A Human Simulation Validation of a Telephone Loop Network Simulation Model

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ABSTRACT

A computer simulation model was built to study various strategies for the assignment of telephone loop network facilities to customers. Results of this analysis are presented along with a novel approach to validate the analysis - simulating the simulation model with real data and real assignment personnel.

1. INTRODUCTION

The local telephone network (known as the loop network) has been the object of many interesting studies encompassing problems such as the optimal design[1] and capacity expansion[2] of the network. In this paper, we are interested not in modifying the network but in administering it. In particular, we study the impact of different strategies for assigning facilities to customers. Since the movement of customers in the system and complexity of the system did not lend itself simply to analytical models, a simulation was built to evaluate various assignment strategies.

After completing the simulation analysis, we encountered the interesting problem of validating the results. The problem of validation of a simulation model has been discussed in the literature over the past decade. "Validation", which is concerned with whether the simulation model matches the real system, is distinct from "verification", which checks that the model does what the developer intended[3]. In general, validation is accomplished by testing whether the simulation outputs match what would be expected in the real system for comparable inputs. Van Horn[4] suggests a type of "Turing Test" where subject experts would be given sets of input and output - some from the simulation and some from the real system - and asked to identify which were real. Fishman[5] proposes a variant where the experts decide on a course of action (or policy decision) based on the output sets; if the action would be the same for the real and simulated outputs then the model is valid. Crabill et al[6] distinguish between "representational validity" - whether the model validly represents reality - and "policy validity" - whether the model can distinguish the effects of different policies.

All of these validation techniques apply real data to a simulation model. In our problem, the simulation represented a small scale model of the real system. However, real data on a small piece of the network would provide a small sample size, so that decades worth of data would be required to provide statistical significance, and the large network could not fit within the capacity of our model. Our solution was to simulate the simulation, using real data and parts of the real system (including people - hence "Human Simulation"). The computer simulation and "Human" simulation outputs are then compared for both "policy validity" and "representational validity."

In the next sections we will present background information on the real system - the telephone loop plant network - and on the process we are interested in optimizing - the assignment of

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circuits to customers. Then the simulation model, which was written in SIMSCRIPT II.5[7], is presented along with the results of the simulation analysis. Sections 6 and 7 present the model validation procedure and results. The final section analyzes our validation approach.

2. THE LOOP NETWORK

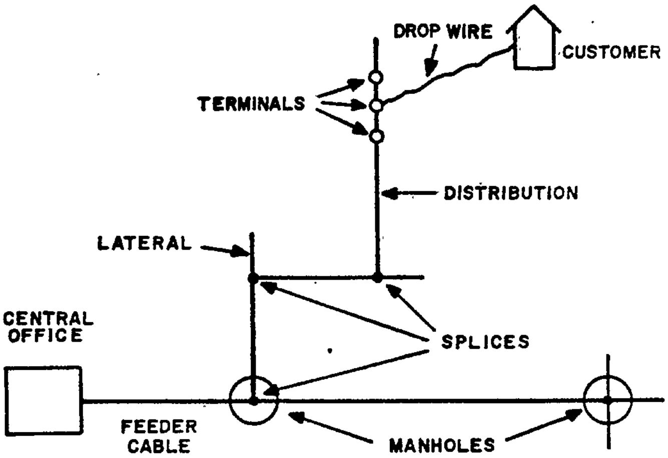
2.1 Physical Design

The physical system being studied is known as the Loop Network[8]. It is that portion of the telephone network which connects the customer to the central office, where the switching occurs. The connection is usually accomplished by a pair of copper wires (known as a pair, for short). Figure 1 shows the path of a typical pair from the central office to the customer. The pair leaves the central office in a large cable called a feeder cable. This feeder cable is located under the street in concrete or plastic conduits interrupted approximately every 500 feet by manholes to provide access to the pairs. The pair later leaves this cable through a splice to a lateral feeder cable and eventually branches into a distribution cable in the neighborhood of the customer. A distribution cable may be found either on poles or buried underground. Somewhere near the customer the pair appears in one or more distribution terminals. The final link is provided by a drop wire from the customer's residence or business to the nearest serving terminal where it is connected to the pair. The interesting aspects of the assignment question arise when none of the pairs appearing in the nearest serving terminal are free to be used for a new customer.

2.2 Topological Design

In general, it is difficult to forecast accurately where new customers will need lines. While one may feel reasonably confident about the number of new lines needed for a large area, it is much more difficult to pinpoint exactly where these new customers will appear. One approach to this problem has been to design the network with flexibility built into it. One way to provide this flexibility is to have some of the pairs be available in more than one terminal. A pair might appear in terminals on two different streets and thus be available for connection to potential customers on either street. Of course, at any given time it can only be used by one customer. This type of plant is called multiple plant (see Figure 2). Other types of plant configurations also exist, but our study applies primarily to multiple plant and we will restrict our presentation to this case. It should be noted that roughly 2/3 of the existing telephone plant can be simulated as multiple plant and that new plant is not designed in this manner anymore.

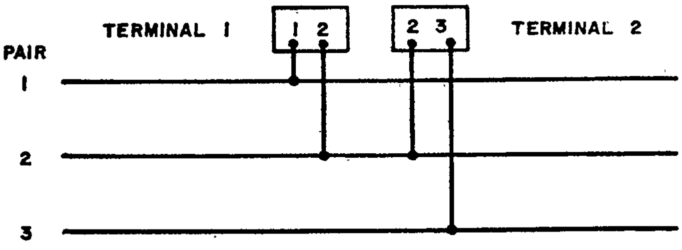
FIGURE 1
LOOP PLANT NETWORK



3. THE ASSIGNMENT PROCESS

Whenever a request for service, (also known as an inward order), is received, a pair must be provided to connect the

FIGURE 2
MULTIPLE PLANT



customer's telephone to the local central office. The provision of this pair (known as an assignment) may require only simple record changes (in the case where a pair is reserved for the customer), or may require some complex network activities to get a free pair where it is needed. Each activity has a cost based on the craft time and material required; these costs are known as the loop network operating costs. The question of interest here is the economical administration of the loop plant in the multiple configuration; that is, which pairs should be provided to which customers to minimize the operating costs over time? In this section, two assignment policies are described along with the set of activities available to be used in providing a pair under each policy.

3.1 Reassignable Policy

Under a reassignable policy, when a customer discontinues service, the drop wire connecting his phone to the network is disconnected; thus any pair which is not actually serving a customer (working) is available for assignment (spare).

Consider an inward order for residential service at a given address. If one or more pairs in the terminal associated with this address is spare, one will be chosen for assignment to the new customer. The connection is completed by having a drop wire connected from the customer's premises to the spare pair at the serving terminal. These two operations, assign a spare and connect a drop wire, are the minimum effort required to provide service in this case.

If no spare is available in the designated serving terminal, additional operations are required to provide service. Figures 3a,b illustrate one possibility known as a line and station transfer (LST). In Figure 3a we have the following situation: there exists in the customer's terminal a working pair not connected to a customer served out of this terminal, but connected through multipling to a customer in a different terminal, and this second terminal has a spare pair. The trick is to transfer the second customer to this spare thereby making a spare available for the first customer (see Figure 3b).

An LST thus involves moving a drop wire from one pair to another (a move which must be carefully coordinated with changes in the central office) on top of the usual work required to connect a spare. This operation can be repeated over several terminals to provide a pair; it is then known as a multiple-stage LST.

Another possibility is an operation simpler than an LST. It consists of stringing a drop wire from the customer's premise to a spare at a different terminal than the one it is associated with (see Figures 4a,b). This is known as a wire out of limits, (WOL). A WOL involves extra effort to secure a longer and thus costlier drop wire. WOLs are also trouble prone and unsightly.

Finally if none of the above operations is possible, the order

FIGURE 3a
LST BEFORE

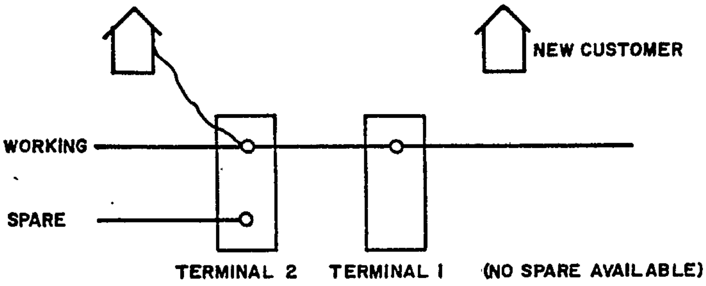
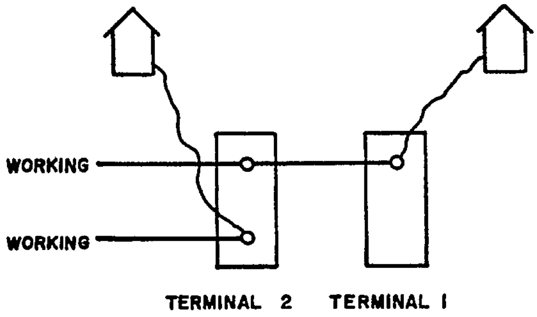


FIGURE 3b
LST AFTER



is referred to the Engineering Department (RE) which will take more drastic measures to provide service.

In summary we have four basic activities, spare assignment, LST single or multiple stage, WOL and RE. Each of these possible ways of providing service involves not only a different cost, but also changes the state of the network in different ways, thus affecting the activities that will be necessary to provide service to subsequent customers.

3.2 Connect-Through Policy

Obviously the costs of disconnecting a pair when a customer discontinues service and of reconnecting a pair for a new customer can be avoided if the line is left connected upon discontinuation of service in anticipation of a new customer moving in at that same location and requiring telephone service. This is called the connect-through policy and the pair thus reserved is called a CT. However, sometimes it may be quite a while before the new customer moves in and requests telephone service. The drawback is that reserving this idle pair for a future customer may force more complex activities (e.g., LST, WOL) to provide service for a present customer who could have used this pair. Furthermore, due to clerical errors and other environmental factors, the CT may in some cases not be usable for the new customer, thus negating any potential savings. The net savings from the CT policy must be traded off against the cost of the LSTs and WOLs necessary to avoid using the idle CTs. There are other tradeoffs that must be considered, including the effect of a CT policy on capacity expansion costs. In this paper we will concentrate only on the operating cost tradeoff. Historically, the decision rule used was to reserve a CT for service at the same location for a fixed amount of time called the holding time (sixty days was the most commonly used holding time). If it is reused during that holding time, the savings due to the CT are obtained; if it is not reused during the holding time, it then becomes available for assignment, if needed, for other locations. Note that when a CT pair is used at another location, the cost of breaking the connection at the original location and reconnecting it at the new location is incurred; this is less than the cost of an LST or WOL. This activity is known as breaking a CT (or BCT).

FIGURE 4a
WOL BEFORE

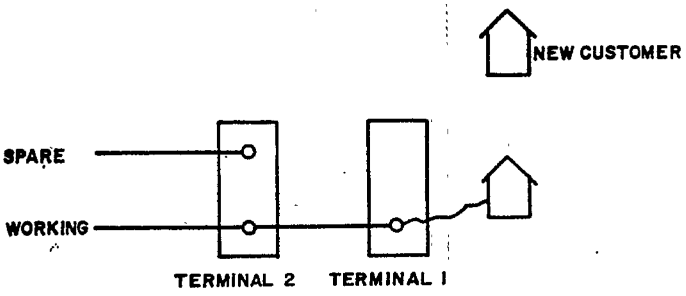
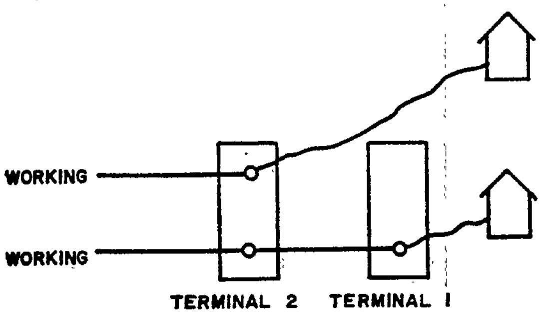


FIGURE 4b
WOL AFTER



Under a CT policy, we now have six activities, reuse CT, spare assignment, LST, WOL, BCT and RE. What should the preference ordering among the activities be? Under which conditions is the CT policy better than the Reassignable Policy? What is the optimal value for the CT holding time? It is with these questions in mind that our simulation was built.

3.3 The Assignment Strategies Studied

More formally, the following assignment strategies were evaluated:

a) Break as Needed: a connect-through policy where CT pairs are broken as needed. This is equivalent to having a holding time equal to zero. The preference ordering among activities is from cheapest to most expensive (Reuse CT, Spare Assignment, BCT, LST, WOL, RE).

b) Non-zero Holding Time: a connect-through policy with a nonzero holding time. The preference ordering is as above, except if the CT is of an age under the holding time then BCT is just ahead of RE. The effect of the holding time on the operating costs was evaluated.

c) Break as a Last Resort: a connect-through policy where CT pairs are broken only as a last resort. This is equivalent to having an infinite holding time. The preference ordering is (Reuse CT, Spare Assignment, LST, WOL, BCT, RE).

d) Reassignable: a policy without connect-throughs. The preference is then simply Spare Assignment, LST, WOL, RE.

The environment in which the network operates is also an important factor affecting operating costs. Therefore, the simulation was built to allow the following three neighborhood characteristics as input variables for study: the average length of time a premises is left without telephone service (vacancy time); the rate of growth in the number of new customers in the neighborhood, and the fraction of CTs which become unusable (abandonment rate).

4. THE SIMULATION MODEL

In this simulation, there are n pairs available for assignment in the neighborhood. These pairs are terminated at a fixed number, m, of equally sized terminals in a manner specified as input (i.e., the multipling scheme or lack of it is reflected in the way the pairs are terminated). At each terminal a number D of potential customers equal to the number of terminations in the terminal is assumed to exist. The terminals are sized for the ultimate number of customers. There are three major sections of the simulation: customer movement, pair assignment and record keeping. Figure 5 illustrates the processing flow in the simulation.

4.1 Customer Movement

The simulation models customer demand in two ways. One is to model growth in the number of customers; the other one is for modelling the inward and outward movement of customers (churn).

4.1.1 The Growth Model

In the growth model, the system is empty at the beginning of the simulation and growth is modelled by having each potential customer enter the system (make his first request for service) at some random time (uniformly distributed) between O and T, where T is chosen so that the expected number of new customers entering the system per year is G, an input variable representing the growth rate. Since there are mD eventual customers, T = mD/G. Once a customer requests service, he uses that service for a random time (exponentially distributed) whose mean value is an input parameter known as the occupancy time, T_o. When a customer moves out, another customer moves into the same location after a random interval (exponentially distributed), whose mean value is an input parameter, known as the vacancy time T_v. Other distributions (e.g., Beta type II) have also been used, but the same results were obtained. The occupancy and vacancy times are characteristics of the neighborhood reflecting the amount of churn. These are often combined into the penetration parameter:

$$p = T_0 / (T_0 + T_v)$$

Penetration reflects the fraction of premises in the system expected to be working (in-service) at any given time.

Each simulation starts at time t=0 with no working or assigned pairs and thus the expected number of working pairs at time t is:

$$E[W(t)] = pGt$$

The simulation continues until the time of working exhaust (when all available pairs are connected to customers).

4.1.2 The No-Growth Model

In the no-growth model, the simulation starts at time 0 with the steady state expected number of customers present in the system:

$$w(0) = pmD \quad \text{where} \quad w(0) < n$$

The other (1-p)mD remaining potential customers, enter the system in an exponentially distributed time with mean T_V. Once a customer is in the system, his movement is governed by the same model as for the growth case. Since all mD customers remain in service for an average time T_o and out of service for an average time T_V, the expected number of customers at any time is:

$$E[w(t)] = [T_o/(T_o+T_V)]mD = pmD = w(0)$$

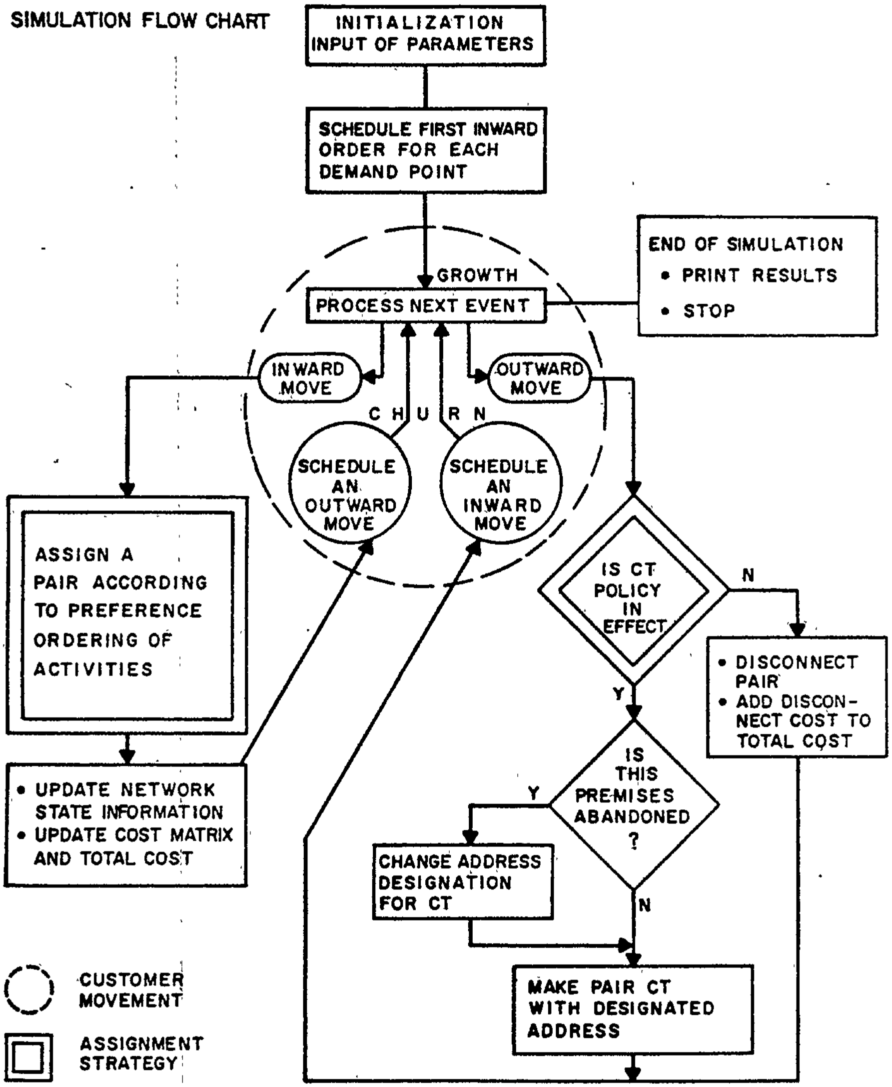
The simulation, in this case, is terminated at a set time or if working exhaust is reached.

4.1.3 Abandonment

Abandonment is another demand phenomenon which the simulation can model. Abandonment is the unreusability of some CT pairs due to either physical abandonment of a premises or to changes or errors in address designation which cause plant assignment procedures to ignore reuse possibilities. This

FIGURE 5

SIMULATION FLOW CHART



is modelled in the simulation by taking each outward order and making it an abandonment with probability A, where A is an input parameter. If abandoned, the pair is left CT and a new inward service order is generated as before, but the customer's address is changed so that the CT can never be reused. The record keeping system (see Section 4.3), however, does not maintain information on which CTs are abandoned since this information is missing in the real world.

4.2 Pair Assignment

When a customer requests service at a terminal, an assignment algorithm is used to find an available pair. The algorithm searches sequentially through 13 possible operations for assigning a pair (the six previously described plus various combinations of them - see Table 1) until it finds one that can be used. The order in which these operations are searched is specified as an input, so that different orderings can be compared, as was described in section 3. Table 1 lists these operations in order of increasing complexity and cost. It is to be noted that when it is specified in the input that a CT plan is not used, the operations involving CT pairs are ignored and a cost of disconnection is assessed every time a customer leaves the system.

4.3 Record Keeping

Two types of records are maintained; the network state (which pairs are assigned to which customers in which terminal) and cost tracking (which activities have been used when).

4.3.1 Network State

At all times, the simulation maintains a complete current record of the network. Each pair in the network has a status - either working, idle CT, or spare. If it is spare it is available at all terminals in which it appears in multiple. If it is working, the address of the customer is recorded. For an idle CT pair, the address of the last customer to which it was connected is maintained; in addition the date of discontinuation is kept for comparison with the holding time as needed. The configuration of the network is also updated as LSTs and WOLs occur. At all times the number of working pairs is monitored to indicate the network fill. The fill of the network is the ratio of the number of working pairs to the total number of available pairs, and is used as a measure of network congestion. In general, more complicated operations will be required more often as fill increases. The number of CT pairs is also monitored to provide a measure of CT penetration. The operating cost at any time will generally be a function of the fill and CT penetration.

TABLE 1

Assignment Operations

1. Reuse a CT pair at the same address.
2. Assign a spare.
3. Break an overage* CT at the same terminal.
4. Break any CT at the same terminal.
5. Break an overage CT at a different terminal.
6. Break any CT at a different terminal.
7. Perform a 1-stage LST.
8. Perform a 1-stage LST by breaking an overage CT.
9. Perform a 1-stage LST by breaking any CT.
10. Perform a 2-stage LST (may include breaking CT).
11. Wire out of limits (assign to any spare pair).
12. Wire out of limits by breaking any CT.
13. Referral to Engineering. This is modelled as having a special operation performed to provide service, such as putting in an electronic "pair gain" system. However, it is removed as the customer leaves and the customer is not counted in the working fill.

4.3.2 Cost Tracking

When an operation is selected in the assignment phase of the simulation, it is tallied in a matrix, N, whose rows represent network fill and whose columns represent the operations. Thus, N(f,i) represents the number of times operation i was used when the fill was f. For each fill level, the probability of requiring operation i can be estimated by

$$\pi_i(f) = N(f,i)/\sum_i N(f,i)$$

The variance of the estimate can be estimated[9] by:

$$\mathrm{Var}[\pi_i(f)] = \pi_i(f)\ (1-\pi_i(f))/\sum_i N(f,i)$$

The average cost per inward service order of customers into the system at a given fill is found from

$$\mathrm{Cost}\ (f) = \sum_i C_i \pi_i(f)$$

where C_i is the cost of operation i.

5. SIMULATION RESULTS

This section will summarize the results of the simulation analysis. A 90 pair group was used for these results with 12 terminals of size 15 where each pair appears in exactly two terminals according to a standard multipling scheme. A small size pair group was chosen in order to keep the computation time low, since analytic models[10] suggested that the pair group size is not an important factor for operating costs. The number of potential customers is 15 per terminal for a total of 12x15 = 180 potential customers.

While the effects of neighborhood characteristics were studied extensively, our emphasis in this paper is on determining an optimal assignment strategy. Vacancy time and growth will only be mentioned in as much as they affect the comparisons between assignment strategies. The abandonment rate was found to have little effect on the results and is not mentioned here.

The criterion used to evaluate the assignment strategies, is the cost per inward service order. This cost is highly dependent on the congestion of the network. At higher fills there is less probability of having a reuse and consequently higher probability of having LSTs, WOLs, and REs (known collectively as blockages) and the cost per inward service order is higher. As a consequence the cost per inward service order is plotted as a function of fill and the curves are used for comparison.

The four different strategies described in Section 3.3 were investigated - Break as needed, Non-zero holding time, Break as a last resort, and a Ressignable policy. The results for the CT strategies under two different environments (long vacancy time/low growth, and short vacancy time/high growth) are illustrated in Figures 6 and 7. A longer holding time tends to increase the CT reuses and decrease the break CTs, but also increases the number of more expensive activities (blockages). In the long vacancy time case, the blockage effect dominates, so the cost is lowest with the break as needed policy. The cost difference between policies becomes more pronounced as the fill increases. For the short vacancy time case, the reuse savings with a holding time policy are more substantial, and at low fills, the cost curves are about the same. However, at higher fills, the blockage effect again dominates, and again the break as needed policy becomes the lowest cost policy. Note that these curves are only shown up to fills of .85 since relief (capacity expansion) is generally provided before the network reaches higher fills.

It appears, therefore, that a CT policy of breaking as needed is the best one to use. But how does it compare to a non-CT policy where all lines are disconnected on an outward order? Figure 8 shows this comparison for the long vacancy time, low growth case. Even though reuses are low due to the long vacancy time, the CT policy is clearly better at all fills. The greatest savings from using a CT plan are at the low fills when the reuse rate is highest. The savings are due mostly to the avoidance of connect and disconnect costs, although the blockage rates are slightly lower under the CT plan.

6. MODEL VALIDATION PROCEDURE

The validation procedure used for the simulation model was to conduct a "human simulation". That is, we simulated the simulation using copies of real cable records (instead of our network state data base), real back service orders representing

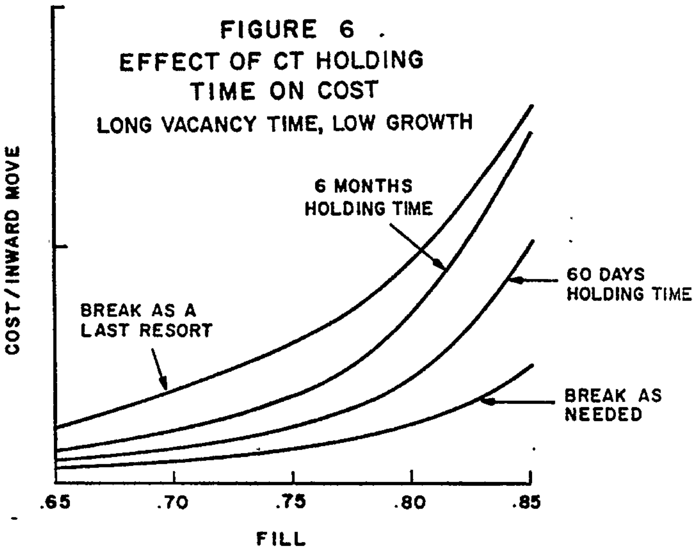


FIGURE 6 . EFFECT OF CT HOLDING TIME ON COST

LONG VACANCY TIME, LOW GROWTH

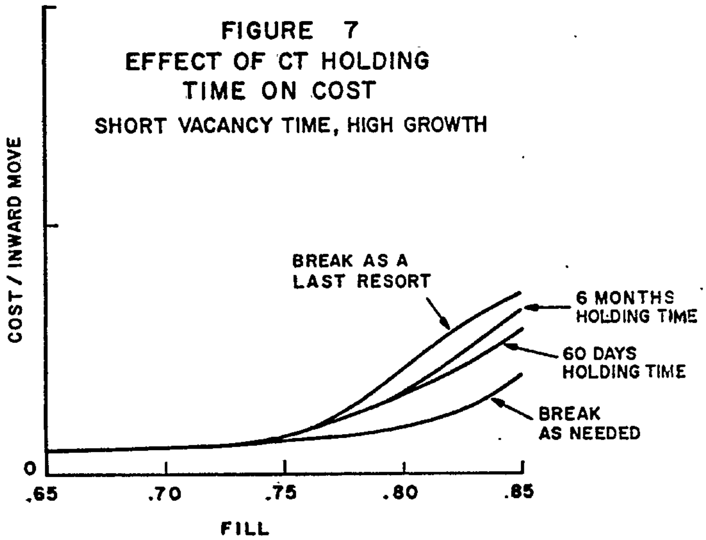


FIGURE 7 EFFECT OF CT HOLDING TIME ON COST

SHORT VACANCY TIME, HIGH GROWTH

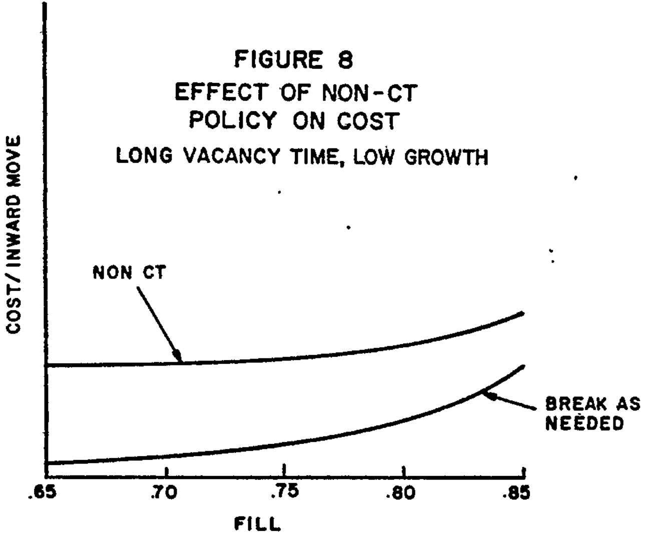


FIGURE 8 EFFECT OF NON-CT POLICY ON COST

LONG VACANCY TIME, LOW GROWTH

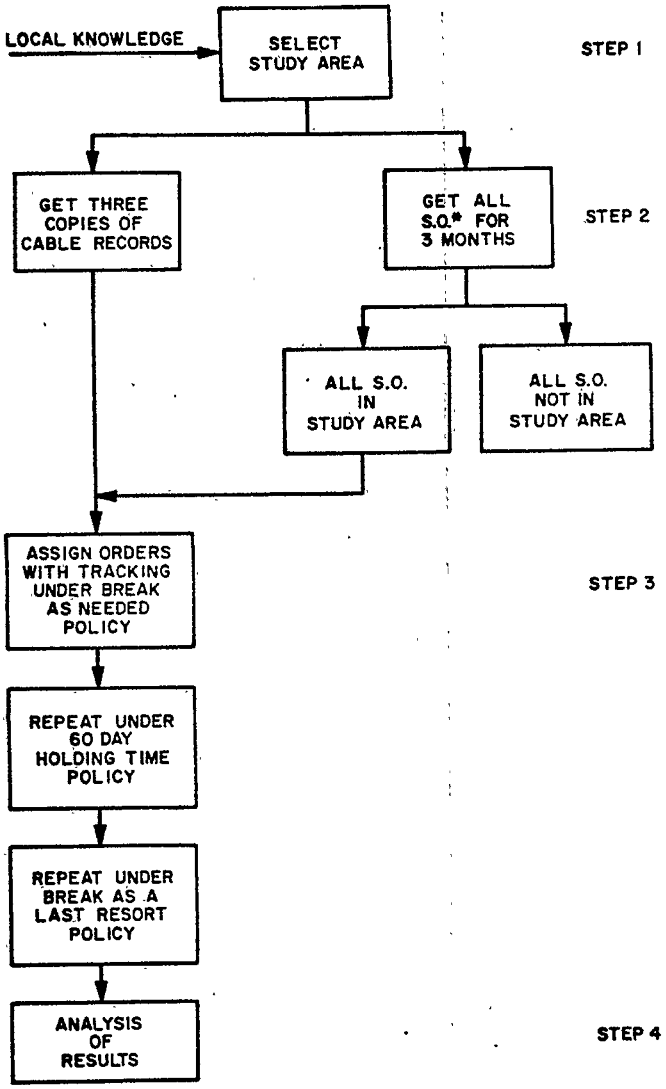
actual customer movement (instead of our random number generator), and a real telephone company assigner to do the assignment of pairs to customers and tracking of activities and costs (instead of our subroutines). By using copies of the actual orders and records, we were able to have the same assigner repeat the procedure three times using the same orders and records but using a different assignment policy each time. Thus our "human simulation" provides a "what would have happened if?" analysis for the entire network - thus avoiding both the small sample size problem from using a piece of the network and the problem of fitting the entire network into our small-scale simulation model. The average cost per inward order is then used to compare the policies.

Figure 9 shows the entire experimental procedure which consists of four basic steps. The first step is to select a study area. A study area consists of one or more contiguous neighborhoods, containing on the order of 3000 living units, all served out of the same central office. Two criteria were used in the selection of study areas - high congestion (to insure a meaningful difference among policies), and around 50 inward orders per month (a tradeoff between statistical accuracy and required assigner time).

Step two is to obtain three copies of the cable records as of a given date, and all of the service orders for the study area for three months subsequent to that date. Obtaining the service orders is a prodigious clerical task since they are stored by central office; the study area is about 1/25 of a central office area, so the approximately 300 orders that we need must be sorted out from the entire set of about 7500. Three months was chosen as a tradeoff again between statistical accuracy and required clerical and assigner time (and thus experimental cost). Although seasonality could cause problems for a three month study, the study areas selected were not known for seasonal demand patterns.

Step three is the actual assignment of the orders by an assigner in the telephone company, along with tracking the disposition (activities required) for each order. This step is

FIGURE 9
EXPERIMENTAL PROCEDURE



*S.O. = SERVICE ORDER

repeated once for each policy being tested. The final step is the analysis of the results which is described in the next section.

Three different locations were chosen for this validation experiment - a suburban area (denoted A), an urban (mostly apartments) area (B), and an urban (mostly single family homes) area (C). Each location tested three policies - a Break as Needed policy (zero holding time), a 60-day holding time policy, and a Break as a Last Resort policy (infinite holding time).

7. VALIDATION RESULTS

7.1 Cost Analysis

The results of these experiments for the three companies are shown in Table 2, and Figure 10. Considering the average over the three locations, these results confirm the predictions of the simulation model - the longer the holding time, the higher the cost. Although one location showed a 60-day policy to be slightly cheaper than Break As Needed, the Break as a Last Resort policy was always much more expensive than Break as Needed. Further analysis shows that the total blockage rate (fraction of orders requiring a BCT, LST or RE) is approximately constant across policies. Although the number of blockages are the same, as the holding time increases, more complex operations are required to clear the blockages, thus leading to the higher costs observed in Figure 10.

7.2 Error Analysis

An important question in the analysis of experimental data is: How accurate are the data? In this experiment, there are several types of errors that must be considered. First is the inherent random nature of a service order stream - how typical are three month's worth of orders? By selecting the number of inward service orders approximately equal to 150 per location

FIGURE 10
COST PER INWARD ORDER

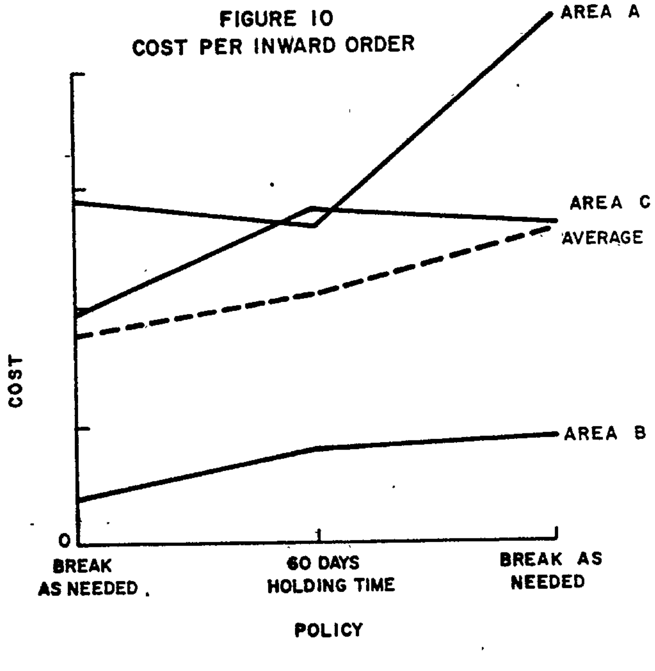


TABLE 2

Experimental Results
Assignment Data

	Area A	Area B	Area C
Reuse Rate[1]			
BAN[4]	.51	.72	.68
HT60	.54	.77	.59
BLR	.56	.71	.61
Blockage Rate[2]			
BAN	.33	.12	.18
HT60	.31	.09	.22
BLR	.29	.14	.21
Inward Moves	166	152	135
Outward Moves	126	144	152
Spares Assigned			
BAN	42	34	23
HT60	41	27	33
BLR	40	31	35

	Area A	Area B	Area C
Break CTs			
BAN	50	18	14
HT60	40	5	16
BLR	19	15	16
LSTs			
BAN	4	0	4
HT60	10	5	5
BLR	9	10	4
Referrals to Eng.[3]			
BAN	6	1	7
HT60	5	4	9
BLR	23	0	9

Notes*

1. Reuse rate — fraction of inward orders resulting in a reuse.
2. Blockage rate — fraction of inward orders requiring a BCT, LST or RE.
3. Wire-out-of-Limits could not be done in this experiment since another necessary set of records were not available.
4. BAN — Break As Needed Policy
   HT60 — 60 day Holding Time Policy
   BLR — Break as a Last Resort Policy

this type of uncertainty was reduced to under five percent. A second type of error is due to the fact that different assigners would sometimes assign the same order differently. Furthermore, since order assignment depends on the way previous orders in the same cable were assigned, these differences tend to be magnified over time. Note that these discrepancies are due both to actual errors on the part of the assigner and to differences in pair selection among equally reasonable assignments.

Three types of actual assigner errors were noted in this experiment:

1. Incorrectly updating the cable records on an outward (disconnect) order so that when a customer returned to that location, what should have been a CT pair appeared working. This would lead to either a spare assignment or a blockage instead of a reuse. This is one of the causes of the CT abandonment problem described earlier.
2. Failing to reuse a reusable CT. The most common cause of this was when the terminal information covered more than one page of the cable records and the assigner failed to check the additional pages. Again this would lead to abandonment.
3. Incorrectly tallying the activities on the tracking form.

In order to estimate the effect of assigner differences on the experimental results, a control experiment was run in which the area A service orders were assigned under a Break as Needed policy by a different assigner. The results are shown in col. 2 of Table 3. Of the 166 orders, 134 (81%) were assigned identically by the assigner and the control. Further checking indicated that of the 32 differences, 5 were attributable to assigner errors, 3 to errors by the control, 10 to different interpretations of the policy specifications or definitions, and the remaining 14 to different pair selection and its consequences.

The above analysis points out a minor shortcoming of the simulation model. The model assumes an infallible, deterministic assigner, whereas in the experiment, different assigners gave different assignments on 19% of the inward orders. The policy comparison results of the models would be unaffected by including assignment uncertainty, but the cost per inward service order predictions of the models should be higher for all policies.

TABLE 3

Inter-Assigner Comparisons

Item	Experiment	Control	Actual
Reuse Rate	.51	.59	.43*
Blockage Rate	.33	.25	.11*
Inward Moves	166	167	166
Outward Moves	126	126	126
Spares Assigned	42	41	96*
Break Cts	50	33	15*
LSTs	4	7	9
Referrals to Eng.	6	4	1

* See Section 7.2 for analysis of these discrepancies.

Further comparison of inter-assigner differences is available by analyzing the actual dispositions of the 166 inward orders; this information was available to us from a different ("completion") copy of the service orders. These results are shown in col. 3 of Table 3. The major discrepancies between the actual dispositions and the experimental results are that reuse and blockage rates are both much smaller in the actual dispositions. This lower reuse rate is due to the fact that orders sometimes cannot be completed as assigned. Although the assigner thinks a reuse is possible according to the records, the installer attempting to make the connection may find the pair defective or even working, so that some other operation would be required. The experiment ignored such phenomena by assuming all assignments could be completed as assigned. The major effect of these service order assignment changes is to lower the number of possible reuses. Since this effect would be approximately the same for all policies, the policy comparisons would be unaffected. Again, the actual costs per inward order would be higher in all cases. The lower blockage rate was traced to the interpretation of the definition of BCT. In the real assignment, any broken CT which was over some age (probably 60 days) was considered like a spare so that the completion copy of the service order contained no information about the broken CT, whereas the experiment considered any broken CT as a BCT. The actual number of blockages other than BCT was about the same as found in the experimental policies.

8. CONCLUSION

The validation successfully helped us convince our users of the validity of our simulation analysis. In addition to providing a decision rule for the assignment problem, the simulation model was subsequently used for analyzing policies in areas with seasonal demands and areas with mixed apartment and single-family housing, and to generate data to test operating cost models used in an optimal timing of capacity expansion analysis[10].

The drawbacks of such a validation are its cost (in craft and clerical time), the limited number of policies which can be tested, and the limited number of orders (events) it can process. However, it accomplished its purpose of allowing the cheaper, faster, less limited simulation to be used with more confidence. Furthermore, it did point out some assumptions of the model which do not hold in the real world. These discrepancies did not affect the policy comparisons studied in this paper, but could be important if other questions are investigated with this simulation. In summary, in this case, the "Human Simulation" approach appears to be a useful way to validate a simulation model.

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