ABSTRACT

The present paper describes a systems engineering approach to telephone network management. Main topics are network, strategy design, and system analysis.

A simulation model of the stochastic traffic process in a circuit-switched 3-level hierarchical network with alternative routing is presented. The arrival process of calls to the network is a Poisson process without repeated-attempt features.

The design of a network management strategy comprises a choice of load indicators, statistical decision rules based on the information from load indicators, and network management controls.

Network management controls considered are, e.g., queue limiter, control of alternative routing and directional reservation. For each of these controls, statistical decision rules and operation criteria are investigated, and a mathematical model is presented.

The system (network with call flow) is first analysed without network controls for different characteristic load patterns, and the bottlenecks in the network are identified.

The network management strategy outlined below is based on a mathematical model of the given set of network management controls and on a set of network load indicators placed at potential bottlenecks (because this is where an overload manifests itself first). This strategy is implemented in the system, and the analysis procedure is repeated in order to see whether the traffic-handling capacity of the network has increased, and to study how the controls have operated.

1 INTRODUCTION

A telecommunication network is optimized from a certain traffic level (busy hour). However, when some kind of traffic disturbances occurs (either due to faults or to an increase of the traffic offered) the network will operate inefficiently and will not any longer satisfy the requirements demanded from it. Those facilities which are incorporated in the network in order to increase its utilization during normal load levels, often act in a negative sense during traffic disturbances. Examples of such facilities are delay system for registers and alternative routing.

In order to increase the effective utilization of the network when traffic disturbances occur, a dynamic control system may be introduced which aims at reducing the negative effect of the various traffic disturbances. A network-control system comprises a series of network controls which must be able to perform the following functions:

1. Obtaining information about the state of the network.
2. Analysing those situations in which traffic disturbances occur.
3. Carrying out control functions which aim at countering these traffic disturbances.

For this purpose, a network management strategy has been developed for some current network-control functions. A network-control strategy comprises:

1. A series of load indicators which obtain information on the state of the network.
2. Decision procedures which, based on information from the load indicators, decide at what time the individual controls shall enter into operation.
3. Operation procedures which, based on the result obtained from the decision procedures, decide how the individual controls shall operate.

The decision procedures describe the statistical decisions to be made in current situations. These procedures contain operational criteria which determine the conditions for the time at which the controls shall enter into operation. When a certain operational criterion has been accomplished, the control operates and carries out the operational procedure for this function.

Those network-control functions which have been studied are priority reservation and queue limiting for the registers. For each of these functions, both theoretical analysis and computer simulations have been carried out.

2 NETWORK MODEL

In order to study the reaction of the network to overload, a simulation model for a telecommunication network has been prepared. Furthermore, a series of controls, the purpose of which is to increase the efficiency of the network during overload, have been inserted in the program. The simulation program has been written by Mr. H. Gram of the University of Oslo. The language used is SIMULA.
Two types of exchanges are used in the model:

1. LE, local exchanges. These are considered as points which generate and terminate traffic without inherent delay.

2. TE, transit exchanges. These can only through connect traffic. In these, inherent delay has been incorporated in the registers. The registers consist of one group with full availability. The transit exchanges are divided into two types, i.e., group exchanges (GE) and toll exchanges (FE).

The switching of the connections are based upon end-to-end signalling. The first transit exchange (group exchange, GE) will then maintain the connection and transmit digits to each of the inserted exchanges. Consequently, the registers of the inserted exchanges are only seized during that time when the digit transmission, switching and clearing take place, i.e. three seconds.

The network model is shown in Fig. 1.

![Fig. 1](image)

The network is dimensioned for a point-to-point congestion of 1%. Routes 1, 2, 3, 4 and 5 consist on one-way and two-way trunks.

The following measures for the traffic-performing ability of the network were chosen:

-All-over average congestion in the network, defined as:

\[
B = \frac{\sum_{i,j} a_{ij} \cdot I_{ij}}{\sum_{i,j} a_{ij} \cdot I_{ij}} \quad (1)
\]

where: \( a_{ij} \) - traffic offered from i to j.
\( I_{ij} \) - congestion from i to j, i and j being terminating exchanges.

-dispersion of the congestion on the routes, which is defined as:

\[
D = \left[ \frac{\sum_{i,j} a_{ij} \cdot I_{ij}^2}{\sum_{i,j} a_{ij} \cdot I_{ij}^2} - B^2 \right]^{1/2} \quad (2)
\]

-Mean establishing time for successfully established connections.

3 SIMULATION WITHOUT NETWORK CONTROL

To start with, the number of registers was dimensioned in presuming a utilization of 0.5 erlang per register. Thereafter, normal load and a general overload of 10%, 25% and 50% were simulated. The results are shown in Table I.

<table>
<thead>
<tr>
<th>Overload %</th>
<th>Congestion %</th>
<th>Establishing time, sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.7</td>
<td>13.0</td>
</tr>
<tr>
<td>10</td>
<td>5.3</td>
<td>13.0</td>
</tr>
<tr>
<td>25</td>
<td>13.7</td>
<td>13.1</td>
</tr>
<tr>
<td>50</td>
<td>27.1</td>
<td>13.2</td>
</tr>
</tbody>
</table>

Table I

In this case, the congestion increased with the load, whereas on the contrary, the establishing time did not increase substantially. This should indicate an overdimensioning of the registers, since the entire congestion was located to the trunks, i.e., the network proved to be trunk limited.

Thereupon, tests were performed by reducing the number of registers. The results showed that a limited reduction of the number of registers did not substantially reduce the traffic-carrying capacity. If, however, this reduction exceeded a certain limit, the traffic-carrying capacity was substantially reduced during overload in spite of small changes during normal load. This gives an indication of how sensitive to load variations a delay system is, which operates with a high degree of utilization.

The following test involved simulation of a 50-% overload with a reduced number of registers. The results are shown in Table II.

<table>
<thead>
<tr>
<th>Original numbers of registers</th>
<th>Reduced number of registers</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.1</td>
<td>72.6</td>
</tr>
<tr>
<td>12.2</td>
<td>12.7</td>
</tr>
<tr>
<td>13.0</td>
<td>21.8</td>
</tr>
</tbody>
</table>

Table II

In this case, the congestion increased to 72.6%, and instead of being located to the trunk network the entire congestion was now located to the registers, i.e., all rejection in the network was due to time-outs. Furthermore, the establishing time increased substantially.

The high degree of congestion obtained in the network was essentially due to a dispersion of the queueing-up in the network. (The register traffic did not increase to such an extent that alone it should have caused such a high degree of congestion, refer to Table X). This effect would finally cause a blocking of the registers in the group exchanges, since in these exchanges the local and transit calls use the same registers. As will appear from Table X, the group exchanges represent the bottlenecks of the system, since the probability for being delayed here is nearly 100%. In these exchanges, the registers are waiting for other, and fewer calls are forwarded to the highest level, at which the probability for being delayed is substantially lower.

4 INTRODUCTION OF NETWORK CONTROL

In order to maintain an optimal utilization of the network during all conditions, a dynamic control system is envisaged, the purpose of which is to counteract the trend to prevent dispersion and limit the effect of the various traffic disturbances which may occur.

The control facilities to be treated in what follows must be able to perform the following functions:

1. Control of waiting time (register delay).
2. Control of the trunk network.

In order to control the waiting times, a register-queue limiter, RQL, is introduced the purpose of which is to prevent an amplified feedback of register delays by limiting the queue of calls waiting for being attached to the
5 PRIORITY-RESERVATION SYSTEM

5.1 Function
A priority-reservation system incorporates the following controls:

1. Protective-Reservation Control, PRC.
2. Directional-Reservation Control, DRC.

For both of these controls, the offered traffic is divided into two types, priority and non-priority traffic, and a number of trunks are reserved for priority traffic. Calls from non-priority traffic sources are served only if more than a specified number of trunks are idle, whereas calls from priority subscribers are served as long as idle trunks are available.

PRC will cancel alternatively routed calls on a trunk group when the seizure exceeds a certain level. Priority is then given to first-routed traffic in preference to alternatively routed traffic.

DRC favors downward-going (in the hierarchy) traffic in preference to upward-going traffic on a two-way final route between two exchanges of different levels. When the seizure exceeds a predetermined level, DRC will direct-trunkize a number of two-way trunks downward in the hierarchy.

5.2 Decision Procedure
In principle, both the control functions mentioned above operate in the same way, in that the control enters into operation at a certain occupation level and gives preference to priority traffic. This results in an equalization of the grade of service (more uniform congestion conditions) in the network, at the same time achieving an overload protection for priority traffic.

5.3 Operational Criteria
In the following, quantities with subscript 1 refer to priority traffic, whereas quantities with subscript 2 refer to non-priority traffic.

\[ A_1 = y_1 \times s \] priority traffic
\[ A_2 = y_2 \times s \] non-priority traffic
\[ A = y \times s = (y_1 \times y_2) \times s \] total traffic offered to the system

The optimization criteria for this system is specified in the following way:

- For a given offered traffic \( (A_1, A_2) \) and a wanted average congestion \( (C_1, C_2) \), that number of trunks \( (n_1, n_2) \) which satisfies the requirements to congestion and at the same time implies the lowest costs, i.e., the minimum number of trunks, should be found.

A priority-reservation system is illustrated in Fig. 3.

5.4 Mathematical Model
A transition diagram for the system is shown in Fig. 4.

In each state, the probabilities are:

\[ P(j, i) \] probability of being in class \( j \), and \( i \) occupied trunks, \( j = (1, 2) \)

From the equilibrium equations in sections (a) - (1) the following expressions for the state probabilities are found:

\[ P(i) = P(1,1) = A_1^i \cdot P(0) \] (a)
\[ X < i \leq N \]

\[ P(1,1) = A_1^i \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \]
\[ + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]

\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]

\[ X < i \leq N \]

\[ P(1,1) = A_1^i \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]

\[ X < i \leq N \]

\[ P(1,1) = A_1^i \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
\[ = A_1^x \cdot P(0) - A_1^x \cdot (1 + X) \cdot \frac{P(1,1)}{A_1^i} + \frac{X \times P(1,1)}{A_1^i} \left( \frac{X+1}{A_1^i} \right) \ldots \left( \frac{X+1}{A_1^i} \right) \cdot P(2,2) \]
Consequently, in order to find the state probabilities, $P(O)$ and $P(Z, X)$ must be determined. These quantities are found by means of the normalization condition:

$$N \sum_{i=0}^{\infty} P(i) = 1$$

and the equation at section (m):

$$P(1, X+Y, y) = \sum_{i=1}^{\infty} P(Z, X, i)$$

The results are given in Appendix A.

The blocking probabilities are:

- Blocking probability for priority traffic:
  $$B_1(n_1, n_2) = P(n_1) = P(N)$$

- The blocking probability for non-priority traffic:
  $$B_2(n_1, n_2) = \sum_{i=1}^{n_1+N} P(2, i)$$

5.5 Results of the Calculations

In the following, examples are given on the use of the above formulas for dimensioning DRC and PRC. In order to find $n_1$ and $n_2$ optimization algorithm as presented by Faulhaber and Dunkel /4/ were used.

A cut-out of a network with one-way and two-way trunks between two exchanges at different levels is shown in Fig. 5.

The term $E_{AC} = 0.002$ represents the congestion on trunk group A-C. We now introduce priority reservation on group A-C by presenting to the first-routed traffic $A_P$ a congestion $E_F$, and to the alternatively routed traffic a congestion $E_A$. The results are shown in Table IV, in which the hysteresis width $Y = 6$.

6 REGISTER-QUEUE LIMITER, RQL

6.1 Function

The most important function for preventing an amplified feedback of the delay in the registers is the limiting of the queue of calls waiting for being attached to the registers. In this case, the number of calls queued up will have to be registered, and the load offered to the exchange must be reduced when the registered number of queued-up calls exceeds a predetermined limit.

6.2 Decision Procedure

As an indication of the registers being overloaded, the number of seized queue places, i.e., the length of the queue, will be used. This principle is shown in Fig. 7. In this case also, an hysteresis effect is envisaged in order to reduce the transition frequency from the one class to another. The hysteresis width is $Y + 1$.

The term $E_D = 0.02$ represents the congestion on the two-way trunks. Now, priority reservation for the two-way trunks will be introduced by representing a higher congestion to upward traffic than that presented to downward traffic. Instead of $E_D$, $E_P$ and $E_Q$ are introduced. The results are shown in Table III, the hysteresis width being $Y = 4$.

Fig. 6 represents a cut-out of a network in which trunk group A-C carries both first-routed and alternatively routed traffic.
in class 2 and remains there until the length of the queue is smaller than \( m \), \( m \) being less than \( m \). In class 1, traffic can be served both from lower-level and higher-level exchanges, whereas in class 2 only traffic from higher-level exchanges is accepted.

6.3 Operational Criteria
Above, two optimizing criteria have been defined which can be used for determining the optimal permitted length of queue for a register-queue limiter.

6.3.1 Criterion A
Criterion A consists in minimizing the total holding time for the registers in the surrounding exchanges. This wasted time comprises the following components:

1. Delay during attachment to register of those calls which must queue up.
2. Holding time in registers for all calls which are blocked due to RQL.
3. Holding time in registers for all calls which are blocked due to time-outs.

Due to analytical causes those contributions to holding times which are due to time-outs, are neglected in what follows. Consequently, the problem is to minimize the following function:

\[
T(a) = W(a) + B(a) \cdot h
\]

\( a \) - traffic offered per register.

\( W \) - mean delay for attachment to register for all calls.

\( B \) - probability for not finding a free trunk, due to RQL.

\( h \) - holding time in originating register for blocked calls.

The time \( T \) then indicates the expected wasted register holding time per offered call.

6.3.2 Criterion B
The number of queue places, \( m \), is determined in such a way that the probability of encountering a delay time greater than a certain value \( t \), shall not exceed a predetermined limit, \( p \).

\[
P(t) < p
\]

\( \frac{n}{m} \)

Consequently, a maximum of \( p \% \) of the calls are allowed to wait for more than \( t \) seconds. The values of \( t \) and \( p \) must be determined from what is assumed to be permissible before a dispersion of the queueing-up in the network is encountered.

6.4 Mathematical Model
A transition diagram of the system is shown in Fig. 8.

\[
\begin{align*}
\text{n} & \text{- number of registers.} \\
\text{a} & \text{- total offered traffic per register.} \\
\text{a}_1 & \text{- offered traffic per register for higher-level exchanges.} \\
P(j,i) & \text{- probability for being in class } j, i \text{ representing the number of queue places seized.} \\
\end{align*}
\]

\( j = \{1, 2\} \)

From the equilibrium equations in sections (a) to (q), the following expressions for the state probabilities are found:

\[
P(i) = P(1, i) = (na)^{i-n} \cdot \frac{n}{i} \cdot P(n)
\]

\( n < i < x \)

\[
P(i) = P(1, i) = a^{i-n} \cdot P(n)
\]

\( X < i < n+m \)

\[
P(1, i) = a^{i-n} \cdot P(n) - P(2, X) \sum_{j=0}^{i-X} \frac{i-j}{1-a_j}
\]

\[
P(2, i) = P(2, X) \sum_{j=0}^{i-X} \frac{i-j}{1-a_j}
\]

\[
P(1) = a^{i-n} \cdot P(n) + \left[ \frac{1-a_i}{1-a_j} - \frac{1-a_i}{1-a} \right] \cdot P(2, X)
\]

\[
P(2) = \frac{1-a_i}{1-a_j} - \frac{1-a_i}{1-a}
\]

\[
P(i) = P(2, i) = a^{i-n} \cdot P(n) + \left[ \frac{1-a_i}{1-a_j} - \frac{1-a_i}{1-a} \right] \cdot P(2, X)
\]
Here, all the state probabilities are expressed by \( P(n) \) and \( P(2, X) \). These expressions are found by means of the normalization condition:

\[
\sum_{i=0}^{n+M} P(i) = 1
\]

and the equation in section (0):

\[
P'(t) = P(2, X) \frac{n}{8}
\]

The results are given in APPENDIX B.

The following quantities may now be found:

**Delays:**

Blocking probability:

\[
B = P(\text{controller operated}) = \sum_{i=K}^{n+M} P(2,i)
\]

The results are based on criterion A, whereas the results shown in Fig. 10 are based on criterion B.

**6.5 Results of Calculations**

In the following, we shall give some examples on the use of the formulas developed for the calculation of optimal queue length. These calculations were carried out under the presumption that RQL rejects approximately all incoming traffic to that exchange in which RQL has operated. Fig. 9 shows the calculations based on criterion A, whereas the results shown in Fig. 10 are based on criterion B.

**Table V**

<table>
<thead>
<tr>
<th>Congestion</th>
<th>Dispersion</th>
<th>Establishing time, sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without control</td>
<td>27.1</td>
<td>2.2</td>
</tr>
<tr>
<td>PRC</td>
<td>26.9</td>
<td>1.3</td>
</tr>
<tr>
<td>DRC</td>
<td>26.3</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Table VI**

<table>
<thead>
<tr>
<th>Route</th>
<th>Number of operations</th>
<th>Operation time in % of simulation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79</td>
<td>32.0</td>
</tr>
<tr>
<td>2</td>
<td>83</td>
<td>44.9</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>33.1</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>32.8</td>
</tr>
<tr>
<td>5</td>
<td>72</td>
<td>31.1</td>
</tr>
</tbody>
</table>

**7.1 Protective-Reservation Control, PRC**

The PRC was implemented on all routes carrying alternatively routed traffic, i.e., on routes 1, 2, 3, 4, and 5. The number of trunks reserved for first-routed traffic was 3, the hysteresis width being \( Y = 5 \).

**7.2 Directional-Reservation Control, DRC**

The DRC was implemented on routes 1, 2, 3, 4, and 5. The number of trunks reserved for downward traffic was 2, the hysteresis width being \( Y = 3 \).

As will appear from Table V, the introduction of DRC does not represent any substantial improvement of the traffic performance. The reason for this, possibly, is that the time delay during the switching of the connections was small and that the network model was relatively simple, so that the relative difference in the completion probability of upward-going and downward-going traffic had no substantial influence on the traffic performance.
As will appear from Table VII, the congestion increased substantially on the trunk groups upwards in the hierarchy, whereas it was heavily reduced on the downward groups.

Table VIII shows the number of times DRC operated on each trunk group, as well as the total operation time in percent of the simulating time.

<table>
<thead>
<tr>
<th>Route</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of operations</td>
<td>68</td>
<td>72</td>
<td>62</td>
<td>61</td>
<td>80</td>
</tr>
<tr>
<td>Operation time in % of simulation time</td>
<td>20.2</td>
<td>30.4</td>
<td>24</td>
<td>29.8</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table VIII

8 SIMULATION WITH REGISTER-QUEUE LIMITER

The register-queue limiter RQL was implemented in all transit exchanges. These simulations were carried out with a 50-% overload and a reduced number of registers. In this case, the registers were somewhat underdimensioned since the congestion was increased to 72.6%, the entire congestion being located to the trunk groups. Consequently, these simulations would indicate what might be achieved by introducing queue limitation under extreme overloads.

At the group exchanges, the number of queue places \( m = 5 \), the hysteresis width being \( Y = 2 \). At the toll exchanges the corresponding numbers were \( m = 4 \) and \( Y = 1 \).

Table IX is a call summary for simulations with and without RQL.

<table>
<thead>
<tr>
<th>Without control</th>
<th>RQL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of offered calls</td>
<td>18026</td>
</tr>
<tr>
<td>Total number of carried calls</td>
<td>4954</td>
</tr>
<tr>
<td>Total number of blocked calls</td>
<td>13084</td>
</tr>
<tr>
<td>Number of blocked calls because of not finding any register</td>
<td>13084</td>
</tr>
<tr>
<td>Mean establishing time sec.</td>
<td>21.8</td>
</tr>
<tr>
<td>Total offered traffic in erlang</td>
<td>870.8</td>
</tr>
<tr>
<td>Carried traffic in erlang</td>
<td>239.3</td>
</tr>
<tr>
<td>Total mean congestion</td>
<td>0.726</td>
</tr>
</tbody>
</table>

Table IX

As will appear from Table IX, when introducing RQL, the congestion was reduced from 72.6% to 27.3%, the establishing time being reduced from 21.8 sec. to 13.6 sec. This result clearly indicates how sensitive a network is for congestion in the registers during a general overload.

After the introduction of RQL, the entire congestion was moved from the registers to the trunk groups. This was due to the fact that a greater number of successful connections were established, resulting in a longer holding time on the trunks.

Data for each transit exchange with and without RQL are shown in Table X. The time congestion, i.e., the percentage of time that all registers were occupied, was extremely high without RQL for the group exchanges, (6, 7, 8, 9 and 10) but it was relatively moderate for the toll exchanges (11, 12, 13 and 14). With RQL, the time congestion was substantially reduced for the group exchanges, whereas for the toll exchanges it was rather unchanged. Consequently, the group exchanges seem to be the bottlenecks of the network. This is what might be expected, as in a network with end-to-end signalling, exchanges equipped with outgoing registers would be most sensitive to congestion. In Table X, the call congestion indicates the percentage of calls that were blocked due to time-outs.

<table>
<thead>
<tr>
<th>Exchange</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of operations</td>
<td>39</td>
<td>14</td>
<td>14</td>
<td>32</td>
<td>69</td>
<td>308</td>
<td>25</td>
<td>39</td>
<td>14</td>
</tr>
<tr>
<td>Operation time in % of simulation time</td>
<td>1.96</td>
<td>0.58</td>
<td>0.99</td>
<td>1.66</td>
<td>2.59</td>
<td>15.29</td>
<td>0.64</td>
<td>1.31</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Table XI

As will appear from Table XI, exchange 11 clearly was the most critical one since its RQL was operated for more than 15% of the simulating time. These simulations clearly show how efficiently RQL did increase the traffic performance of the network. The RQL maintained the register queues on a limited level and thus prevented a build-up of queues in the exchanges. Congestion and time delays were not given any opportunity to spread, and a locking-up of the group-exchange registers was avoided.
9 CONCLUSION

In the above sections, the strategy of a priority-reservation system and a register-queue limiter have been presented. During the study of these facilities, analytical calculations were performed in order to determine the optimal operational criteria and simulations in order to estimate the effect on the traffic performance of the network.

The network model was too simple to give a complete image of the effect of introducing priority reservation. However, the simulations showed that PFC and DRC were operated on the individual routes in correspondence with the strategy envisaged. The simulations with register-queue limiter clearly showed the efficiency of this facility during overloads, but since in this case the common equipment was rather simplified with only one type of register, the effect in a real network might not be as high.

In order to check that the mathematical formulas developed give optimal operational criteria, a series of simulations with different values of the operational criteria will have to be carried out. This will be done in the next phase of the work.

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References.


APPENDIX A

Calculation of priority-reservation system.

Substituting the state probabilities, equations (4) to (8) in the normalizing conditions, equation (9), we get

\[
P(0) = \frac{1 + P(2, X)}{1 + \sum_{i=0}^{\infty} S_i X^i} = \frac{1 + P(2, X)}{1 + \sum_{i=0}^{\infty} S_i X^i}
\]

having substituted

\[
S_i = \frac{1}{A_1 A_2^{i-1}} \left( \frac{X}{A_1} \right)^i \frac{X+Y}{A_1^{i-2}} \frac{1}{A_1^{i-1}}
\]

The term \(P(2, X)\) may be found from equation (10), where the term \(P(1, X+Y)\) is given by equation (5). Substituting then \(P(0)\) from equation (26) in the term \(P(1, X+Y)\) as given by equation (5), we get \(P(1, X+Y)\) expressed by \(P(2, X)\). The terms thus found for \(P(2, X)\) and \(P(0)\) are given by equations (29) and (30).
APPENDIX B

Calculation of Register-Queue Limiter.

Substituting the state probabilities, equations (15) to (20) in the normalizing conditions, equation (21), we get

\[ n \sum_{i=0}^{\infty} \text{P}(i) + \sum_{i=0}^{\infty} \text{P}(i+n) + \sum_{i=0}^{\infty} \text{P}(i+X-n) + \sum_{i=0}^{\infty} \text{P}(i+X+M-n) = 1 \]  

(31)

giving the following relation between \( \text{P}(n) \) and \( \text{P}(2, X) \):

\[ \text{P}(n) \left( \frac{1}{\text{E}(na)} \right) + S_1 + S_2 + S_7 + \text{P}(2, X) \left[ S_3 - S_4 - S_5 + S_6 + S_8 \right] = 1 \]  

(32)

where: \( \text{E}(na) \) - Erlang's loss formula.

Another relation between \( \text{P}(n) \) and \( \text{P}(2, X) \) may be found from equation (22). Thus, substituting in equation (22) the term \( \text{P}(i, n+m) \) as found from equation (17), we get

\[ \frac{n+M-1}{n+M-1} \text{P}(i) \cdot \text{P}^{(i)}(n) = e^{-(n+M-1) t} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(43)

\[ \text{P}^{(i)}(n) = \sum_{i=n+M-1}^{n+M-1} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(44)

Average waiting time in state i:

\[ W(i) = \frac{n}{n+M-1} \text{P}(i) \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(45)

Average waiting time for all calls:

\[ W = \sum_{i=n}^{n+M-1} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(46)

Another relation between \( \text{P}(n) \) and \( \text{P}(2, X) \) may be found from equation (22). Thus, substituting in equation (22) the term \( \text{P}(i, n+m) \) as found from equation (17), we get

\[ \text{P}(2, X) = \text{P}(n+1) \cdot \text{P}^{(n+1)}(i) \]  

(47)

\[ \text{P}^{(n+1)}(i) = \sum_{i=n}^{n+M-1} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(48)

A table of equation (49) will be found in /5/.

Calculation of waiting times:

The conditional probability for encountering a waiting time greater than \( t \) when the system is in state \( i \):

\[ \text{P}(>t/i) = e^{-x} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(49)

\[ \int_{0}^{\infty} x \text{e}^{-x} dx = \frac{1}{2} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(50)

\[ \int_{0}^{\infty} x^2 \text{e}^{-x} dx = \frac{1}{2} \int_{0}^{\infty} \text{E}^{(a)}(t) \frac{a}{n+M-1} \int_{0}^{\infty} e^{-x} dx \]  

(51)