ABSTRACT

This paper focuses on the role of subscriber
behaviour in the research of setting up suitable
strategies in order to improve the network grade
of service and revenue.

A study activity to evaluate the impact of
repeated call attempts on the network has been
carried out by the aid of an analytical and
simulation model.

Moreover the input data for the simulation
model and results of some case studies are
explained in detail.

1. INTRODUCTION

The subscriber retrial behaviour has been
extensively studied in the environment of
traffic engineering. Indeed the aim of these
surveys has been very often the determination of
real offered traffic on the basis of carried
one. The dimensioning standards and the well
known network design method don't take into
account of repeated attempts.

The goal of this paper is to deal with the
impact of the subscriber behaviour on the
network design, grade of service, call
completion ratio and the revenue. As a
consequence of the repeated attempts caused by
the network congestion and mainly by the busy
called party, offered traffic increases
fictitiously affecting the call completion ratio
and the revenue. Charge policy and some
marketing oriented strategies could change the
user behaviour, improving, at the same time,
both the completion ratio and the revenue,
avoiding to modify the network dimensioning and
the relevant plant cost. As the user behaviour
is depending both on the social, economic, human
aspects peculiar of each country and on the
network performance, the studies carried out on
this subject cannot be easily standardized, it is
suitable that each operating telephone
company detects the behaviour of own users
through appropriate observation campaigns and
evaluates the corresponding results.

First of all in the paper an observation
campaign conducted in order to investigate the
subscribers behaviour is described.

The second step of the paper is relevant to
a study conducted by the aid of a simulation
method modelled in order to detect the
parameters of the subscriber behaviour which
have a sensible impact on the network grade of
service.

The results of the simulation are compared
with those obtained by classical analytical
model in order to demonstrate the insufficiency
of this last one and the necessity to define a
new traffic model comprehensive of the
subscriber retrial behaviour.

The third stage has just been the definition
of this analytic model suitable to investigate
the call congestion. The underlying theoretical
basis for our approach was developed by
Frederiks and Reisner.

The fourth stage, on the basis of:
- the observation campaign;
- the most important parameters pointed out by
the simulation;
- the call congestion analytically determined,
evaluates the impact on plant costs, revenue and
network grade of service of the marketing
policies, whose aim is to modify user behaviour.
These evaluations are made undertaking a
second simulation study comprehensive of both
the network, as a whole, and the user behaviour
(caller and called party) inserting one at time
the fixed marketing policy.

2. MEASUREMENT RESULTS

All the operating telephone companies
concentrate more and more a steady care in
supervising the flow of telephone traffic by
means of suitable measurement campaigns carried
out in the SPC exchanges directly by the common
control system and as relevant to the
electromechanical ones by "ad hoc" additional
measurement equipments.

The measurement data are gathered with the
purpose of supporting the fundamental activities
of traffic engineering, operation, network
management, traffic administration.

The analysis of measurement methodologies
and of the most suitable apparatus able to
detect the traffic parameters is out of the goal
of this paper.

Here it is only reported some data gathered
by usual and special measurements relevant to
subscriber behaviour, to call completion ratio
and to the holding times quantitatively and
concisely described by parameters to be used in
a network simulation conducted with the goal to
achieve suitable analyses of the grade of
service, traffic offered and revenues versus
subscriber behaviour. The measurement results
are concerned with the toll traffic originated
by some representative toll nodes and the
incoming traffic terminating to a sample of
10 000 subscribers in a local exchange of Rome.

4.2B-4-1
As relevant the first survey a total of 1,900,820 call attempts has been recorded whose disposition is:

a) call attempts failed for the behaviour of caller subscriber = 7%.
   This category encompasses:
   - abandon, i.e. caller hangs up before the end of dialing or does not wait the answer;
   - subscriber mishandling;
   - no such number;
   - customer dialed wrong number;
   - customer omitting an access code;

b) ineffective call attempts due to network problems including the exchange (BL) = 3%.
   This category encompasses:
   - failures such as: no ring, equipment irregularities;
   - network congestion;
   - exchange congestion;

c) call attempts failed due to the status of called subscriber = 36%.
   This category is split into:
   - called customer did not answer (NA) = 16%;
   - called customer busy (BY) = 20%;

d) successful call attempts (with answer) = 54%.

In the following instead of use the call completion ratio (equal to 0.54 in our case), it is used the inverse fraction i.e. the number of attempts per message (M1) (= 1.85 in our case).

In conclusion 90% of originated traffic reaches the called subscriber, so if we refer the percentage to the incoming traffic, BY becomes 22% and NA 18%.

As relevant to the holding times, the measurements have shown:

e) average conversation time = 190 s;

f) average holding time = 135 s;

g) average holding time for BY = 25 s;

h) average holding time for NA = 45 s.

As aforementioned, in order to investigate in detail the unsuccessful call attempts for user not in (NA), a special measurement has been undertaken sampling the traffic terminating to 10,000 customers. This survey has two basic aspects relevant to marketing strategy and grade of service (AM). In fact if an amount of subscribers were provided with simple equipments as phone answerers able to give the answer signal and to transmit a short message, two goals would be achieved: first an improvement of the revenue, second a decrease of AM i.e. an improvement of call completion ratio.

The results achieved with this second measurement on the incoming traffic are in agreement with the previous one. In fact on a sample of about 1 million of terminating call attempts on the 10,000 selected subscriber lines, 18% result ineffective because the user is not in.

The cumulative distribution of NA versus subscribers (the subscribers are directly sorted according to the relevant NA) is sketched in fig.1. Note that only 10% of subscribers cause 99% of unsuccessful call attempts, and 18% of subscribers 50% of unsuccessful call attempts.

3. SIMULATION - BASIC TRAFFIC PARAMETERS

The phenomenon of repeated call attempts represents still a very complicated problem and not yet completely understood. Various theoretical approaches and simulation studies have been carried out since the early fifties. An analytical approach without adopting a simplified outline of the telephone system with repeated attempts seems to be very difficult. The simulation study presented in this paragraph has the aim to offer a contribution in evaluating the impact of repeated attempts on the telephone system and in determining few but basic parameters able to define the traffic model. In this way it will be possible to set up a simplified analytical model avoiding the complexity of the state equations and also to define a further more sophisticated simulation model able to satisfy wider objectives like to evaluate different marketing policies versus ineffective call attempts due to called subscriber behaviour.

The hypothesis of Erlang traffic model, disregarding the phenomenon of repeated attempts, becomes always less and less able to keep up with the real traffic conditions as more sophisticated facilities which allow a fast and retrial access to network are provided to the users. Therefore this calls for setting up new analytical approaches and simulation models able to confirm the theoretical result.

3.1. Simulation model

The system considered in the simulation whose logical scheme is reported in fig.2, is represented by a full available trunk group to which the traffic generated by a great number of subscribers is offered. The connection of A-subscriber with B-subscriber requires only a free circuit of the trunk group. If all the circuits of the trunk group are busy the call attempt will result unsuccessful and further attempts may be generated.
Let \( P \) the probability to find no idle circuit in the trunk group (network congestion), \( BY \) and \( NA \) the probability respectively to find the called subscriber busy or not in, the probability to have a successful call attempt will be: \( 1 - P - BY - NA \).

The blocked call attempts due to congestion and called subscriber status don't disappear completely but they re-present to the system according to a perseverance function. The grade of perseverance is defined as:

\[
H(x) = \frac{A(x+1)}{B(x)}
\]

where:
- \( A(x+1) \) is the number of attempts that produced an \((x+1)\)-th attempt;
- \( B(x) \) is the number of 1-st attempts that produced an \(x\)-th unsuccessful attempt.

It has been derived qualitatively in the measurement campaign 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. As we couldn't quantify the perseverance functions we have adopted those presented by Roberts [2]. Likewise for the functions for repetition times of the blocked calls, \( BY \)-calls and \( NA \)-calls, in the following we use, failing a measurement verification, those reported by Evers [3].

### 3.2. Simulation results

The main results achieved by the simulation and that will be the basic inputs for the analytical models, are outlined as follows:

a) the call congestion is not substantially modified adopting for each cause of failure the average value of the perseverance function instead of the value relevant each attempt rank;

b) there are no meaningful differences assuming the repetition times for the \( BY \) and \( NA \) repeated retrials are very long compared with the holding time. This means that the repeated call-attempts caused by the called subscriber status don't modify the traffic distribution that remain of Poisson type with an higher average value;

c) on the contrary the congestion probability is strongly affected by the distribution of the repetition time of the call-attempts blocked for network congestion.

These three basic conclusions are sketched in fig.3 where the call congestion versus traffic offered is reported for a trunk group of 10 circuits.

The dotted line represents the call congestion according to the real traffic condition. The curve \( a \) represents the call congestion assuming the average perseverance. The curve \( b \) represents the call congestion considering as "fresh" traffic the \( BY \) and \( NA \) repeated call attempts. The curve \( c \) represents the call congestion assuming for the call attempts blocked by the system the same hypothesis relevant to curve \( b \).

Note that the curves \( a \) and \( b \) fit very well the real one while the curve \( c \) doesn't.

Therefore for the repeated calls it is necessary to assume a more complex but more real interarrival time distribution defined as follows:

\[
R(t) = A[1 - \exp(-t/a)] + (1-A)[1 - \exp(-t/b)]
\]
which represents the probability to have a repeated attempt after a time t.

In fig.4 the function $G(t) = 1 - R(t)$ for the RL, BY, and NA call attempts is reported.

![Graph](image)

**Fig.4-Arrival distribution for repeated attempts.**

The parameters A, a and b appearing in the function (1) (this function has already been proposed by Evers [4] and Liu [5]) have the following meanings:

- A is proportional to the percentage of RL-repeated call attempts which represent themselves almost immediately;
- a represents the average value of the time repetition interval for the BL-repeated call attempts which represent themselves immediately;
- b represents the average value of the time repetition interval for the call attempts which don’t represent themselves immediately.

As usual the a-value is about some seconds while b-value is about thousands of seconds.

In the following it will be shown the function (1), assuming some suitable hypotheses, depends only by two parameters: A and a.

4. ANALYTICAL MODEL

The results achieved by the simulation have allowed to define some basic simplified parameters which have been used to set up an analytical model. As regard the unsuccessful call attempts caused by the called subscriber status (BY and NA), the simulation has proved that it is possible to assume for them a very long inter-arrival time. This means hence that there is no difference between “fresh” calls and those BY and NA repeated call-attempts. Therefore, except the effects of system congestion, to the network a pure chance traffic independent from the trunks status is offered. Moreover the perseverance rate may be considered independent by the attempt rank. Finally, if $F$ and $H$ denote respectively the failure probability and the perseverance rate, the following value:

$$C = H_{BY} F_{BY} + H_{NA} F_{NA}$$

named repetition constant, represents the probability that a fresh call-attempt generates a repeated attempt caused by the called subscriber status. This C parameter is, as shown later, the sole parameter necessary to take into account of the BY and NA call attempts in the traffic model.

Let:

- $l_i$ = the average birth rate (for fresh+repeated call attempts) when there are i circuits busy;
- $l_0$ = the Poisson input rate;
- $S_i$ = the average retrial intensity for RL-call attempts when there are i circuits busy;
- $U_i$ = the average retrial intensity for BY and NA call attempts when there are i circuits busy.

There is the following relation:

$$l_i = l_0 + S_i + H_i$$  \((2)\)

If $l$ denotes the intensity of the total traffic offered to the system, we obtain:

$$l = \sum_{i=0}^{n} l_i$$

where:

- $n$ is the number of circuits of the trunk group;
- $p_i$ is the probability that i circuits are busy at a time t.

Noting that it is feasible to assume as “fresh” the BY and NA repeated call attempts, as the simulation proved, we obtain:

$$U_i = l_i (1-B) . C$$

where $B$ is the congestion of the trunk group evaluated with Erlang-B formula.

Note that $U_i$ results independent from the number of busy trunks.

Introducing in the formula due to Fredericks and Reisner [6] the expression:

$$S_i = B H / P_i \int_{t=0}^{T} dG(t)$$

where:

- $P_i$ is the probability that there are $n$ busy circuits at the time $t$ and i busy circuits at the time $t$;
- $R(t)$ is the interarrival distribution function reported in (1).
and noting that the value of \( b \) is great enough to assume:

\[
\frac{1}{b} \int_{0}^{\infty} f_n(t) \exp(-t/b) \, dt = P_l
\]

We have:

\[
S = B_n \frac{H/P_0}{I_l} \left( \frac{A}{a} \right) L \left[ P_n(t/a) \right] + (1-A) P_0
\]

where \( L \) denotes the Laplace transform.

Finally the equation (2) becomes:

\[
I_l = I_0 + (1-3)C \times S
\]

(3)

Using the Fredericks and Reisner iteration scheme it is possible from (3) calculate \( I_l \) and \( P_l \) and then the call congestion

\[
R_l = \frac{1}{P_0} \sum_{n=0}^{\infty} I_l \times P_l
\]

(4)

The call congestion for the "fresh" call attempts derived from (4), is:

\[
R = \frac{1}{P_0} \sum_{n=0}^{\infty} I_l \times P_l
\]

Note that the call congestion for the fresh call attempts is equal to the time-congestion.

For comparison in fig.5 the call congestion values versus traffic offered calculated by simulation, by the proposed formula (4) and by Erlang-B formula are reported.

The conclusions that can be pointed out are the following:

- the classical Erlang traffic model in case of not negligible network congestion is inadequate to represent the real traffic flow;
- in the study of repeated call attempts it is necessary to take into account the failure causes because the caller subscriber behaviour is strongly dependent by these ones. In fact the time interarrival distribution (see fig.4) is quite different according to the failure causes;
- the failures caused by the telephone system worse the network performance, because the retrials occur immediately when the system is still in congestion.

5. NETWORK PERFORMANCE VERSUS CALLED SUBSCRIBER BEHAVIOUR

As usual the network is dimensioned in order to carry out the "fresh" traffic offered by the users, but really the network is also loaded by repeated call attempts generated by the caller user according to his perseverance rate. Even in normal traffic conditions the system presents a loss probability sufficient to provoke a not negligible repeated attempt process. This process is, in its turn, more and more stressed by the called subscriber status.

The analytical approach doesn't allow to evaluate the overall grade of service of the network in real traffic conditions that is in presence of repeated call attempts, failures and overload phenomena. Therefore a second more sophisticated simulation method has been set up in order to take into account all the links between two users.

The Italian telephone network (serving about 15 million subscribers) is presently structured on five switching levels. The whole territory is subdivided into 231 District areas of univocal numbering and identified by different areas codes; the local area consists of 2 levels and the toll network consists of three hierarchical levels on 231 District Centers (CD), 21 Compartment Centers (CC) and 2 higher-level Transit Centers (TC). In the adopted simulation scheme (reported in fig.6) the connection of the user to the relevant toll center (CD) consists in one trunk group for the caller and an other one for the called user.

This means to concentrate the loss probability for the outgoing and incoming toll traffic in one exchange and one trunk group. An other simplification has been to consider as a whole the toll network. The simulation has taken into account of:

4.2B-45.
- caller subscriber behaviour;
- failures;
- network congestion;
- called subscriber behaviour.

The traffic parameters relevant to average holding and conversation time, to the successful and unsuccessful call attempts have been fixed according to the values gathered by the measurement campaign. The perseverance function, as aforementioned, has been derived by Roberts and as far as the interarrival retrials the function (1) reported in the analytical model has been used.

5.1. Grade of Service Analysis.

First of all the relation between the parameter AM - number of attempts for message, i.e. the inverse of completion ratio-and the average point-to-point network loss probability has been investigated.

The results are sketched in fig.7, in which is reported AM versus the point-to-point loss probability (B). Note that really there is no correlation between B and AM; indeed in the B-range 1.5%~2.5%, AM doesn't practically vary changing from 1.58 to 1.60.

![Fig.7 - AM-parameter versus point-to-point blocking probability (B).](image)

On the other hand the network cost has a tight and sensible relation versus the point-to-point loss probability. In fact note that the results-obtained by using a network design optimization method [7] - sketched in fig.8 - show that the drop of the point-to-point loss probability B from 2.5% to 1.5% causes an additional network cost of about 5% without improving, as already seen, the call completion ratio. As far as this last point more interesting results can be achieved acting on the called subscriber behaviour; in fact this causes the 78% of the unsuccessful attempts while the network congestion and failures represent only 7% (the remaining 15% is due to caller subscriber behaviour).

![Fig.8-Network cost variations versus point-to-point blocking probability.](image)

5.2. Called subscriber behaviour analysis

In order to take into account the called subscriber behaviour a variational analysis of offered traffic, grade of service, expressed by AM parameter, versus the BY and NA probability has been carried out. The approach used has been to maintain alternatively constant one of the two values (BY or NA) and to detect the influence of the other one on the inverse of call completion ratio and on the offered traffic, expressed in number of messages (MN) and conversation time (CT).

The modification of NA probability may be achieved installing to the subscriber lines simple phone-answerers able to transmit a short message.

The effects of such strategy are outlined in fig.9 and 10 which respectively yield the variation of the inverse of completion ratio (AM) and traffic offered (CT, MN) versus the probability that the called user is not in (NA) for a fixed value of the probability that called subscriber is busy (BY=20%).

The following considerations can be drawn:

- AM-parameter is quite sensible versus NA probability. As an example a decrease of NA from 20% to 10% provokes an improvement of AM from 1.77 to 1.54;
- the number of completed calls (MN) improves of about 5.7%, while the average conversation time (CT) has a more limited variation of about 1.2%;
- the carried traffic doesn't register any real variation; in fact the holding time elapsing between the start of ringing tone and the abandon (in case of called not in) is substituted by the length of the phone answerer message.
An other analysis with the aid of the same simulation method has been carried out to evaluate the influence of BY probability. The improvement of AM and the increase of CT versus BY (maintaining constant NA=16%) are roughly equal to those just described and relevant to NA variations. On the contrary the variation of MN is smaller. Also in this case the carried traffic and hence the design traffic remain practically constant.

In order to modify BY, the subscriber lines with high busy rate can be augmented. Studies [8] have proved that adding only 3% of the lines, the busy rate decrease of about 50%.

In conclusion for a telephone operating company it is more suitable to set up strategies relevant to subscriber behaviour than to adopt more stringent design criteria in order to improve the call completion ratio and to alleviate the effect of repeated call attempts.

In this manner moreover it is possible to limit the calls which cannot be delayed and hence are definitively lost. An estimate of this variable is very difficult, Liu [5] evaluates in about 10% this amount.

Technological advances and competition for new revenue opportunities in the telecommunications industries have stimulated an increasing rate of introduction of new network services. The knowledges of behaviour subscriber will be more and more useful especially regarding the economical evaluation of the diffusion of such services.

REFERENCES

4.2B-4.7