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Designing a Communication Network Using Simulation

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In this paper, a private telephone communication network of an electrical energy distribution company has been studied analytically and through discrete event system simulation. Considering the pitfalls and difficulties associated with the analytical approach in designing such a network and the power and performance of a simulation methodology in this regard, a simulation model was developed using GPSS/H simulation language. After data collection and analysis, model development and validation, initial transient study and design of experimental phases, the model was applied to determine the operating performance of the current system, as well as to evaluate the performance of any newly designed network before the installation and implementation of the new equipment.

INTRODUCTION

One of the essential roles of a communication network is to satisfy the users' needs, demands and expectations. Higher system availability and adequate system operation for the current users, simple system development and comprehensive communication ability for the new users are the goals of the system manager. Monitoring the state and condition of the network is quite important in evaluating system performance and specifying user satisfaction. By monitoring the system, the manager is able to understand system behavior and recognize system bottlenecks and critical points. Besides, in order to satisfy new users' needs and improve system performances, especially at peak times, network design is another task of the system manager [1].

Determining the critical points and bottlenecks of a communication network is possible only through analyzing system behavior. This analysis usually contains measurements of system parameters such as throughput, the probability of losing a connection, system delays, the number of demands waiting for connections and the utilization of system nodes and communication lines. This analysis is usually made through one of the following four different general procedures: (1) Analytical modeling, (2) Experts' experience, historical experiments and linear estimation, (3) Experiments with the real system and (4) Simulation modeling.

The first and fourth approaches are fundamental disciplines that engineers and researchers working in this field must be familiar with, in order to evaluate alternative concepts and designs. Furthermore, they are the two main methods for carrying out network performance analysis and planning. The analytical method (i.e., queuing theory) is an exact but less applicable method, because it requires many assumptions regarding system behavior and functions that may not be appropriate (impossible to formulate or solve) and the user must be familiar with sophisticated mathematical and statistical formulation. However, in order to grasp a general overview of the system and approximate the system parameters, analytical modeling and mathematical methods are usually useful in the early stage of a communication network design. The simulation approach, which provides a good rather than exact solution, has many desirable properties. It is simple to apply and understand; does not require many unrealistic assumptions; the user is not required to have a good mathematical foundation and it is easy to explain to system users, as well as system managers [2-8]. The use of a simulation approach is justified in three cases: (1) When the analytical modeling is extremely hard to apply, (2) The analytical

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modeling can be applied, but the solution to the modeling is very difficult (if not impossible) to reach and (3) Many different and unrealistic assumptions in analytical modeling have to be made, such that the modeling task become possible, but the solution is far beyond reality and of no use.

The second approach is limited in application. Since the relationship between the parameters of the network, such as load, holding time per connection or demand frequencies, are not linear in nature, one should be very careful in applying the experts' experience and using the linear estimation. The third procedure, because of its highly expensive nature, is a very unusual and uneconomical method [2,9-11].

The main objectives in applying a typical simulation modeling in the design and analysis of communication networks are as follows [2,5,6,12]:

1. To understand network performance under specified circumstances,
2. To compare several alternative designs,
3. To calculate the effect of variations in network performances,
4. To improve network performance,
5. To reduce the costs of system expansion and installation,
6. To make sure that the network satisfies its planned objectives,
7. To identify bottlenecks before installing the network,
8. To reduce the time required in expanding the system.

Furthermore, one can only answer many specific communication problems and questions through a simulation analysis. Some of these questions are: How does the network deal with an increase in traffic load? If a link in the network were to break, how would the system respond? How does one design a new communication network? What is the probability of a call not being connected? etc. [5,12,13].

A typical simulation analysis of a communication network is undertaken through five main phases. Phase one consists of system study and recognition. Necessary data collection comes next in phase two. Demand modeling is done in phase three. A response modeling is undertaken in phase four and, finally, the output analysis is the fifth phase of the analysis.

The demand for resources in a communication network, which is sensitive to the type of network application, has a random behavior and is modeled by two types of random variables. One is for the time between two consecutive calls and the other is for the time used when holding the line. Both of these random variables, usually, are analytically modeled by an exponential distribution. However, in simulation modeling, the actual arrival traffic is measured historically and, then, is deployed to the model. Response modeling in a simulation analysis is the most important part of the study. In order to develop a computerized model of the real system, one should consider the relation between the level of details, complexity of model and time required for analysis. The more details the model contains, the more complexity and time will be involved. In the output analysis of the simulation modeling, one should note that since the input of the model is random in nature, the output is also a random variable. Hence, running the simulation model of the system only once and treating the output as being the true system performance is more like tossing the dice just once and concluding that the outcome will continuously be the true result of the experiment. Therefore, to increase the preciseness of the results and to reduce the variance of the estimators, the following considerations have to be made: How long should the model be run? How many independent times (replications) should it be run? What should the length of the transition (warm-up) period be before statistics are collected? etc.

Also, in modeling communication networks, system performances are usually measured in the steady-state phase. In general and in short, the modeler should have a good knowledge of simulation modeling and classical, as well as non-classical, statistical analysis. A combination of this knowledge and personal creativity provides the managers with a reliable and useful understanding of the real system and answers to his/her questions about the system [2,6].

In this research, the simulation modeling approach is applied to a communication network system in the real world. The behavior of such a system is so complicated that the analytical approach is either very hard to apply or so many unrealistic assumptions have to be made to model the system. It will be seen that through a simulation analysis, one can recognize system performance and bottlenecks such that he/she can plan to prepare for extending the network to satisfy its demands in a reasonable and economical manner.

In the remaining part of the paper, first the existing telephone communication network under study is described. Then, a brief description is given on the analytical approach. The statement of the problem, data collection procedure and case representation come next. Then, the simulation language is selected and the simulation model of the telephone communication network is described. Model verification and validation comes next and the initial transient, run length and number of independent replications of the model are studied in the next section. Then, the model undergoes experiment and, finally, the paper is concluded with some recommendations for future research.

EXISTING COMMUNICATION NETWORK

Optimum utilization of huge investments made on production, transformation and distribution of electrical energy depends upon the existence of a reliable communication network. This communication network usually covers power plants, high voltage stations, operation centers, maintenance and repair stations, control centers of the power network and different offices. This communication network also provides different communication methods, such as voice transfer, data transfer and control signals for power network managers.

The private communication network of the Ministry of Energy is the second biggest communication network in the Islamic Republic of Iran; the first being managed by the Ministry of Post, Telegram & Telephone. This network covers the electrical energy transfer division of the Ministry of Energy, which consists of more than 150 switching centers, more than 1000 communication channels on high-voltage Power Line Carriers (PLC) and many macro-wave communication lines. The need for future development and extensions of power transfer lines and the electric companies' tendency to use communications in lower voltage transfers (i.e., 132 kilo volts and 63 kilo volts), make an extension of the communication network necessary.

Two of the most important engineering and economical considerations in designing such a major private network are:

1. The reliability of such systems, compared to the one used in public communication networks, must be very high;
2. The cost of establishing a private channel in this network depends on different parameters, such as the type of communication environment and the length and number of channels in the communication route, etc. In most cases, it varies between 10 and 90 thousands dollars per channel. Hence, the economical aspect of the expansion plan is as important as the engineering aspect. In the management of communication networks, maximum utilization of the existing capacity is an important way to minimize the number of new communication channels in a sense that all of the present and future communication needs are satisfied, the required reliability is achieved and, most importantly, a low network blocking is guaranteed [14].

This research studies the telephone communication network of Yazd Province Regional Electric Company. This network satisfies the following demands: (1) Telephone communication among the operational, technical and administrative centers, (2) Data and control command transfers in 63 kilo volts dispatching centers, (3) Maintenance command transfers and (4) Direct data and telephone communication among 400, 230 and 132 kilo volts centers and dispatching centers. Between the above, only numbers (1) and (3) will be considered in the simulation study. The others are not random in nature and the number of required channels in those cases is easily determined by elementary mathematical methods.

ANALYTICAL APPROACH

A telephone communication network is one of the most complicated queuing systems that is made up of communication channels and switching centers. Today, designing such a network is undertaken so that the probability of connecting a call would be high during peak hours. To design a public telephone communication network, a pre-specified probability distribution (Poisson) for "number of demands per unit of time" and a pre-specified probability distribution (exponential) for "duration of a call", with the mean based on standards and cultural behaviors, are assumed. Then, for a pre-specified level of network blocking, the required number of channels is determined using Erlang distribution. It is assumed that the instantaneous number of demands is equal to practical infinity. However, since the number of users is limited in private networks, the number of demands per period of time is not independent of the number of demands that are being served at that period, hence, tables based on the Engset probability distribution are used. In this case, for a known traffic, the number of required channels is usually lower than that of public networks. For a specific trunk group, having the value of three parameters out of four possible parameters would be enough to determine the value of the fourth parameter. These parameters are: (1) Number of channels, (2) Applied traffic intensity, (3) Level of instantaneous demands and (4) Grade of service (system utilization percentage) [15].

It is worthy to note that the independent and identically distributed random variables modeling the traffic generating resources for a specific trunk group are basic assumptions and are fundamental in deriving the tables in the Engset method. In cases where customers are the only traffic generating resources, these assumptions are usually true, while, in cases where the traffic generating resources are a combination of customer and other trunk groups, they are usually not. Moreover, there are some limitations in applying the Engset tables, which make computation very complicated. These limitations are:

1. Telephone traffic generators are not inherently identical;
2. Alternative routes for specific connections are not considered;
3. Estimating the amount of excess traffic of a route on other routes is not possible;
4. When specific priorities are considered, the Engset method is not efficient to determine the number of required channels;
5. Customer limitation level to the entire network cannot be considered.

The above limitations, plus the need to estimate the general performance of the network through the parameters, such as the overall system grade of service (the percentage of successful connections out of the total requests), all justify the use of computer simulation.

STATEMENT OF THE PROBLEM

To design and analyze the required telephone communication network, a simulation approach is taken, such that, before purchasing and installing expensive equipment, the following objectives will help managers make decisions. It is clear that this research is general in nature and, by employing different data and minor changes, the same objectives can be achieved in different telephone communication networks of the same kind:

1. Evaluating the performance and bottlenecks of the proposed telephone communication network,
2. Evaluating the performance of any extended telephone communication network,
3. Offering a procedure to statistically optimize the extension plan of the current network in terms of maximum channel utilization, minimum number of channel replacements, adding an economically justified number of channels to the network, while increasing (or at least maintaining) system reliability.

DATA COLLECTION

Traffic generators in a telephone communication network are an input to the simulation model and, once the necessary data is gathered, their statistical properties could be derived by statistical procedures. Telephone center metering devices (network-analyzing device in digital systems) usually perform the data collection phase automatically. Many such devices can provide the user with statistics on network traffic.

Since the telephone communication system under study is relatively old and is an analogue (as opposed to digital system), the data collection task could not be made automatically. Hence, the required data was collected through a questionnaire and interviewing method. The raw data was, then, processed and the necessary information on the number of phone calls per hour at different locations of the telephone communication network, as well as the average duration of a phone call, was obtained. The results are summarized in Table 1.

Table 1. Current number of phone calls per hour and duration.

No.	Location(s)-Location(s)	Number of Calls per Hour	Average Duration of Phone Calls (Minute)
1	Super distribution dispatching center with:		
1-1	200 kilo volts post	3	3
1-2	Each of the 230 kilo volts posts	2	3
1-3	Each of the other posts	1	3
1-4	The management building	1	3
2	230 kilo volts posts with each other	2	3
3	Each of the feeder posts with the posts in direct electrical connections	1	3
4	The management building with:		
4-1	The university post	2	3
4-2	Each of the technical-administrative center	1	3
4-3	The dispatching center	1	3
5	Each of the technical-administrative center with its neighbor post	1	3
6	The management building with the electric distribution company	2	3

Table 2. Posts and technical-administrative centers coding.

No.	Station Name	Code	No.	Station Name	Code
1	Bafgh 1 (132 kv)	B	21	South Yazd (63 kv)	Y1C
2	Bafgh 2	BA	22	Fahraj (63 kv)	Y1D
3	Kooshk (132 kv)	BB	23	Nir	Y1E
4	North Yazd (132 kv)	N	24	Poshtkooh (63 kv)	Y1F
5	Salman	NA	25	Feiz Abad (63 kv)	Y1G
6	Ghesmat 2	NB	26	Yazd 2 (400 kv)	Y2
7	East Yazd (63 kv)	NC	27	Shahrake Sanati (63 kv)	Y2A
8	Current building	ND	28	ChadorOmlo (230 kv)	C
9	Emamshahr 1(63 kv)	E	29	New manag. building	M
10	Shahid Rejaei 1,2	EA	30	Yazd University (63 kv)	U
11	Ghesmat 1	EB	31	Safaieye	UA
12	Emam Shahr 2	EC	32	Power dist. Co	UB
13	West Yazd(63 kv)	G	33	Darvazeh Ghoran (63 kv)	D
14	Taft 1	GA	34	Ashkadz	DA
15	Taft 2	GB	35	Ardakan 2 (230 kv)	A
16	Azadshahr	GC	36	Meibod 2	AA
17	West Storage	GD	37	Meibod 1 (63 kv)	AB
18	Yazd 1 (400 kv)	Y1	38	Ardakan 1,3	AC
19	Mehriz 1 (63 kv)	Y1A	39	Ardakan 1,2 (63 kv)	AD
20	Mehriz 2	Y1B			

CASE REPRESENTATION

Based on the existing communication network and through the questionnaire and interviewing method, the telephone network under study, which is suitable for the corresponding high voltage network and the technical-administrative locations, was designed, which is given in Figure 1, along with the communication demands. The location of the telephone centers, allocation of customers to these centers and communication routes, are designed, based on some limitations on the one hand and on the number of degrees of freedom on the other. In Figure 1, the telephone centers are located at Yazd 2, Yazd 1, Ardakan 2, ChadorOmlo, North Yazd, Bafgh 2, Emam Shahr 1, Darvazeh Ghoran, Yazd University, West Yazd and the New Management Building. Administrative offices, technical centers and different electrical posts, which do not have telephone centers, become the customers of one of the above telephone centers (internal customers). For future purposes, a code was assigned to each center and to each customer in the network. Table 2 contains these codes. The communication demands of the technical and administrative centers are summarized in Figure 2. The alphabetical codes in Figure 2 come from Table 2, while the number of plus and cross signs in Figure 2 correspond to the number of operational and administrative calls per hour. In addition, the number of internal customers to each telephone center is given in Figure 1, along with the external customers. The objective of this research is to find the necessary number of channels in each route such that the required network conversations have a good chance of being established on the first try. Table 3 summarizes the results of the analytical method. The first column of this table contains the route numbers given in Figure 1. The next column contains the sum of the traffic on each route, which is divided by 60 to get the Erlang number in the 3rd column. Based on the traffic intensity computed in column 2, one percent blocking and infinite demand assumptions, the 4th column of Table 3 is derived [5]. The infinite number of demands on the sub-routes, originated from both telephone centers on two sides of the main routes (the internal as well as the external customers of the centers), are then considered to compute the numbers in the 5th column of Table 3. Using pre-calculated tables [15], the last column of Table 3 is derived, based on the numbers in column 5 and the allowed blocking percentages (less than 1 percent).

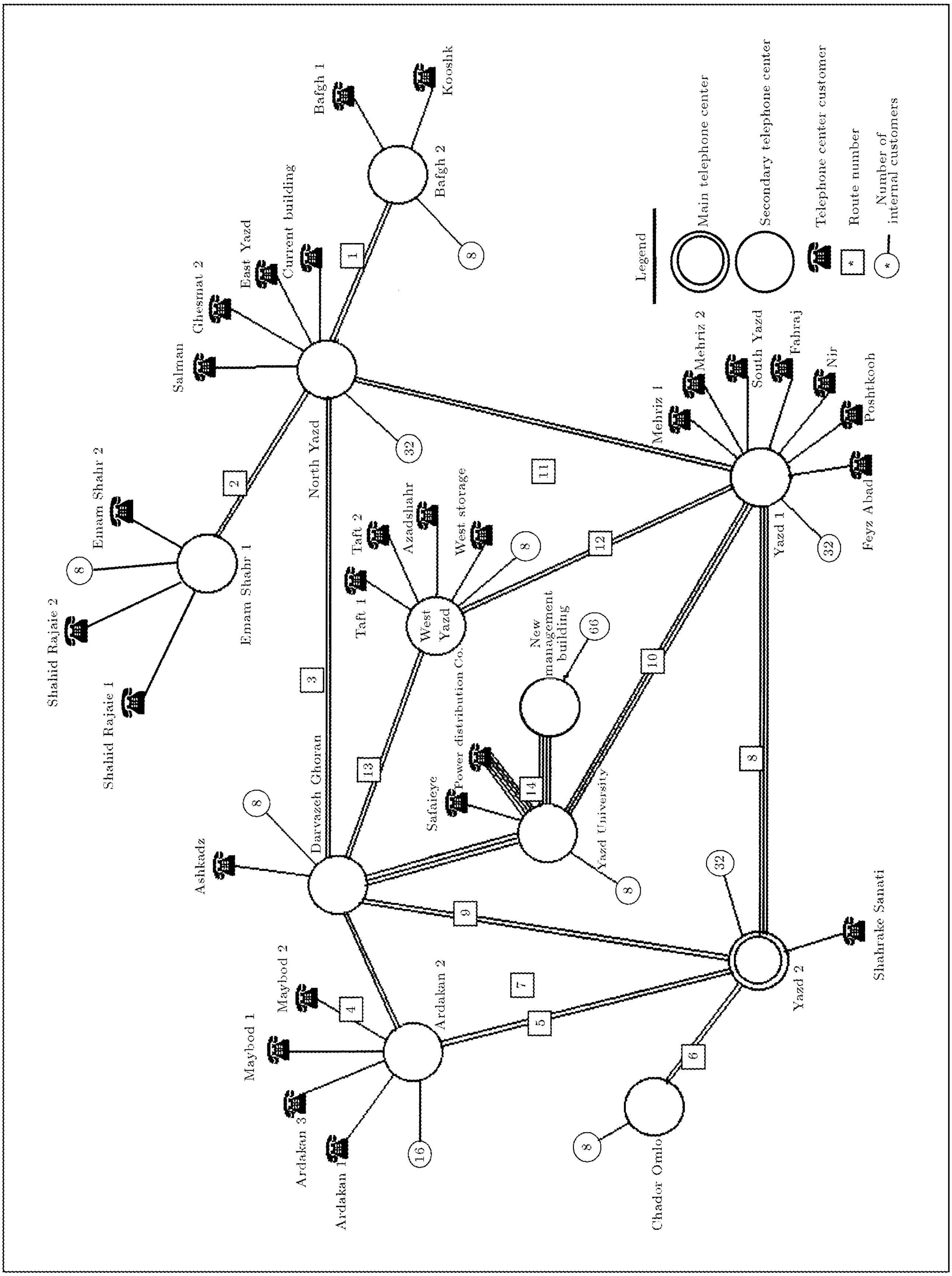

Figure 1. Telecommunication network of the regional power company.

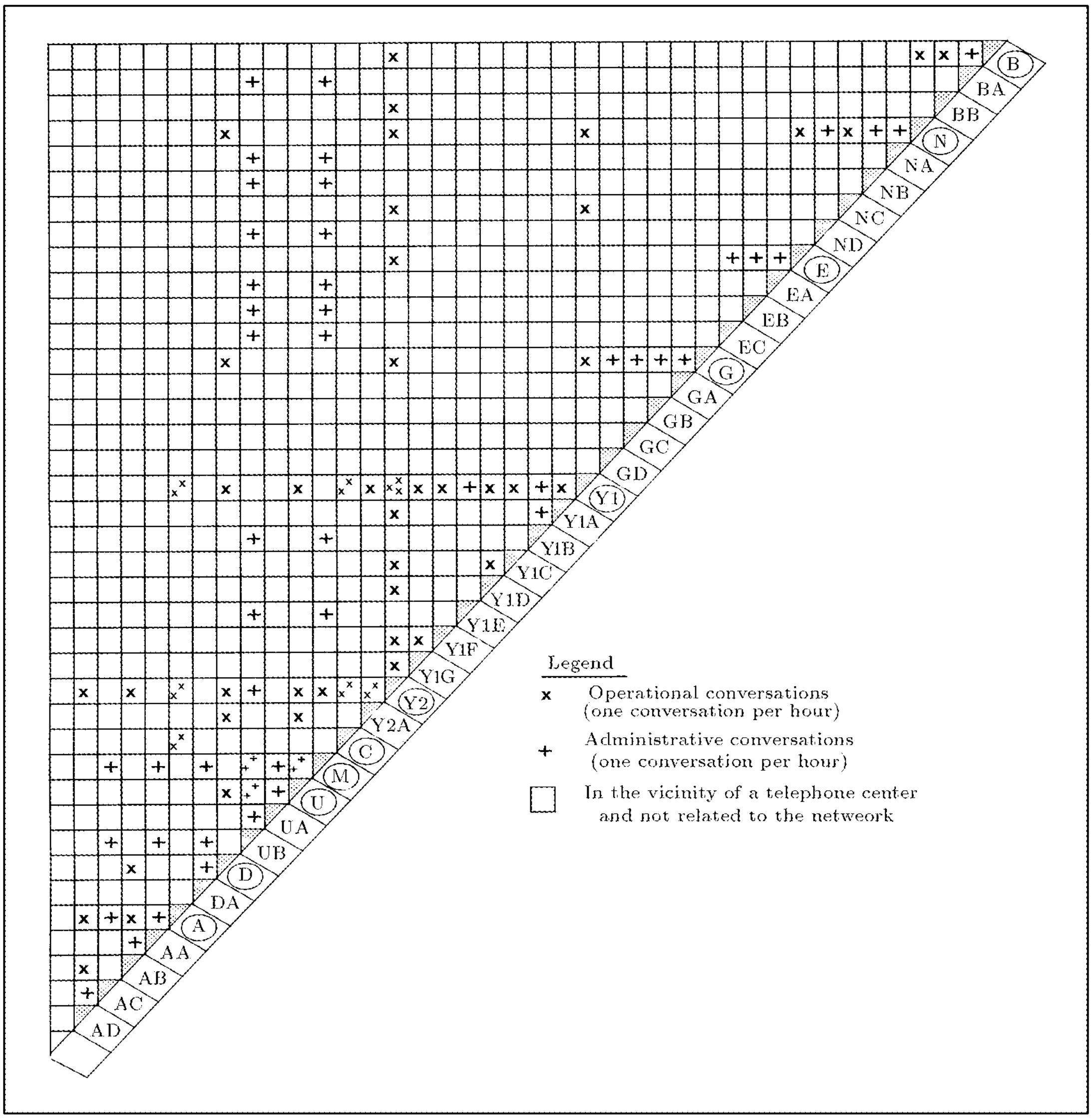

Figure 2. The communication demands of electrical posts and technical-administrative centers.

SIMULATION LANGUAGE SELECTION

Simulation modeling can be done in a few ways. Firstly, one can write his or her own simulation program using general programming languages such as C, FORTRAN, Pascal, etc. This approach is quite applicable for small and simple networks, but, as the network becomes larger and more complex, the programming task becomes more difficult. Secondly, one can use a general-purpose simulation language such as GPSS [8], SLAM [16], AWESIM [17], SIMAN [18], SIMUL8 [19] or ARENA [13]. These languages handle most of the simulation "internal" and the user only has to worry about the modeling task [6,7]. Lastly, some simulation tools, such as GENESIS, TOPNET, TOPSIM, COMNET, OPNET, etc. are specifically designed for simulation modeling of communication networks [10,20-22]. These tools have all the simulation details built-in and, usually, provide the user with icons for different types of networks, such as token ring, Ethernet, FDDI, ATM, etc. They may even have a higher layer protocol, such as TCP/IP defined. In this method, the user only has to build a network using the icons. Of course, in order to use these tools, the user must have a very good understanding of his or her network and traffic pattern, etc., otherwise his or her study may have misleading results.

Selecting a suitable simulation language depends on many factors. These factors are:

1. The system to be simulated,
2. Cost (software and hardware purchasing, training costs, software and hardware maintenance costs, etc.) considerations,
3. User friendliness (ease of learning, developing, debugging, etc.),

Table 3. Analytical modeling results.

Route No.	Total Traffic (Minutes Per Hour)	Erlang Number	No. of Channels for Infinite Demand and 1% Blocking	No. of Demands	Blocking Percentage	No. of Channels
1	15	0.25	3	57	2.50	2
2	24	0.40	3	58	5.25	2
3	30	0.50	4	69	7.70	2
4	15	0.25	3	47	2.50	2
5	24	0.40	3	66	5.40	2
6	18	0.30	3	51	3.36	2
7	24	0.40	3	67	5.40	2
8	51	0.85	4	93	4.47	3
9	60	1.00	5	46	5.99	3
10	54	0.90	5	74	5.01	3
11	36	0.60	4	97	10.05	2
12	21	0.35	3	67	4.37	2
13	18	0.30	3	39	3.18	2
14	66	1.10	5	88	0.40	5

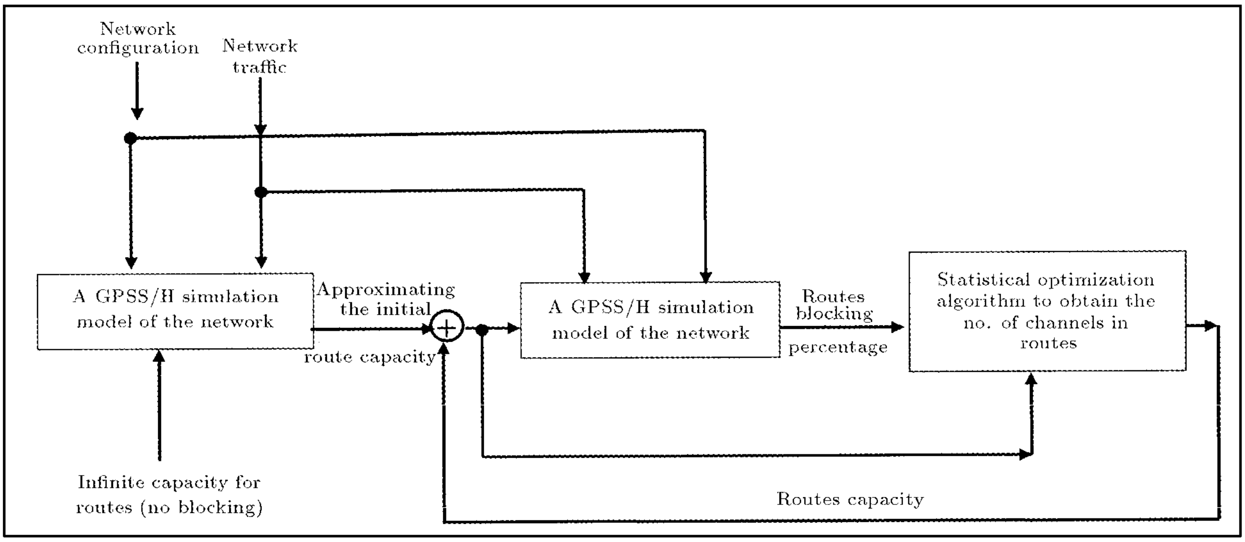

Figure 3. General simulation approach.

4. Technical performance (model flexibility, maximum model size, random number generators, data management, ability to design the experiments, statistical and mathematical abilities, graphical performance, post processor, model library, etc.),
5. User support (technical references, guaranties, training methods, etc.) [1,5,23].

In this research, the GPSS/H (General Purpose Simulation System) simulation language is adopted because of its availability, documentation, understandability and ability to model the communication network.

SIMULATION MODEL OF THE COMMUNICATION NETWORK

The general overview of the simulation modeling process for the telephone communication network is depicted in Figure 3. In this figure, the first and second GPSS/H models are identical, except that the first one

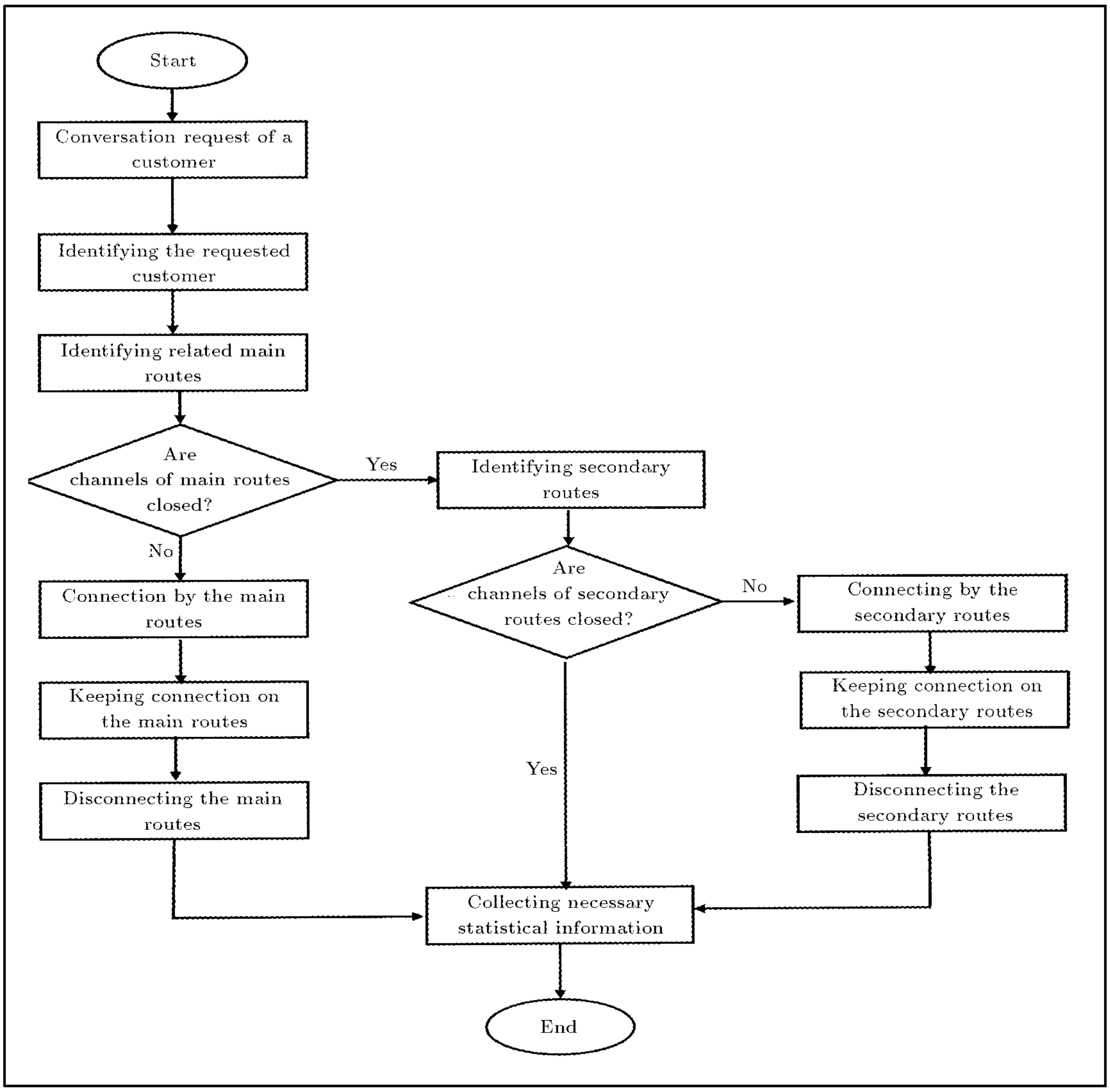

Figure 4. General flowchart of the simulation program.

will run on a system with the routes considered to contain infinite capacity. In this case, the maximum contents from the GPSS/H standard storage report will determine the initial route capacities. Part of the output from the second GPSS/H model will determine route, as well as network, utilization. The output of the second model will be the input for the statistical optimization algorithm, such that the optimal number of channels for the routes will be determined. In this algorithm, one can apply the Response Surface Methodology (RSM) to find a good solution that is statistically optimum, in terms of the number of channels per route. RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several factors and the objective is to optimize this response. In RSM, regression analysis is used, along with the method of steepest ascent (descent), repeatedly, to determine a region of the factor space in which operating requirements are satisfied [24,25]. In this research, the response could be network utilization or blocking percentage and the factors affecting the response are network configuration, input traffic and channel capacities. Note that the objective of this research is to determine the number of channels in the network routes such that, with a given network configuration, input traffic and channel capacities, the desired routes and network utilization, as well as the desired network blocking percentage, will be obtained. Hence, the statistical optimization algorithm is considered to be beyond the scope of this research.

The general flowchart of the simulation model is given in Figure 4. This figure depicts how the simulation model works for an entity. According to Figure 1, each of the fourteen main routes in the network is simulated via storages. The capacities of these storages are given in the 7th column of Table 3. The simulation model consists of two main parts. In the first part, the traffic units are simulated through transactions with their own parameters. For each of the traffic resources, which are the telephone centers, posts and administration offices, one GENERATE block is defined in the simulation model. Considering conversational needs from Table 2, the time between two conversational requests was modeled, according to exponential distribution. In order to determine the destination of the generated traffic request, the discrete FUNCTIONs were applied, with an independent random number stream. These functions were defined, based on the information in Table 2 and Figure 3. For example, consider Bafgh 2 (B) post. This post needs to contact the other posts twice an hour: One with North Yazd (N) and the other with the regional dispatching center in Yazd 2 (Y). Hence, once a traffic request is generated through the GENERATE block of GPSS/H, it goes to N and Y, with an equal probability of 0.5, by the functional transfer block. In this regard, one of the two pre-determined routines is called BNP for Bafgh 2 to North Yazd, or BY2P for Bafgh 2 to Yazd 2.

In the second part of the simulation model, the way of connecting different centers is simulated. It should be noted that in this specific network, there are two ways to connect centers: the primary and the secondary route. The initial and final destination of each conversation are denoted with labels. For example, in the primary routes, BNP refers to a conversation between the B and the N centers. If this conversation is made through the secondary route, the SR (Secondary Route) prefixes to the BNP as SRBNP. Using the GATE block, the routes are first checked for available capacity. Then, the conversational routes are filled with requests through the ENTER block. Note that the telephone communication network under study works as a loss system, i.e., if the primary and secondary routes were both busy, the customer would hear a busy beep. Hence, there would be no waiting line of customers requesting to use the ENTER block. The second objective of using the GATE block is that if a customer were to request the use of a channel and, if the requested channel in the primary route were busy, then, it would try a channel on the secondary route. In general, the way the centers are connected is simulated by a routine consisting of some GATE and ENTER blocks. Also the ADVANCE, LEAVE and TRANSFER blocks are used in this routine to hold the transaction, leave the corresponding resource and route to one of the two TERMINATE blocks in the model, respectively. Each transaction can be destroyed in two ways. The first TERMINATE block (STORFF) is for main traffic and the second TERMINATE block is for overflow traffic. Also, for calculating and collecting non-standard output, some amper-variables are used in the simulation model.

Route and network utilization, amount of overflow traffic and network blocking are defined as system performance measures, which are obtained as follows:

a) Route utilization is the ratio between the total amount of time the demands are served by the route to total simulation run time. This number is a part of the standard storage output;

b) Network utilization is the ratio between the total amount of time the network is busy serving demands to total simulation run time. This number is also a part of the standard storage output in GPSS/H;

c) Overflow traffic ratio is the ratio between the number of times the conversations have been made through secondary routes to the total number of times the conversational requests have been made. This objective has been achieved using transaction parameters and the number of times specific blocks in the model have been executed;

d) Network blocking ratio is the ratio between the total number of conversational requests that have not been satisfied and the total number of times conversational requests have been made. This number is obtained by using the transaction parameter and the number of times the TERMINATE block has been executed.

The complete source of the simulation model is available upon request.

MODEL VERIFICATION AND VALIDATION

One of the most difficult problems facing simulation analysts is that of trying to determine whether a simulation model is verified, i.e., whether the simulation model assumptions have been correctly translated into a computer program and whether it is valid (accurate enough to represent the actual system being studied). There has been a considerable amount of research in this subject so far. Important work on validation includes Balci [9] and Banks et al. [3]. As Law and Kelton [26] indicate, "there is no such thing as absolute model validity." In other words, the more time and money spent on model development, in general, the more valid the model should be. It is also worth mentioning that one should always develop a simulation model for a particular set of purposes. In fact, a valid model for one purpose may not be valid for another.

There are many theoretical and practical points of view to verify and to validate a simulation model. Among those, the following have been adopted:

a) Using the debugging capability of GPSS/H and running a GPSS/H simulation model in "test" mode, it was possible to trace the way a transaction is generated, how it moves through different blocks in the model and how it is terminated from the model. This work was performed in different situations as well as for different transactions. In all of these cases, no logical fault was discovered;

b) The simulation results were compared with those of the analytical approach. Table 4 shows the results of running the simulation model. Comparing these results with the results from the analytical approach, which is given in Table 3, leads one to conclude that, although there is a difference between them, the overall route utilizations are almost the same for both cases. For example, in both cases, the worst utilization corresponds to route 11 and the best utilization refers to route 14. In addition, in both cases, the amount of difference in the utilization of different routes follows almost the same pattern. Note that analytical route utilization in every route is higher than simulation route utilization. This is because of the simplifications and the usual assumptions in the analytical approach, which are not necessary for consideration in the simulation study;

c) First, the system bottlenecks were recognized and, then, the routes' capacities altered to see whether logical changes occur in the results and in the system performance. This process will be referred to in the latter section of this paper.

Table 4. Comparison between the simulation and analytical route utilization.

Route Number	Analytical Route Utilization	Simulation Route Utilization	Absolute Difference
1	0.9750	0.9579	0.0171
2	0.9460	0.9290	0.0170
3	0.9230	0.8924	0.0306
4	0.9750	0.9340	0.0360
5	0.9460	0.9170	0.0290
6	0.9660	0.9111	0.0549
7	0.9460	0.9315	0.0145
8	0.9550	0.9261	0.0289
9	0.9400	0.9054	0.0346
10	0.9500	0.9044	0.0456
11	0.8990	0.8881	0.0109
12	0.9560	0.9303	0.0257
13	0.9680	0.9421	0.0259
14	0.9960	0.9791	0.0169

INITIAL TRANSIENT, RUN LENGTH AND NUMBER OF INDEPENDENT REPLICATIONS

The simulation model at hand, since there is no natural event to specify the length of a run, is a non-terminating simulation. In this kind of simulation, since the observations near the beginning of the simulation may not accurately represent steady-state behavior, due to the choice of initial conditions, the usual practice is to delete some number of observations from the beginning of a run [3,4,8,16,26-28]. This practice is usually called warming up the model or initial-data deletion.

A measure of performance for such a simulation is said to be a steady-state parameter if it is a characteristic of the steady-state distribution of some output stochastic process. In order to estimate the transient parameter, which is assumed to converge to a steady-state parameter, one needs to run the model long enough until it warms up. However, the question is: How long is enough and how does one choose the deletion amount of data from the beginning of the run? The simplest and the most generally used technique is a graphical procedure, according to Welch [29].

In this research, the model was run for 9 different lengths $(1, 10, 100, 125, 150, 250, 500, 1000,$ and 10000 hours), independently, and the response (the routes' average utilizations) was obtained for each run. Then, the graph of the response against these different run lengths was obtained for each route. The amount of data to be deleted from the beginning of each run was obtained, such that, for the rest of the data, the average utilization does not fluctuate much (at most, 1% fluctuation was allowed). Figure 5 shows 6 of these graphs. From the graphs it was concluded that 150 hours of initial data deletion is quite enough in order to not to have more than 1% fluctuation in the average utilization of all the routes. In order to have an estimate of the run length, one should be quite sure that the system has been working in a situation such that all of the telephone traffic resources have been activated for long enough, the telephone traffic deployed in all of the routes and realization of the average utilization is a good representative of the steady-state behavior of the simulation. Running the model in test mode and checking different sections of the simulation model ensured that, after 1000 hours of running the model, a good estimate of the response could be achieved. To make sure that a good estimate of the average utilization is obtained, the method of independent replications was applied to the simulation model. In this case, the model was run n times,

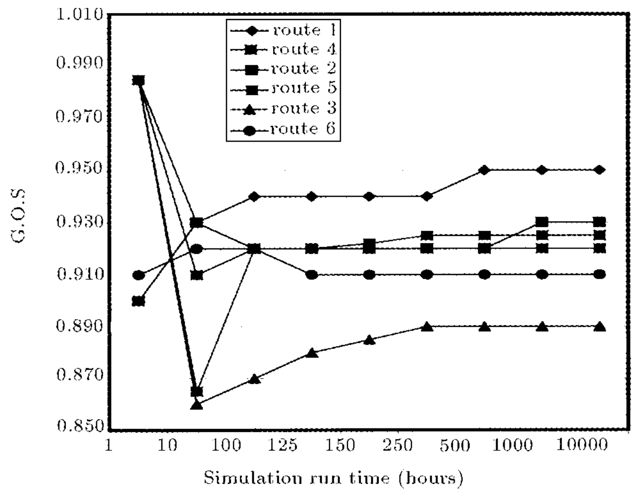

Figure 5. Warm-up periods for routes 1 to 6.

each with different streams of random numbers. To determine the number of replications (n), an estimate of the variance of the average utilization is needed. For this purpose, a pilot experiment was run with 10 different streams of random numbers. Table 5 contains the results of this experiment. The worst standard deviation in this table is 0.0107 for route number 11 and the average utilization for this route is estimated to be 0.884.

If X were defined as the route utilization in each replication and $\overline{X}$ and S as its sample mean and sample standard deviation, respectively, then, using the central limit theorem, a $(1-\alpha)\%$ approximate confidence interval for the true average utilization (μ)

Table 5. The average utilization and the standard deviation in 10 independent replications of the model.

Route Number	Average Utilization	Standard Deviation
1	0.965	0.008430
2	0.928	0.009189
3	0.892	0.007880
4	0.934	0.005164
5	0.920	0.006670
6	0.907	0.004830
7	0.932	0.010300
8	0.931	0.005676
9	0.906	0.008430
10	0.907	0.009487
11	0.884	0.010700
12	0.935	0.009718
13	0.944	0.010600
14	0.979	0.003160

in n replications would be:

$$P\left(\overline{X} - t_{\frac{\alpha}{2},n-1}\frac{S}{\sqrt{n}} < \mu < \overline{X} + t_{\frac{\alpha}{2},n-1}\frac{S}{\sqrt{n}}\right) = 1-\alpha. \quad (1)$$

In order for the width of the 99% confidence to be 0.02, then, the required number of replications for the worst case is:

$$t_{\frac{\alpha}{2},n-1}\frac{S}{\sqrt{n}} = 0.01 \;\Rightarrow\; t \approx \sqrt{n}$$

Using student-t table and trial & error method $\Rightarrow$

$n \approx 12$.

Hence, in order to have quite a good estimate of the steady-state average utilization, one needs to run the simulation model 12 times, each time with 1150 hours, such that the first 150 hours of data from each replication are deleted and the rest are used to obtain the estimates.

EXPERIMENT WITH THE MODEL

Now that the number of independent replications, length of each run and the warm-up period is known, the simulation model can be tested to obtain reliable statistical results. The results obtained from testing a model with the number of channels given in Table 3 (the analytical results), are summarized in Table 6. These results are obtained through 12 independent replications of the model, each for 1150 hours and the first 150 hours of data were deleted in each. The overall network utilization, route utilization sample mean and sample standard deviations are given in this table. In addition, a 99% confidence interval is given for the true average utilization in each case. The results show that, although route utilization is lower than that of analytical computations, considering the overall utilization of the network, which is very hard to obtain analytically, the proposed network design is quite suitable and can be used to satisfy customer demand in the regional power telephone communication network. This conclusion can be reached through the results obtained for network blocking and overflow traffic percentages, which are summarized in Table 7. Again, the numbers and figures in Table 7 were obtained through 12 replications of the simulation model, such that the length of each replication was 1150 hours and the first 150 hours of data were deleted for the initial transient case.

In order to improve network performance, first, the bottlenecks were detected. Then, more experiments were designed, ran and analyzed, involving increases

Table 6. Average, standard deviation and confidence interval on utilization of the analytically designed network.

Route Number	No. of Channels	Average Utilization	Standard Deviation of Utilization	99% Confidence Interval
1	2	0.9579	0.0027	(0.9555,0.9603)
2	2	0.9290	0.0024	(0.9268,0.9311)
3	2	0.8924	0.0026	(0.8901,0.8947)
4	2	0.9340	0.0036	(0.9308,0.9372)
5	2	0.9170	0.0026	(0.9147,0.9193)
6	2	0.9111	0.0021	(0.9268,0.9130)
7	2	0.9315	0.0031	(0.9287,0.9343)
8	3	0.9261	0.0026	(0.9238,0.9284)
9	3	0.9054	0.0022	(0.9034,0.9074)
10	3	0.9044	0.0026	(0.9021,0.9067)
11	2	0.8881	0.0030	(0.8854,0.8911)
12	2	0.9303	0.0036	(0.9271,0.9335)
13	2	0.9421	0.0029	(0.9395,0.9447)
14	5	0.9791	0.0011	(0.9781,0.9901)
Overall		0.9654	0.0009	(0.9646,0.9662)

Table 7. Network blocking and traffic overflow percentages in 12 independent replications.

Replication Number	Network Blocking Percentage	Network Overflow Traffic Percentage
1	3.43	5.92
2	3.47	6.09
3	3.63	6.22
4	3.66	6.08
5	3.42	6.05
6	3.36	5.94
7	3.45	6.00
8	3.42	6.17
9	3.46	6.00
10	3.34	6.09
11	3.42	6.11
12	3.46	6.00

in the capacity of the bottleneck channels. Table 8 contains the summarized results. In this case, 5 different alterations were considered. For each of the capacity changes, 12 independent replications of the simulation model were considered, such that each replication contained 1150 hours of simulated results, in which the first 150 hours of data were deleted. The numbers in Table 8 are average routes and network utilization.

In the first alternative, the analytically calculated number of channels, were considered, detecting routes 3 and 11 as the bottlenecks with an 89% Grade Of Services (G.O.S) in both routes (the numbers are highlighted in the table). The network grade of service in this case is 96.54%. In the second experiment, the number of channels in routes 3 and 11 were increased from 2 to 3 (the corresponding numbers are highlighted) and the grade of services for routes 3 and 11 were increased to 96% and 97%, respectively. However, routes 6 and 9 were considered as bottlenecks, in this case, with a 91% grade of services in both routes. Note that, in this experiment, the overall network grade of service is increased from 96.54% to 96.96%. In the third experiment, the number of channels for routes 6 and 9 were increased to 3 and 4, respectively, but, the results show that route 5 has the lowest grade of service at 91%. The overall network grade of service was increased to 98.09%. The fourth and fifth experiments were undertaken in the same manner and, in both cases, by increasing the number of channels in bottleneck routes, the grade of service, as well as the overall grade of service, were improved. It is obvious that when the number of channels in the network is increased, the route and network performance will both be improved. Here, 5 different scenarios were presented along with their performance. Considering the cost and the time taken for efforts associated with each scenario,

Table 8. Experimental results obtained from different network alternatives.

Route No.	Alternative 1		Alternative 2		Alternative 3		Alternative 4		Alternative 5	
	No. of Channels	G.O.S	No. of Channel	G.O.S	No. of Channel	G.O.S	No. of Channel	G.O.S	No. of Channels	G.O.S
1	2	96%	2	97%	2	97%	2	97%	2	97%
2	2	93%	2	94%	2	94%	2	94%	2	94%
3	2	**89%**	**3**	96%	3	98%	3	98%	3	98%
4	2	93%	2	93%	2	94%	2	96%	2	96%
5	2	92%	2	92%	2	**91%**	**3**	97%	3	99%
6	2	91%	2	**91%**	**3**	98%	3	98%	3	98%
7	2	93%	2	93%	2	93%	2	94%	2	97%
8	3	93%	3	93%	3	93%	3	**93%**	**4**	98%
9	3	91%	3	**91%**	**4**	96%	4	96%	4	97%
10	3	90%	3	92%	3	93%	3	**93%**	**4**	97%
11	2	**89%**	**3**	97%	3	97%	3	97%	3	98%
12	2	93%	2	93%	2	93%	2	**93%**	**3**	99%
13	2	94%	2	94%	2	94%	2	94%	2	96%
14	5	98%	5	98%	5	99%	5	99%	5	99%
Overall Network G.O.S	96.54%		96.96%		98.09%		98.27%		98.83%	

it is the network managers' responsibility to choose between different alternatives.

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

In this paper, the telephone communication network of a regional electric company was studied both analytically and through simulation methodology. The shortcomings and difficulties associated with the analytical approach in designing such a communication network is mentioned and the power of a simulation methodology, in this regard, was discussed. Considering the pros and cons of the GPSS/H simulation language, it was chosen for modeling the system. After data collection and analysis, model development, model verification and validation, initial transient study and design of experimental phases, the simulation model was applied to determine the operating performance of the analytically designed system, as well as to evaluate the performance of any newly designed network, before installation and the implementation of new equipment.

In the current research, only a valid simulation model was developed and ways to experiment with the model were discussed, such that management could perform different tests to evaluate different alternatives, before actually purchasing and installing new equipment in the system. In general, this research has provided network managers with a model, such that he or she can test different changes in the actual system and see the results. Moreover, bottlenecks of the analytically designed network were recognized and it was concluded that, if the number of channels were increased in bottleneck routes, an improvement in the overall performance of the network and the routes would be observed.

For future research in this area, the following recommendations are proposed:

1. There were some difficulties in this research and, hence, some simple assumptions have been made to make the model easy to understand and apply. Specifically, in the input data collection of this research, it was observed that because of the existing analog telephone communication network, the automatic method of accessing the time between calls from different points of the system was not possible. Therefore, the usual distribution fitting to the input data could not be done. In a digital telephone communication network, this task can be undertaken more easily and with higher precision, such that the simulation model becomes closer to

real one. In addition, service time distribution was assumed to be an exponential distribution with the means obtained by interviewing experts and current system operators. Having a digital network enables the analyst to fit a proper distribution to the data at hand;

2. An extension module can be added to the simulation model, such that it can take the results obtained from the experimental design as input and come up with a statistical optimum solution of the network by the response surface methodology. The area of integrating simulation and optimization has, recently, undergone remarkable changes. New advances are making available applications of simulation, which previously had been considered infeasible or beyond the scope of current technology, more applicable. In this regard, some software has been developed employing graphics to show the performance of search mechanisms. This was beyond the scope of this research and, certainly, could be undertaken in future research;
3. In order to economically evaluate different alternatives, such that it will help network managers in the decision-making process, another economical study needs to be made. Also, in this study, the cost and benefits of increasing channels in bottleneck routes need to be considered.

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