributions of repetition intervals for local and trunk calls respectively. Separate distributions are given for each of three failure causes ("busy", "no reply" and "abandon") and for the intervals following the 1st, 2nd, 3rd and 4th failed attempts. The distributions are omitted when fewer than 100 intervals have been recorded. The distributions are given in terms of the proportions of calls which have a repetition interval which is smaller than the given time. For example, of 7 416 call intents of which the first two attempts failed with busy tone, 52 % are repeated within the space of 3 minutes.

The last column, "Day", gives the proportion of calls repeated at any time within the measurement period (normally one day).

Cause of failure	At	Calls	< 1 m	< 3 m	< 10	< 1 h	Day
BY	1	18 504	44	59	68	77	81
	2	7 416	33	52	69	81	86
	3	3 650	37	56	73	84	88
	4	2 023	42	61	75	86	90
NR	1	17 606	10	26	33	45	55
	2	3 766	4	14	26	48	60
	3	1 169	4	13	28	55	66
	4	450	2	11	30	58	69
AB	1	3 833	73	80	83	85	87
	2	259	55	67	72	80	81

Table 3 : Percentages of calls repeated in given time limits - local calls.

Cause of failure	At	Calls	< 1 m	< 3 m	< 10	< 1 h	Day
BY	1	5 135	36	59	73	85	90
	2	1 776	30	54	72	87	92
	3	742	32	62	83	90	93
	4	348	37	63	83	91	95
NR	1	2 922	2	22	32	45	58
	2	531	1	12	22	43	57
	3	140	1	11	26	53	71
AB	1	424	21	52	65	76	79

Table 4 : Percentages of calls repeated in given time limits - trunk calls

The figures in this column correspond to the perseverance functions of Tables 1 and 2 except that, in the present case, only those call intents for which all the attempts up to and including the considered attempt have the same failure cause, have been conserved.

The tables show that the perseverance after busy tone is mainly rapid, in marked contrast to the reactions in case of no reply where a significant proportion of repetition intervals exceed the hour. The dissimilarity in the distributions of intervals following the abandon of local and trunk calls before the final tone reflects the influence of the transfer tone.

For all failure causes there is a fundamental difference between the distribution of first repetition intervals and the distributions of subsequent intervals. The difference lies in the frequency of very short repetition intervals (< 3 minutes). After a first failure, certain callers repeat immediately as if to test the "tenacity" of the failure cause (e.g. a network is normally congested for very brief periods, fault conditions are usually bypassed on a second attempt) but, in the event of confirmation of the failure at a second attempt, they are persuaded to wait longer before making a third attempt.

Figure 1 reproduces the distributions of the first intervals for failures due to busy tone conditions and ringing tone-no reply. The horizontal scale is logarithmic. The figure gives the mean and standard deviation of the repetition intervals but it must be emphasized that these are far from sufficient as representations of the distributions. Their values depend heavily on the proportions of long intervals whereas the effect of repeat attempts on network performance is determined mainly by the distribution of the smallest intervals. Any approximation should give most weight to the closeness of fit to the earliest part of the distribution even if the mean interval is reduced in consequence.

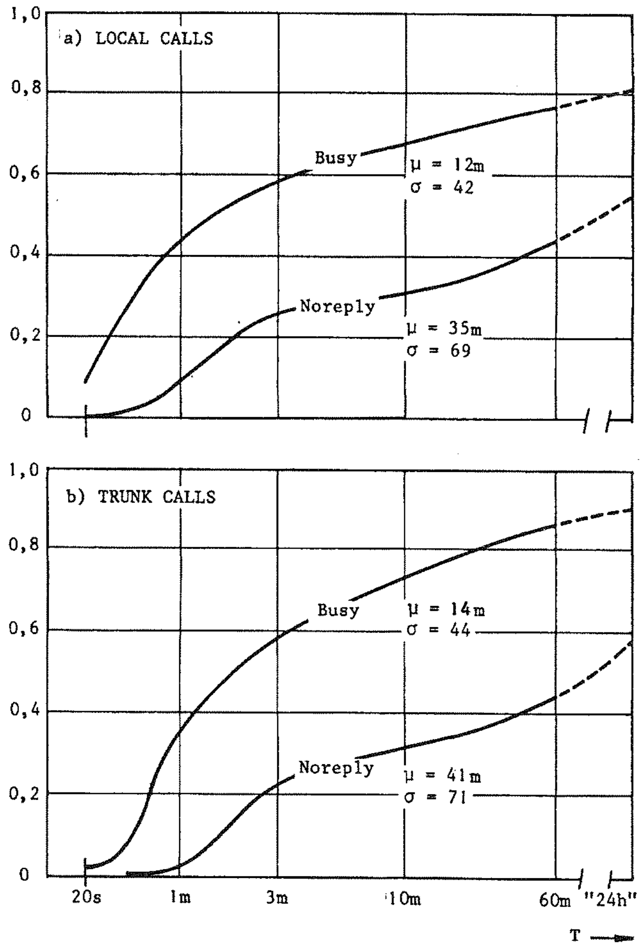

Figure 1 : Probability that the repetition interval after the failure of the first attempt is less than T.

3.1.3. DEPENDENCE OF THE PERSEVERANCE PROBABILITIES ON THE TOTAL TIME LAPSED SINCE THE FIRST ATTEMPT

The increasing nature of the perseverance functions is a somewhat counter-intuitive result seeming to imply that subscribers become more and more perseverant when one would expect, on the contrary, that they would grow more inclined to abandon as the number of failures increases. In fact, these functions do not reflect individual subscriber behaviour and the decrease in the proportion of abandoned attempts, explained by the selection effect, is an expression of the differences between subscribers. To gain more insight into the variation of individual subscriber perseverance, we have sought to show up the dependence of his behaviour on the total time lapsed since the start of the first unsuccessful attempt, completely disregarding the rank of the repeat attempts.

Table 5 gives the results of this investigation for calls failing due to busy tone and no reply conditions. Each row of the table corresponds to a given range for the length of the period lapsed since the first attempt and gives :

1. The numbers of repeat attempts made within the interval which fail for the stated cause (each interval may include several attempts of the same call intent).

2. The percentages of these attempts which are again repeated.

Only those calls for which all attempts up to and including the considered attempt have the same failure cause are considered in 1.

Inspection of these results reveals that the perseverance tends to decrease slightly with increasing length of lapsed time. Several explanations of this observation are possible, including the above mentioned intuitive understanding of subscriber's behaviour whereby he eventually tires of making repeat attempts.
However, whatever the cause of the apparent variation in perseverance, the most interesting observation is that the variation is only slight and mainly confined to the longest periods (> 1 hour).

It follows that the description of the repeat attempt phenomenon by models in which the subscriber's behaviour depends only on attempt rank and cause of failure, does not introduce significant errors. In other words, it may reasonably be supposed that subscribers all have the same repeat attempt behaviour, conforming to the perseverance functions and distributions of intervals presented in the preceding tables of this paper.

Time elapsed	Local calls				Trunk calls			
	BY		NR		BY		NR	
	*	**	*	**	*	**	*	**
0 to 3 mn	9740	89	1748	66	1826	94	207	65
3 to 10 mn	3712	89	806	69	788	93	118	68
10 to 20 mn	1468	87	633	70	254	91	78	65
20 to 60 mn	1652	86	1118	65	354	90	153	63
> 60 mn	974	76	1488	50	139	81	221	52

* number of attempts in interval
** percentage of attempts repeated

Table 5 Dependence of perseverance on toal time elapsed since first attempt

3.1.4. DEPENDENCE OF FAILURE PROBABILITIES ON THE LENGTH OF THE REPETITION INTERVAL

Myskja and Aagesen [6] have identified two reasons for the increase in the probability of failure with the attempt rank (cf. Tables 1 and 2) :

- the statistical dependence between the state of the network (including the called party) on successive attempts, and
- the "selection effect" by which the act of failing "selects" the calls whose destinations are the most difficult to reach.

The statistical dependence derives from the fact that a cause of failure (e.g. network congestion, called party absent, ...) persists for a certain time and, if a call is repeated rapidly, the caller is likely to meet with the same fate on successive attempts. The failure probability of a repeat attempt is higher as the repetition interval is smaller [7].

The selection effect is independent of the length of the repetition interval. Even for intervals which are so long that the statistical dependence of the network state is negligible, the proportion of repeat attempts of rank x which fail will be greater than the corresponding proportion of x-1th attempts [6].

The presence of these two effects may therefore be illustrated by an investigation of the dependence of the probability of failure of repeat attempts on the length of the repetition interval. The results obtained in the present study are given in Tables 6 and 7 for local and trunk calls, respectively.

The call intents are divided into classes according to the length of their repetition interval, I : 0 < I < 1 minute ; 1 < I < 3 minutes ; 3 < I < 10 minutes ; 10 < I < 60 minutes ; 60 < I.
For each class, the tables give the results of the repeat attempts as percentages of the number of calls in the class. For example, the first column of Table 6 (b) reads : of those calls whose first attempt failed because of the no reply condition, 1673 were repeated within 1 minute ; of these 1673 calls, 53 % were effective and 35 % failed again because of "no reply" ; the remaining 12 % failed due to some other cause. In tables 6 (a), 6 (c) and 7 (a), the calls meeting "no reply" (NR) have been grouped together with the effective calls (EF) to form the class of calls which have successfully avoided the original cause of failure in arriving at the called party's line.

To illustrate more directly the variation of the failure probabilities with the length of the repetition interval, the data relative to local calls, for first repetitions following busy and no reply failure conditions, are presented graphically in figure 2. The horizontal axis has been divided into classes of repetition interval, smaller than those adopted in Tables 6 and 7, and the apportionment of the calls in these classes to the considered results (EF + NR, BY, ...) is represented by the vertical segmentation.

Interval :		0-1m	1-3m	3-10	10-60	>60
	Calls	8216	2628	1739	1628	685
2nd att	EF + NR	37	42	52	62	69
	BY	57	52	41	33	23
	Other	6	6	7	5	8
	Calls	2455	1416	1209	934	334
3rd att	EF + NR	24	31	46	58	68
	BY	70	63	50	37	27
	Other	6	6	4	5	5

a) busy tone on first attempts

	Calls	1673	2852	1232	2166	1725
2nd att	EF	53	52	43	44	51
	NR	35	37	44	44	37
	Other	12	11	13	12	12

b) No reply on first attempt

	Calls	2794	291	96	84	65
2nd att	EF + NR	75	66	73	67	74
	AB	7	12	10	11	8
	Other	18	22	17	22	18

c) No tone (AB) on first attempt

Table 6 : Dependence of result (%) of repeat attempts on length of repetition interval - local calls.

For the busy tone failures, Tables 6 (a), 7 (a) and Figure 2 (a) show clearly the two causes for the increase in the failure probabilities. The influence of the statistical dependance may be seen in the fall in the failure rate with increasing length of the repetition interval. This fall is initially very sharp (supposing a 100 % failure rate for hypothetical, zero length repetition intervals) but is then very gradual, extending over more than an hour.

This behaviour no doubt reflects the preponderant influence of the called party busy condition.

The selection effect is clearly illustrated by the variation of the failure rate of calls having a repetition interval greater than one hour. Far from falling to the busy tone probability of first attempts (0,09 and 0,11 for local and trunk calls, respectively), the corresponding probability for these second attempts remains at around 0,22 and is even higher for third attempts.

The variation of the answer rate with the length of the repetition interval (Tables 6 (b) and 7 (b) and Figure 2 (b)) is quite different. While one might expect to see the expression of the same statistical dependance and selection effects, the results show that the answer rate (proportion of effective attempts) is initially high and then decreases as the repetition interval increases (before increasing slightly for very long intervals). This behaviour is perhaps due to the preponderant influence among the attempts which fail due to the no reply condition of those calls which are addressed to PBX subscribers with overloaded operators. After waiting a certain time for the operator to answer, a caller, who knows the called party is not absent, may prefer to make a new attempt in the hope that his call will arrive on a different, more frequently answered line.

	Interval :	0-1m	1-3m	3-10	10-60	>60
2nd att	Calls	1828	1191	739	611	231
	EF + NR	39	44	58	65	71
	BY	46	42	32	25	20
	Other	15	14	10	10	9
3rd att	Calls	538	421	327	261	82
	EF + NR	28	38	47	63	62
	BY	57	49	40	30	26
	Other	15	13	13	7	12

a) Busy tone on first attempts

2nd att	Calls	58	587	272	403	362
	EF	61	47	46	45	54
	NR	17	33	34	35	26
	Other	22	20	20	20	20

b) No reply on first attempt

Table 7 : Dependance of result (%) of repeat attempts on length of repetition interval - trunk calls.

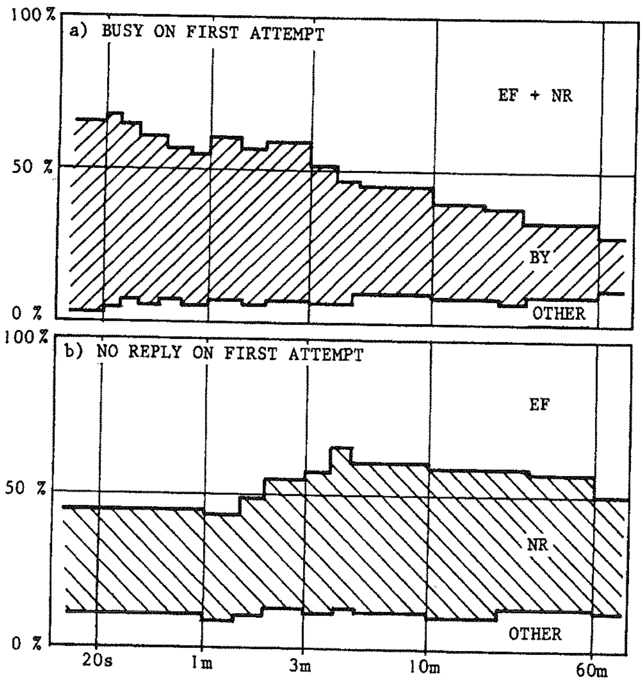

Figure 2 : Percentage results of second attempts against repetition interval - Local calls

Table 6 (c), concerning local calls, abandoned before the caller hears a tone, shows that this type of failure is rarely repeated on a second attempt.

3.2. INTERNATIONAL CALLS

The international network is distinguished by its size and by the diversity of its component parts. The vast and steadily increasing investment which this network represents and the economic and social importance of international communications demand a particularly efficient and reliable telephone service based on a sound understanding of the nature of international traffic. The importance of the presence of repeat attempts in this traffic has been recognized in recent studies undertaken under the aegis of the CCITT.

In observing several subscribers with a relatively high level of international traffic, we have sought to show up any differences in their behaviour in making international and national calls and, consequently, to determine what modifications, if any, need to be made to the models describing subscriber behaviour which have been developed from observation of national calls. In this section we present the results obtained relative to directly dialled international calls.

In France, access to the international network is gained by dialling the code "19" which connects the subscriber to a register of the outgoing international switching centre. The caller must wait for a second dial tone before dialling the desired country code and national number. Selection proceeds as soon as the international register has received sufficient digits to recognize the required route (normally, 6 digits). Congestion within the international switching centre and on the outgoing route is signalled by the busy tone or a recorded announcement. Congestion in the distant national network and called party busy may be indicated by national tones or recorded announcements or by the French busy tone if the "busy flash" signal is used. The setting up of international calls takes place in silence : there is no transfer tone.

Differing operating practices (number plan, tones, ..) and prevailing quality of service conditions necessitate an analysis of international calls by individual country. We report the results obtained for the six countries (North America and major European nations) having the greatest number of offered calls. These countries are clearly not representative of the entire international network but the quantity of data concerning other destinations was insufficient for the deduction of meaningful statistics.

3.2.1. FAILURE AND PERSEVERANCE PROBABILITIES

In view of the relatively small number of call intents observed, we have grouped together second and subsequent attempts and calculated overall repeat attempt failure rates and perseverance probabilities. Table 8 gives the observed mix of results of first attempts and repeat attempts of calls to the six destinations considered and Table 9 shows the proportions of failed attempts which are repeated. The apportionment of attempts to particular results is made according to the same categories used for national calls.

The relatively high proportion of attempts classed as "other failures" reflects the difficulty involved in the identification of failure causes of international calls. By a close inspection of a sample of some 400 calls, the major reasons for non identification have been estimated as

recorded announcements	35 %
special tones	9 %
silence plus noise	15 %
busy tone plus noise	10 %
ringing tone plus noise	5 %
exceptional tone frequency	4 %

The category "OF" also includes 2 to 3 % of call attempts abandoned immediately by the caller (i.e. hang-up less than 5 seconds after the end of dialling).

Despite the uncertainty caused by the non identification of all failure causes, interesting conclusions may be drawn from the data of Table 8. For all countries except country C, the failure rate is around 40 % for first attempts and rises to between 50 and 60 % for repetitions. The proportional increase is not as marked as for national calls (cf. Tables 1 and 2), probably reflecting the greater influence of equipment congestion and faults in the international network.

The large proportion of calls abandoned before the reception of a tone would indicate a high frequency of serious routing delays. The reactions of subscribers to the post dialling delay is discussed in detail in section 4.

The perseverance probabilities represented in Table 9 are similar to those obtained for national trunk calls (Table 2). The variations in the results for different countries are probably not statistically significant. It is interesting to note that subscriber behaviour is similar even for country C where the quality of service is much worse than for the other five countries.

*	First attempts						Repeat attempts					
	Atts	EF	BY	NR	AB	OF	Atts	EF	BY	NR	AB	OF
A	4530	58	9	1	12	20	2967	40	15	2	17	28
B	5938	63	12	3	9	13	3224	49	21	4	9	17
C	2831	36	22	3	18	21	4204	26	26	3	18	25
D	5390	62	13	4	9	12	2544	50	17	7	12	14
E	6209	60	12	4	10	14	3415	45	19	6	14	16
F	3647	60	14	4	8	13	2214	44	21	6	10	19

* Country

Table 8 : Failure rates (%) for international calls.

*	First attempts					Repeat attempts				
	BY	NR	AB	OF	ALL	BY	NR	AB	OF	ALL
A	91	51	75	67	74	93	51	81	84	84
B	86	56	81	75	78	91	61	89	88	87
C	84	62	82	73	79	89	67	89	87	88
D	83	48	80	68	74	91	62	88	75	82
E	83	46	79	70	74	89	53	88	79	82
F	89	49	84	71	78	92	61	84	81	84

* Country

Table 9 : Peseverance probabilities (%) for international calls.

3.2.2. REPETITION INTERVALS

We consider only the repetition interval for the two most important causes of failure, busy tone and subscriber abandon. Table 10 gives the proportions of calls repeated within the given time limits after the failure of the first attempt for each of the considered countries.

*	Calls	<1m	<3m	<10m	<60m	'Day'
A	402	59	80	86	90	91
B	699	42	68	78	84	86
C	626	34	67	77	82	84
D	694	57	75	79	82	83
E	741	48	68	75	81	83
F	529	49	76	84	87	89

a) Busy tone on first attempt

A	541	28	56	63	71	75
B	545	43	68	75	80	81
C	508	29	70	77	80	82
D	486	56	73	76	78	80
E	619	43	69	74	77	80
F	308	46	75	78	82	84

b) Abandon (no tone) on first attempt

* Country

Table 10 : Percentages of calls repeated within given time limits - international calls.

Comparison with Tables 3 and 4 reveals that the subscribers repeat international calls much more rapidly than they do local and trunk calls. Approximately 80 % of international calls failing at the first attempt with busy tone, are repeated within 10 minutes.

Table 11 gives the results of second attempts according to whether the repetition interval is less than or greater than 1 minute. The limit of one minute divides the intervals into two approximately equal classes. A finer division is not practicable in view of the restricted number of calls concerned.

The results are surprising in that they would imply that the length of the interval has very little influence on the failure probabilities of repeat attempts in the international network. This may simply be due to the rapidity of state changes in a large network.

Another explanation lies in the diversity of paths available to international calls. Effectively random selection of different groups of common equipement, trunks and paths through connecting networks may enable a repeat attempt to completely avoid the bottleneck which caused the original failure.

*	a) BY on first attempt				b) AB on first attempt			
	Int<1m		Int>1m		Int<1m		Int>1m	
	EF + NR	BY	EF + NR	BY	EF + NR	AB	EF + NR	AB
A	54	21	44	19	47	21	50	26
B	51	30	58	22	61	8	65	10
C	40	27	33	29	40	23	38	27
D	60	20	60	17	65	11	65	19
E	60	20	53	22	63	13	51	21
F	59	23	61	21	59	13	44	23

* Country

Table 11 : Dependence of result (%) of second attempts on length of repetition interval - International calls.

4. SUBSCRIBER REACTIONS TO POST-DIALLING DELAYS

The post-dialling delay (PDD) is that period in the setting up of a call from the end of dialling to the start of the tone or recorded announcement which informs the caller of the result of his call attempt or to the abandon of the call without tone. For trunk calls in the French network this delay is accompanied by the transfer tone ; for other types of call, the caller waits in silence. In this section we analyse the PDD's of the calls recorded in the present observation campaign.

4.1. IMPORTANCE OF THE PDD

The PDD is a measure of the time taken by the network to set up a call once the caller has provided all the necessary routinginformation. This time depends on the actual operation time necessary for switching and signalling but may be considerably lengthened by the accumulation of waiting times and the action of automatic retrials in case of congestion or faults. Clearly, long PDD's are undesirable for both the operating administration, who must invest to carry non-revenue earning traffic, and for the subscriber, who must spend a considerable time obtaining his communication. The length of the PDD is therefore a particularly important aspect of the quality of service although, because of practical difficulties, it is rarely monitored in current practice.

In case of an excessively long PDD, the caller may abandon his attempt, assuming rightly or wrongly that his call no longer has any chance of success. The length of time after which a subscriber takes this decision clearly depends on many factors and varies from subscriber to subscriber and from call to call. A knowledge of this variation or, more specifically, of the probability distribution of the time to abandon of an arbitrary call, is of considerable importance in estimating the effects on the quality of service of routing delays.

The present observation campaign has provided a rare opportunity for the observation of PDD's and of the consequent subscriber reactions. It is appropriate, however, to note that the results presented below are subject to some uncertainty due to the impossibility of identifying the tone of every call. One of the reasons for non-identification is the presence of spurious noise (subscriber talking, ...), particularly for international calls and it will be appreciated that this event is the more probable, the longer is the PDD. It follows that the observed distribution of PDD's of calls prematurely abandoned constitutes an underestimation of the real situation.

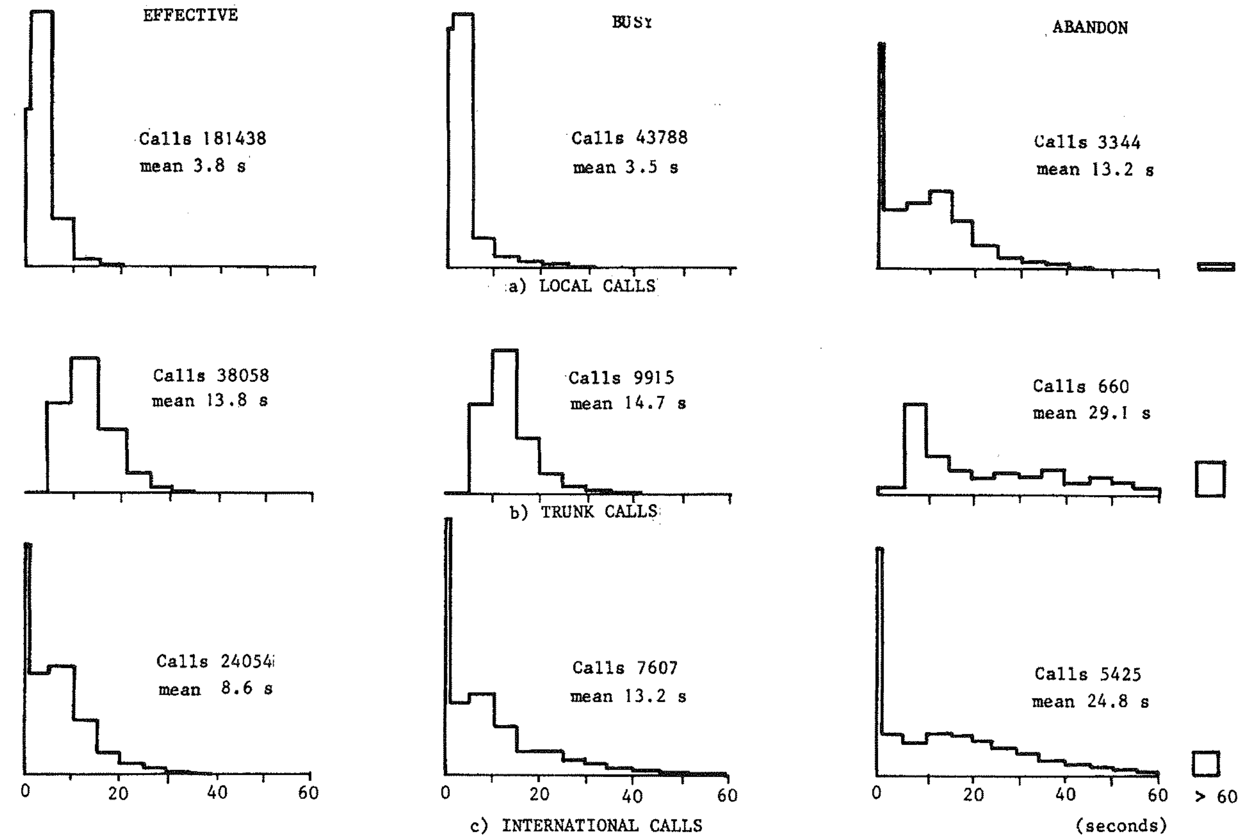

Figure 3 : Histograms of observed post-dialling delays

4.2. DISTRIBUTIONS OF OBSERVED POST-DIALLING DELAYS

Frequency distributions of the observed post-dialling delays are given in Table 12 and presented in the form of histograms in Figure 3. Separate distributions are given for local, trunk and international calls and for calls leading to ring tone, busy tone and no tone. The international calls concern the six countries considered in section 3.2. In the case of trunk calls, only those call attempts for which the transfer tone was present have been considered.

For local calls, the time to ring tone or busy tone is very short, as one might expect. The distribution of the time to abandon reflects both the influence of subscriber mishandling (zero or very short PDD) and the caller's interpretation of what constitutes an abnormal delay.

A minimum delay of 5 seconds for trunk calls is due to a certain necessary operation time for calls receiving the transfer tone. The mean time to tone for trunk calls is the greatest of the three call types. The form of the distribution of the time to abandon is less significant than the fact that only a very small proportion of trunk calls (with transfer tone) are actually abandoned.

It may at first be surprising to note that the PDD of trunk calls should be, on average, greater than those of international calls. In fact, for calls from Paris to major foreign cities, the number of switching stages may be less than for many national calls. It must also be remembered that the PDD depends on the time taken in dialling and, for international calls, the time between the start of switching (at the 6th digit) and the end of dialling may be considerable. It is true, however, that at least in the case of ring tone, the observed zero length PDD's must result from interpretation errors. These may be caused by spurious variations in the line potential at certain phases of the call which imitate dial pulses or simply by the caller dialling more digits than are necessary.

It will be recognized that these distributions of "time to tone" and "time to abandon" are not independent and cannot be used directly as descriptions of the network performance and subscriber behaviour, respectively. We only observe the times to tone of those calls for which the setting up time is shorter than the caller's patience and conversely, the times to abandon concern only those calls for which the setting up time is the longer. In the next section we derive estimates of the distributions of setting up times and subscriber patience.

Time (sec)	Local			Trunk			International		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
5	83	85	25	0	0	3	38	32	20
10	98	93	45	29	28	33	71	57	29
15	99	96	69	70	69	46	87	72	42
20	100	98	83	91	86	54	94	79	54
30	100	99	94	98	95	65	98	92	72
40	100	100	97	99	98	77	99	97	84
50	100	100	98	100	99	87	100	98	90
60	100	100	99	100	99	93	100	98	93

(1) Effective + no reply (2) Busy (3) Abandon

Table 12 : Percentages of PDD less than the given times

4.3. SETTING UP TIMES AND SUBSCRIBER PATIENCE

The call setting up time is here defined to be the interval between the end of dialling and the instant at which a tone would be given if the caller were still waiting. For a given call, let V be the setting up time and let U be the time after which the caller would abandon if there were no tone. The observed PDD is the smaller of U and V. We wish to find the probability distributions of U and V denoted by F(t) and G(t), respectively. Let the observed distribution of the time to tone be A(t), and the observed distribution of the time to abandon be B(t). Then,

$$A(t) = \Pr\{U < V \text{ and } U < t\} = \int_0^t (1-F(u))\, dG(u)$$

$$B(t) = \Pr\{V < U \text{ and } V < t\} = \int_0^t (1-G(u))\, dF(u)$$

Differentiating gives

$$(1-F)\,\frac{dG}{dt} = \frac{dA}{dt} \qquad \text{and} \qquad (1-G)\,\frac{dF}{dt} = \frac{dB}{dt}$$

These equations can be solved if A and B are approximated by curves made up of linear segments :

$$\left.\begin{aligned} A(t) &= a_i t + A(t_{i-1}) \\ B(t) &= b_i t + B(t_{i-1}) \end{aligned}\right\} \quad t_{i-1} < t \leq t_i$$

where $t_o = 0$, $A(o) = 0 = B(o)$ and a_i and b_i are deduced from the observation results. The solution for G is (for $t_{i-1} < t \leq t_i$).

$$G(t) = 1 - (1-Go)^{\frac{b_i}{a_i+b_i}} \left[(1-Go) - \frac{(a_i+b_i)\ (t-t_{i-1})}{1-Fo}\right]^{\frac{a_i}{a_i+b_i}}$$

where $Go = G(t_{i-1})$ and $Fo = F(t_{i-1})$

F is given simply on interchanging F and G and a_i and b_i.

The distributions A(t) and B(t) have been deduced from the results given in section 4.2, (i.e. without taking into account the calls for which the failure cause is not identified). It is felt that this should not greatly affect the form of A(t) but that, for the reasons already mentioned, the distribution B(t) represents an underestimation of the true times to abandon.

Histograms representing the derived densities dF(t) and dG(t) for local, trunk and international calls are shown in Figure 4. Comparison with Figure 3 reveals that the distribution of the time to abandon gives much greater importance to early abandons than the true distribution of subscriber patience.

Time (sec)	Local		Trunk		International	
	(1)	(2)	(1)	(2)	(1)	(2)
10	,96	,05	,28	,00	,60	,06
20	,99	,37	,90	,01	,82	,19
30	,99	,60	,97	,04	,89	,38
40	1,00	,74	,99	,13	,92	,55
50	1,00	,83	,99	,25	,94	,68
60	1,00	,88	1,00	,38	,95	,76

(1) $G(t) = Pr\{\text{setting up time} < t\}$

(2) $F(t) = Pr\{\text{patience} < t\}$

Table 13 : Distributions of setting up times and subscriber patience

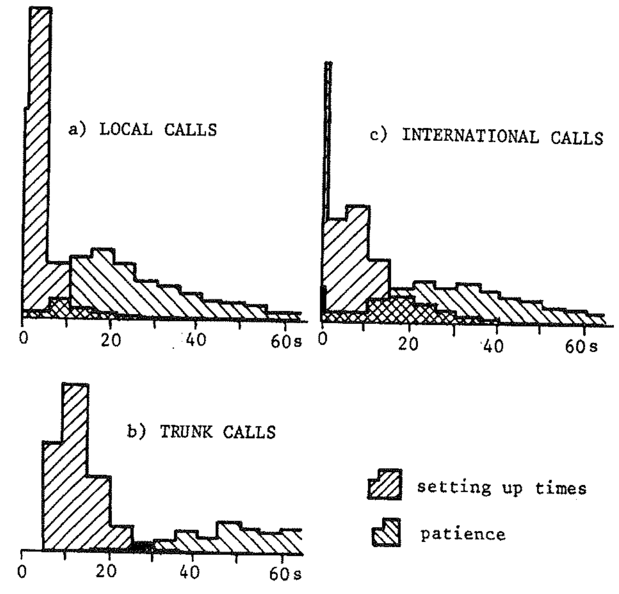

Figure 4 : Distributions of setting up times and subscriber patience

Table 13, gives certain values of the functions F and G. The results for trunk calls are striking : only 3 % of setting up times are greater than 30 seconds yet, in the presence of the transfer tone, 96 % of subscribers are prepared to wait longer than this. For international calls, the callers are much less persevering even though they should be used to a greater proportion of long setting up times. This contrast is a clear demonstration of the effectiveness of the transfer tone in persuading callers to wait.

5. CONCLUSIONS

The present subscriber behaviour observation campaign has enabled the determination of the probabilities of perseverance, in case of failure for a given cause, of the successive attempts of local, trunk and international call intents (Tables 1, 2, 9). It has been shown that these perseverance probabilities do not greatly depend on the total time elapsed since the epoch of the first unsuccessful attempt (Table 5), justifying certain hypotheses of the repeat attempt model [7].

The observed increase in the probabilities of failure with attempt rank is due to the statistical dependence between successive attempts and to a certain "selection effect". The relative importance of these two effects has been revealed by an investigation of the dependence of the failure probabilities on the length of the repetition interval (Tables 6, 7, 11, Figure 2).

From measurements of post-dialling delays, we have derived estimates of the probability distributions of subscriber patience and call setting up times (Table 13, Figure 4). The results of this analysis show, in particular, that the transfer tone, transmitted during the setting up of trunk calls, considerably reduces the probability of premature hang up.

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