OPERATIONS RESEARCH, Vol. 25, No. 3, May-June 1977

Turfing

M. SEGAL and D. B. WEINBERGER

Bell Laboratories, Holmdel, New Jersey

(Received original June 1976; final, November 1976)

We discuss both the analytical methods and some implementation considerations involved in enriching the job of telephone repairpersons/installers by letting each take full responsibility for all jobs within his own territory, or "turf." For the problem of carving the region into turfs, which bears a great similarity to the political districting problem, we use a highly interactive software system at the heart of which is a heuristic algorithm combining shortest path, minimum cost flow, and enumerative techniques. We also discuss a stochastic model of the work backlog in a turf, based on the variability of the demand for service. Preliminary experience seems to indicate that this mode of operation is both workable and desirable. It should therefore be noted that, while the discussion takes place in the context of telephone repairpersons/installers, it is of considerably wider applicability.

THE AGE of automation has brought with it high industrial production rates, but in many cases dissatisfied employees as well. This has led to increased attention to the question of work motivation.

Studies by Herzberg [9] led him to conclude that factors such as achievement, recognition, work itself, responsibility, advancement, and growth are prime motivators. In contrast with the traditional industrial engineering approach that attempts to simplify and dissect the work, he suggested redesigning the job to enrich it by taking into consideration the motivational factors.

Following this approach Ford [5] suggested the "module" as a reasonable slice of work. A module is created by enlarging the job until the employee assigned to it has responsibility for either an outside customer, an in-house client, or a complete task. The idea is to let the employee have full responsibility and control over the module. In order for this to be effective, feedback of performance should go directly to the employee. In some situations responsibility for such a module could lie with a group of people rather than a single person (e.g., assembly of engines [1] and rock drills [2]).

This approach to the redesign of work slices has been reported to be successful in some clerical work associated with the telephone business [5]. It should also be mentioned that the redesign of work has not always had the desired results [7].

Ford [5] suggested that the jobs of telephone installer and telephone repairperson might be good candidates for such redesign. In particular, these

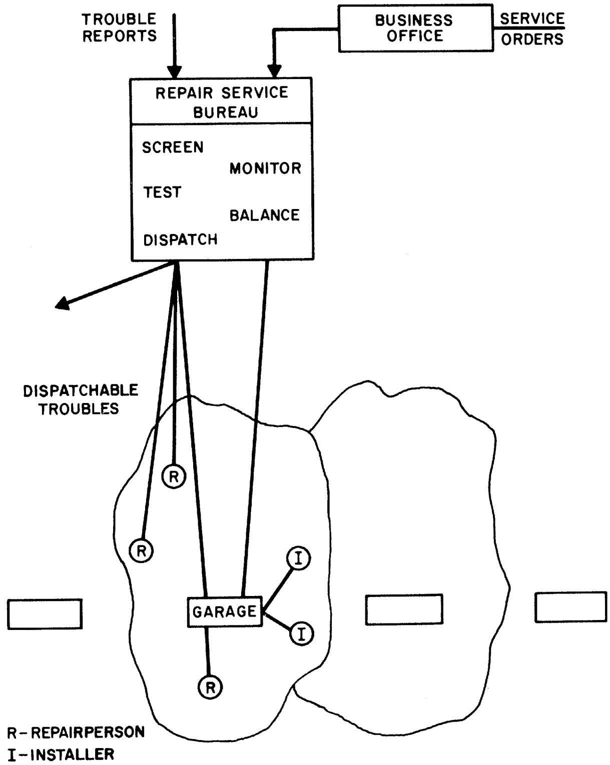

Figure 1. Flow of installation and repair jobs.

jobs could be performed by the same employee, and that employee could be responsible for all new installations and repair jobs in a well-defined geographical area—a "turf."

In the traditional mode of operations, a group of installers and a group of repairpersons serve a large district. A simplified description of the operation is shown in Figure 1. Dispatchable troubles are assigned by the dispatcher to repairpersons as they report completion of jobs, according to the commitment time given to the customer when he called to report trouble. (In some locations dispatchable troubles that are not affecting service are assigned in bulk to a repairperson in the morning.) Completion dates for new installation are negotiated according to the known backlog of the installers. The group supervisor balances the load daily among the installers.

At first glance it might seem that dividing a district that is being served by, say, 20 servers into 20 turfs served by one server each goes against the well-known result from queuing theory that large teams of servers are more efficient than small ones. This queuing result is based on the assumptions that the large team and the many small ones have identical distribution of service times. In the case of installation and repair the service time includes travel to the work location. This suggests that the "turfed" system might have a shorter service time due to reduction in travel and the servers' greater familiarity with their turfs, in addition to the motivational factors mentioned above.

The discussion above leads to two fundamental technical problems:

a) How should one divide a district into turfs? The first section of this paper describes a model used to develop a computer system for solving this problem.
b) The incoming work load is subject to daily fluctuations. On high days the "turfperson" might receive outside assistance or he might use overtime to reduce the backlog of work. On low days he may do maintenance work or go out of his turf to assist in a neighboring turf. The second section is devoted to the development of a model for the turfperson's backlog at the start of the day.

In addition to these technical problems, there are a number of practical administrative issues that must be resolved in order to change to a turfed mode of operation. Section 3 deals with some of these issues.

1. CREATING TURFS

The central technical problem in implementing a turfed system is that of carving the district into turfs that are of appropriate geography and workload. The geographical considerations involve such factors as road systems, traffic patterns, and neighborhood boundaries, as well as the more obvious criteria of connectedness and shape.

In order to design turfs of appropriate workload, we must assess the distribution of the demand for service throughout the district. Toward this end, we ask that the district be partitioned into small blocks for data collection purposes. This partitioning is done by a person (or people) very familiar with the geography and traffic patterns of the district. As an ideal, we ask that he try to develop blocks that will yield an average of about 1 hr of work per day. If there are many blocks that generate a much greater workload than this, they will inhibit the flexibility of the clustering procedures used to build turfs out of the blocks. On the other hand, if there are many blocks smaller than this, the data collection task will be increased unnecessarily. Of course, since the person doing the partitioning has little a priori knowledge of local demands, he can only estimate the eventual workloads of his blocks, and they will tend to vary considerably. Also, in some cases a district may already have been partitioned into blocks for some other purpose, and we may use these blocks if they are at all reasonable for our purposes

Once the blocks have been developed, we collect data reflecting the workload generated each day in each block. Such data are collected, typically, for 3–6 months before the turfs are designed. The data collection process will be discussed further in Section 3.

Given, then, day-by-day data in each block, we must cluster these blocks to yield appropriate turfs. We use the mean daily workload of a given block as the natural measure of the load it generates. (Some important issues concerning the day-to-day variability of the workload will be discussed from a mathematical point of view in Section 2 and from an administrative point of view in Section 3.) The number of turfs to be designed is determined by the total workload of the district, and our goal is to generate turfs of equal load and appropriate geographical characteristics. The problem is very similar to the well-known "political districting problem," where the goal is to cluster census tracts of known populations into a given number of equally populated districts of appropriate shape (see, e.g., [6, 10]). In our problem the geographic concerns are a little more complex and subjective than in the political districting problem, but the two problems are fundamentally the same.

Given the highly subjective nature of a "good" turf, we felt it important that the user of the turf design system be intimately involved in the design process. This meant that the system should operate in a highly interactive mode and that our underlying algorithms should be fast heuristics rather than slower "optimal" procedures. (The notion of optimality is really not appropriate here because the nature of the geographic considerations precludes the formulation of any objective function that truly reflects the "goodness" of a set of turfs.) The objective then was to design a heuristic procedure that would generate turfs of basically equal load and of reasonable geographic characteristics, and then let the user make adjustments to satisfy these subjective criteria. This led us to develop a system based on an interactive modification of the approach taken in [10].

The basic idea is as follows. If the user wants the region carved into m turfs, he names m blocks to serve as "centers" for these turfs. We then construct a transportation network as shown in Figure 2. Each node on the left corresponds to a block of the region, and each node on the right corresponds to a "center." There is an arc from each block to each "center" to which it might reasonably be assigned. The supply at each node on the left is the load of that block. The demand at each node on the right is $1/m$ of the total workload for the region. (Since we use the out-of-kilter algorithm [4] for solving this network problem, all data must be integral. Hence, the real data are scaled and integerized appropriately to provide feasible integral data.) The cost on each arc represents the distance from the block on the left to the block ("center") on the right. The method of determining these costs will be described below.

Given this network structure, we find a minimum-cost feasible flow. The demands on the nodes at the right ensure that each center has the

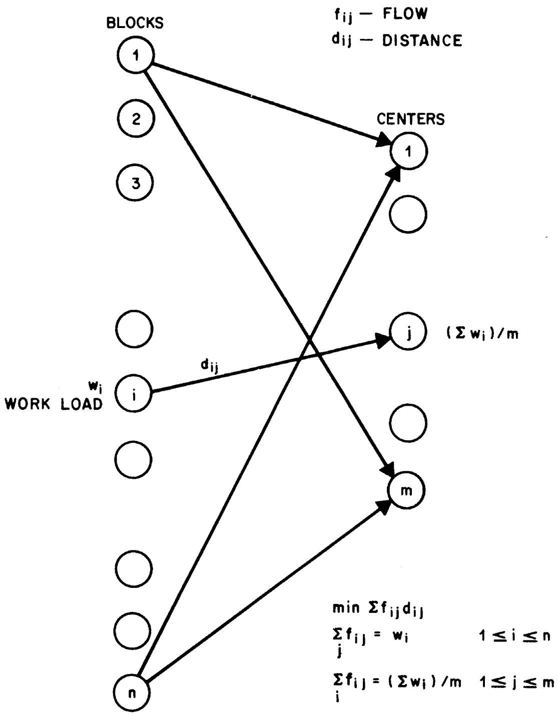

Figure 2. A transportation model for carving turfs.

appropriate workload assigned to it. The costs on the arcs drive the algorithm to try to meet these demands with nearby blocks—this tends to cluster the blocks in the appropriate geographic fashion. However, the minimum-cost solution to the flow problem may have positive flow on several arcs out of the same block node. These "split" blocks must be recombined since the blocks were chosen as basic, indivisible geographic units, and there are no data to indicate how to divide a block geographically to achieve the desired split of the workload.

If the potential number of split blocks (and pieces into which they were split) were arbitrary, the above network step would be of questionable value, since finding a good way to recombine the ensuing splits would be tantamount to solving the problem from scratch. However, the reader familiar with linear programming will note that any basic solution to the network problem above can have at most $m-1$ splits. Since m is small relative to the total number of blocks (on the order of $\frac{1}{8}$), this gives a reasonable bound to the computational work involved in this step.

Whenever possible we try every combination of assignments of split blocks to the various centers between which they are split. Our criterion here is to minimize the maximum absolute deviation of a turf load from the average turf load. The secondary criterion ("tie-breaker") is to minimize the second worst deviation, and the tertiary criterion is to minimize the sum of the absolute deviations over all turfs. This total enumeration can be accomplished with essentially instantaneous response at the terminal as long as the number of split blocks is less than 15 or so (we are dimensioned to turf regions of up to 200 blocks and 25 turfs). If there are more than 15 splits, we assign the most skewed splits in the obvious fashion without enumeration, and the ennumerate over the remaining splits. This heuristic procedure works quite well.

One further note is in order here. We use the out-of-kilter algorithm to solve the network problem, and this method can terminate with a nonbasic optimal solution (if one exists). Such a solution could have more than $m-1$ splits. This creates no real problem since, as described above, we use a partial enumeration if the number of splits is large. The existence of a nonbasic optimal solution depends, of course, on a degeneracy relation among the costs of the arcs, and this occurrence is fairly rare (although not as rare as it might first seem—because of the way the costs are determined).[1]

The costs on the arcs in the network problem described above are based on the distance between the respective blocks. Their purpose is to drive the algorithm to create turfs that are connected and of reasonable shape. Exact measure of distance is not important but what is important is that the distance measure reflect ground travel restrictions. For example, if two blocks are directly across a river from one another but the only bridge is miles away, then the distance from one to the other must reflect the travel to and from the bridge, and a turf ought not include both of these blocks unless it includes all the intervening blocks on the way to and from the bridge.

Because of such considerations we logically represent the region by an adjacency graph that has a node for each block and an arc connecting each pair of nodes that represent adjacent blocks (i.e., one can drive directly from one block to the other without passing through intervening blocks).

[1] If nonbasic optimal solutions occurred frequently or caused any serious problem when they did occur, it would be a simple matter to post-process the out-of-kilter solution to find a basic optimal solution. Alternatively, a primal network algorithm could be used in place of the out-of-kilter to ensure basic solutions.

Figures 3 and 4 illustrate this logical representation. The length of each arc in this graph is taken to be the straight-line distance between the (approximate) centers of the two blocks (measured in any convenient units). For any two blocks that are not adjacent, the distance between them is defined to be the shortest path between them in this graph. This is the measure of distance that is used as the cost function in the network problem. It is a measure that is sufficiently precise for our purposes and

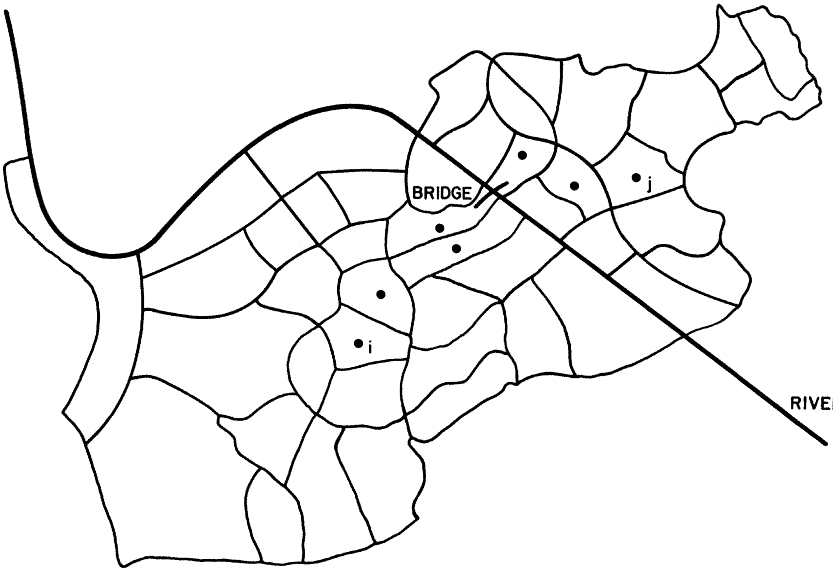

Figure 3. Subdivision into blocks.

requires as input data only the coordinates of the center of each block and a list of the adjacencies.

Putting the above pieces together, we can describe the flow of the algorithm:

(i) The user inputs a set of blocks to serve as "centers" for the turfs.

(ii) For each center a set of blocks that are candidates for assignment to that turf is selected. This step is done to reduce computation in the shortest path and network flow parts of the algorithm and is not intended to impose any additional constraints on the solution. Hence the set of candidates is made quite large.[2]

[2] If the number of turfs is five or fewer, all blocks are candidates for all turfs. If the number of turfs is greater than five, the set of candidates is chosen by the following iterative procedure. Start with the center and all its adjacencies, and at each step add in any blocks that are adjacent to some block in the current candidate set. Stop when there are at least 5 · (total number of blocks/total number of turfs) blocks in the candidate set at the end of some iteration.

(iii) Compute the shortest path (in the adjacency graph described above) between each center and all the blocks in its candidate set. (We use the simple Ford algorithm here as it is highly efficient for low density problems such as these—see [11].)

(iv) Set up the network flow problem described above and solve it. This gives an assignment of blocks to "centers," but some blocks may be split between several centers.

(v) Use an enumerative procedure to determine a single assignment for each split block. Output to the user the turfs thus generated.

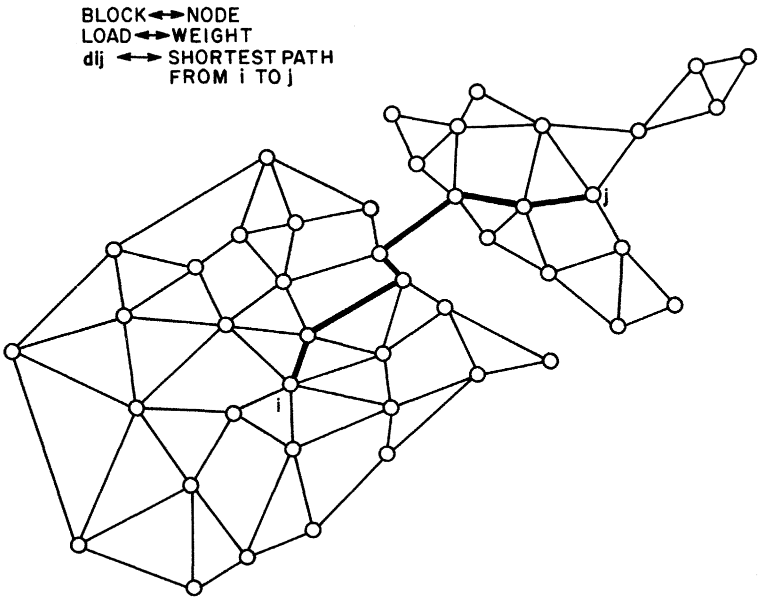

Figure 4. A graph representing the subdivision.

Note that the loads of the turfs thus created will vary some (this is, of course, forced in general by the indivisibility of the blocks) and that the geographical properties of the turfs are not guaranteed to be satisfactory. It is even possible for a turf created by this algorithm to be disconnected. In general, however, the turfs generated by this procedure are quite good. The important point here, though, is that these turfs are not necessarily expected to be the final turfs settled on by the user. He is free to make changes to them by shifting blocks around from turf to turf, or he can abandon this particular set of turfs and try a new set of centers. Since the algorithm gives essentially instant response at the terminal, the user has great flexibilty in using it as a basic tool for carving turfs.

The above commentary is not meant to downplay the quality of the turfs that the algorithm generates. In each of the two regions where this system has actually been used to carve turfs (one with 45 blocks and 7 turfs, the other with 47 blocks and 12 turfs), a set of centers was chosen, the algorithm generated a set of turfs, and the final turfs were arrived at with just 2- or 3-block adjustments.

Once the user is satisfied with the turfs he has created, he can request information on the day-to-day variability of the turf workloads. In particular, he inputs upper and lower workload bounds and the system informs him of the percentage of days in the data base on which the workload was above the upper bound or below the lower bound for the collection of blocks comprising each of his current turfs. This information is of value in terms of administrative planning for the turfed system.

One final note on the turfing software package. At the front end of the system, data concerning workloads in the blocks are analyzed to determine the daily mean workload for each block. By continuing to collect raw data once the turfed mode of operation is in effect, the user can use this software to monitor the turfs or to review them periodically to discover changing trends in workloads. Such trends may necessitate modification of the existing turfs, and such modifications can be easily arrived at with this same software system.

The previous discussion of the turfing software system has not included all of the provisions and options of that system, but is rather just an overview of the basic features. A schematic representation of the flow of the program (from the user's point of view) is given in Figure 5.

2. THE BACKLOG MODEL

Most models for queuing systems assume that the service times are independent of the queue length, and, in equilibrium when the system is not saturated, the fraction of time a server is occupied will be strictly smaller than one. This is the case, for instance, in teams of directory assistance operators.

In contrast, turfpersons clear backlogs, and it is expected that they will be productively employed 100% of their work time. When the backlog is low, the server can work on maintenance jobs or remove left-in stations. When the backlog is high, he can reduce it by working overtime. A group of turfpersons may also have "floaters" whose function is to assist the individual turfpersons when their load is high. Similarly, two neighboring turfpersons may assist each other when one's load is high and the other's low.

The purpose of this section is to develop a stochastic model for the work backlog in a turf, where the rate at which work is cleared is determined by the turfperson according to the backlog he observes in the morning. Such a model serves to give the manager a general idea of the relationships between use of overtime (or help from floaters), performance of maintenance work, and promptness of service (as indicated by low backlog).

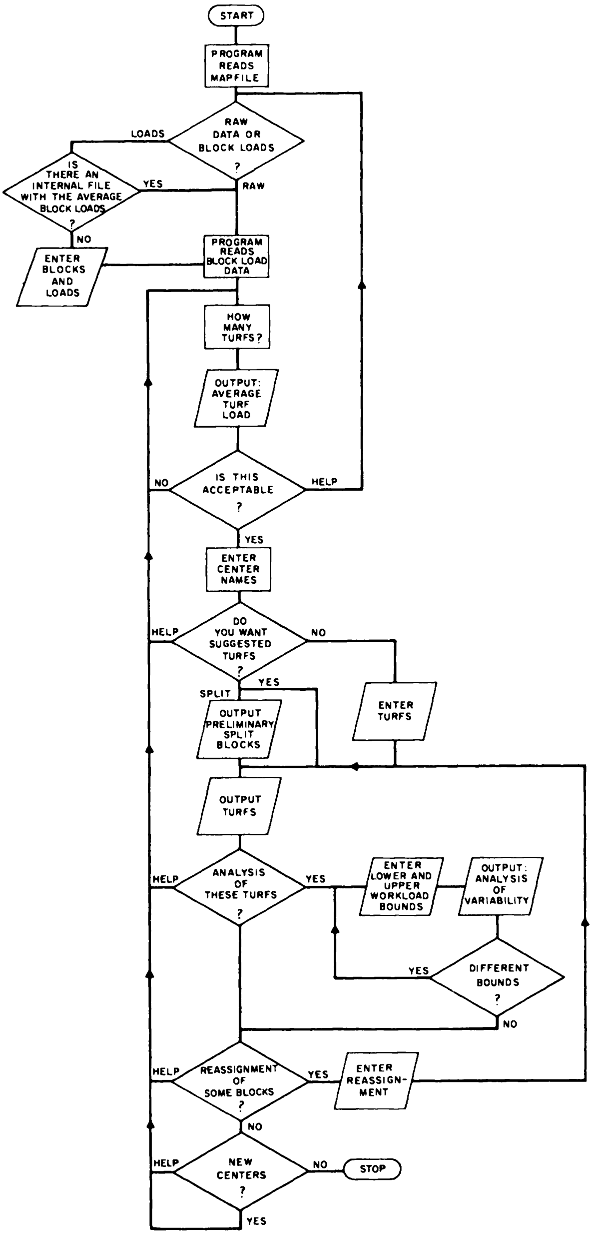

Figure 5. Schematic representation of interactive computer program for turfing.

We shall assume that a turf is served by one server. At, say, 8:00 a.m. on day n the turfperson observes the backlog of work, b_n, and accordingly decides that $\phi(b_n)$ hours of work will be made available for installation and repair during the nth working day. If $\phi(b_n)$ is larger than his normal day's work, he can stay overtime on day n or call for assistance. If $\phi(b_n)$ is less than his normal day, the rest of his time will be used in programmed maintenance work. We also assume that jobs are divisible, i.e., a job that is begun on day n can be continued on day $(n+1)$ without penalty, and that work load arriving in day n may be processed the same day.

The business office schedules new installations a few days in advance, taking into account the already committed jobs. Rarely is there a need to schedule installation work, unlike repair work, on the same day it is requested. We therefore assume that the *installation workload* in day n, z_n, is distributed according to density g_z, but the value of z_n is known at the start of day n. The *repair work*, x_n, that arrives during the day receives more immediate treatment and is distributed according to f_x. The variable y_n represents the work carried over at the end of the day. The *total known load* on the morning of day n, which we will refer to as backlog, is $b_n=y_{n-1}+z_n$.

The above assumptions lead to the fundamental backlog equation

$$y_n=\max\,(b_n+x_n-\phi(b_n),0) \tag{1}$$

with $b_n=y_{n-1}+z_n$. We shall define $s_n=b_n+x_n-\phi(b_n)$, and note that s_n^- is the amount of time available for interruptable nonprogrammed work. Equation (1) is closely related to the stochastic process defined by a recursive scheme in [3] and its derivatives.

A possible function $\phi(b)$ is a step function, such as that illustrated in Figure 6. When $B_1<b\leqq B_2$, the turfperson makes $L=8$ hr available for clearing installation and repair work in his turf. When $b\leqq B_1$, $R=4$ hr are devoted to programmable maintenance or outside work. When $b>B_2$, the additional $\theta=2$ hr are added through overtime or outside assistance from other turfpersons.

It is important to note that R in $\phi(b)$ represents a deliberate decision in the morning to devote R hours to work other than installation and repair in a home turf. In contrast, s_n^- represents a chance occurrence of intervals of time when the turfperson can work on interruptable jobs other than installation and repair in his home turf.

To solve for the equilibrium probability distribution of the carried-over work y governed by (1), one resorts to numerical approximation. A finite state Markov chain is created by discretizing x, z, and y, measuring them in, say, units of quarter hours. The state space of y is truncated; that is, $0\leqq y\leqq M$. The transition matrix P_{ij} (see Figure 7) is given by $P_{ij}=\sum f_x g_z$, where the sum is carried over all x and z such that

$$x+z\begin{cases} \geqq M+\phi(i+z)-i; & j=M \\ =j+\phi(i+z)-i; & 0<j<M \\ \leqq \phi(i+z)-i; & j=0. \end{cases}$$

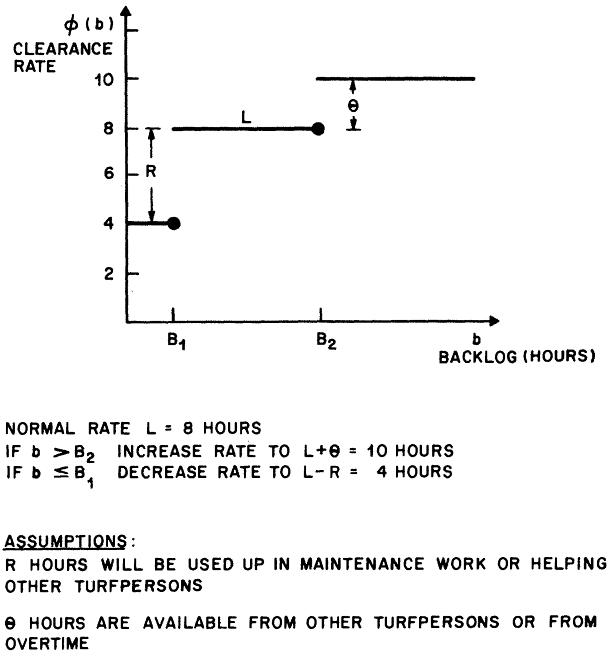

Figure 6. Backlog clearance rate.

The equilibrium probability π_i solves $\sum_i \pi_i P_{ij} = \pi_j$ and $\sum_{i=0}^{M} \pi_i = 1$. And the cumulative distribution of the carried-over work is given by $F(y) = \sum_{i=0}^{y} \pi_i$.

Once $F(y)$ is known one can convolve it with g_z to obtain the distribution of the backlog. The probability that the turfperson will require overtime or assistance is given by $P_2 = P(y+z > B_2)$. The probability that he will be able to release his time for assistance to other turfpersons or to do programmable maintenance work is given by $P_1 = P(y+z \leqq B_1)$. The expected interruptable work time is then given by $E(s^-) = L + P_2\theta - P_1 R - E(x) - E(z)$, and the amount of time used for clearing installation and repair jobs is $s^* = \phi(b) - s^-$.

A typical turf is examined in Figures 8 and 9. The density f_x was assumed to be negative binomial with mean 4.1 hr and variance 8.2 hr.^{2} The density g_z was also assumed to be negative binomial with mean 5.65 hr and variance 12.15 hr.^{2} (These parameters were based on field trial data—see

Section 5.) The clearance policy was assumed to have three steps with $R=4$, $L=8$, $\theta=8$, $B_1=2$, and $B_2=11$ hr in Figure 8. B_2 is varied in Figure 9. All numerical examples were computed by discretizing the variables into quarter hours and solving for equilibrium in a $M+1=137$ state Markov chain.

In Figure 8 we show the equilibrium distribution of the carried-over work y and the backlog work $(y+z)$ for a typical turf. Figure 9 illustrates

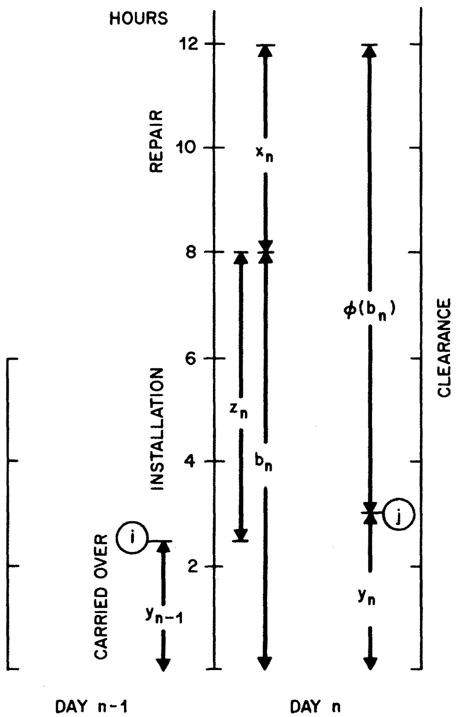

Figure 7. Transition in the Markov chain.

how B_2 affects the means and variances of various measures discussed above.

3. IMPLEMENTATION CONSIDERATIONS

A prime concern initially is the collection of data that will allow for a sensible carving of the region into turfs. Toward this end, the region must be divided into small blocks that will serve as the basic geographical units of data collection, as was described in Section 1. Once the blocks have been created and labeled (typically with numbers that help identify their locations), we must make a file that enables a clerk to determine the block in which any given address lies. A typical card reading might be:

SPRUCE STREET

1–699	Block 534
700–899	Block 533
900 and above	Block 524

Once this file is created, each incoming job can easily be labeled with the appropriate block number. Workload data are collected for several months, broken down by day and by block. Installation hours and repair hours are collected separately for the purpose of statistical analysis, although they are aggregated for the purpose of carving the turfs. Three to six months of data should be sufficient for carving the turfs, but the user himself should be aware of possible seasonal variation during the carving process. Even after the turfed system is implemented, daily block load data must be collected periodically in order to monitor possible shifts in workload patterns throughout the region.

In preparation for using the turfing programs to carve the turfs, we must create a file that describes the region being turfed. This file contains, for

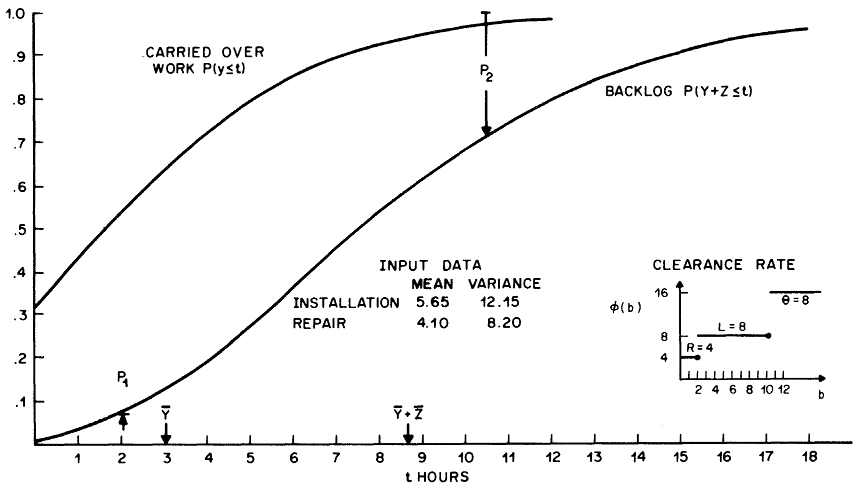

Figure 8. A typical turf—distribution of carried over work.

each block, the block name, the location of the (approximate) center of the block (measured on any arbitrary grid laid over the map), and a list of all other blocks adjacent to it.

There are a number of administrative details that must be carefully worked out before switching over to a turfed mode of operation. Several that we have found to be of major importance are

(i) Appropriate way to orient personnel involved with the new system;
(ii) Procedures for sending "floaters" into overloaded turfs or for al-

lowing underloaded turfpersons to cross over into other turfs—these procedures are crucial to a smoothly functioning system;

(iii) Coordination of the procedures in (ii) with the dispatch personnel;

(iv) Procedures for handling vacations, sick days, odd shifts, etc.—i.e., those occasions on which a turfperson is not around to cover the turf (nights and weekends will probably be left unturfed);

(v) Procedures for review and possible adjustment of turf boundaries if workloads shift.

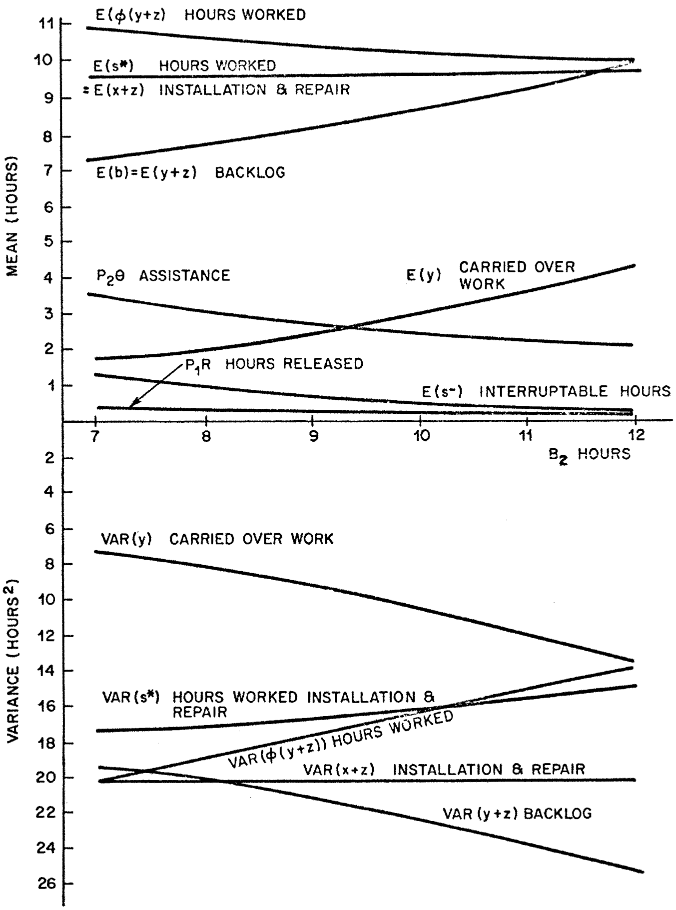

Figure 9. A typical turf—means and variances, effect of B_2.

In order to evaluate the benefits of a turfed system, before and after comparisons should be made in at least the following areas:

(i) Normal productivity measures;

(ii) Gasoline consumption and vehicle mileage;

(iii) Employee attitude and morale.

For further discussion of general implementation considerations in any such job enrichment program, see [7].

4. PRELIMINARY FIELD TRIAL EXPERIENCE

In October 1974 part of a district in Pennsylvania began operating under a turfed system. The software system described previously was used to carve the area into seven turfs, and an additional three employees were designated as floaters. The floaters help control backlog and substitute for sick, vacationing, or otherwise absent turfpersons.

After 5 months under the turfed system of operation, the local management made a preliminary evaluation and noted that employee morale had improved (this was confirmed by results from a job attitude survey [8]) and the absence rate for the people involved had decreased (9 total days of absence during the 5 months of the turfed system compared with 26 days during the previous 9 months of 1974 and 30 days during 1973). Total vehicle mileage for the 10 people involved was down by about 1100 miles per month[3]—a reduction of about 21 percent.

Comparing with 9 months before turfing, overall employee productivity increased over the 5-month period as well. There were several striking improvements and a few smaller decreases. Table I shows the change in productivity for the 10 people involved. There was an overall improvement of about five percent in time spent per installation job and about three percent in time spent per repair job. After 10 months these figures were 8% and 5%, respectively, indicating continuous improvement in productivity. It is estimated that before turfing a repairperson/installer spent about 1 hr of his day traveling. The 21% reduction in travel mileage will then correspond roughly to $^{21}\!/_{8}$, or 2.5% reduction in service time. This reduction is a part of the improvement in productivity shown in Table I.

For completeness we have included some basic statistical data on the area involved. Figure 10 shows the distribution of the daily completed workload, by turf. Negative binomial distributions have been fitted to the data by the method of moments. Since the person in Turf 4 has additional responsibilities within the garage, his turf was intentionally created with a lower workload. Overall, turfpersons spent about 8–10% of their work time outside the turfed area. In addition, about 5–7% of a turfperson's time was spent in a different turf. Finally, in Table II we show the mean

[3] This figure was arrived at by comparing vehicle mileage during the turfing trial with the previous 9 months' mileage of the same vehicles. A more appropriate comparison would have been with the total mileage used to service the turfed area during the period prior to the turfed system, but such figures were unavailable. However, vehicles are assigned to the same employee most of the time and 5 of the 10 people involved worked in this area prior to the turfed system.

and variance of the daily completed workload, broken down into installation and repair. As discussed in the backlog model in Section 2, it is appropriate to treat the distribution of completed hours of installation as the arrival distribution (since installation jobs are scheduled in such a way that appointments are rarely missed). However, the arrival distribution of repair hours cannot be directly inferred from the completion distribution because some repair work (e.g., nonservice-affecting) is carried over to the next day. Hence, to compare the actual variance of work completed with that predicted by the model that was developed in Section 2, we assumed a variance to mean ratio of 2 for the arrival distribution of repair work. This value seemed consistent with the data of Figure 10. We assumed a clearance policy of $L=8$, $R=4$, $\theta=8$, $B_1=2$, and $B_2=10.5$

TABLE I
CHANGE IN PRODUCTIVITY

Employee	Percent Reduction in Service Times*			
	After 5 months of turf		After 10 months of turf	
	Installation	Repair	Installation	Repair
1†	4	−16	12	−10
2†	32	21	34	22
3†	21	−4	26	0
4†	8	3	7	8
5†	10	0	12	1
6	6	−9	8	−10
7	−6	−3	−3	2
8	6	19	13	16
9	−1	4	−3	2
10	−1	5	2	4
Crew	5	3	8	5
Crew service times (hours)‡	0.96	0.73	0.93	0.71

* Base is 9-month period before turfing.
† Worked in same area before turf project.
‡ Service times of crew in 9 months before turfing: 1.01 hr/installation, 0.75 hr/repair.

hr. Comparisons of variances of total work completed indicate that the model captures the essence of the actual mode of operation. In addition, the total expected released time (P_1R in Table II) of 2.25 hr per day (4%) is fairly consistent with the figure of 5–7% that the turfpersons spent outside their turfs.

5. SUMMARY

We have discussed both the analytical methods and some implementation considerations involved in redefining the job role of most telephone repairpersons/installers so that each may take full responsibility for all jobs within his own territory or "turf." The analytical methods have been implemented as software packages and this mode of operation is being tested in a field trial environment. One should be cautious about drawing final conclusions from these preliminary trial results since they represent

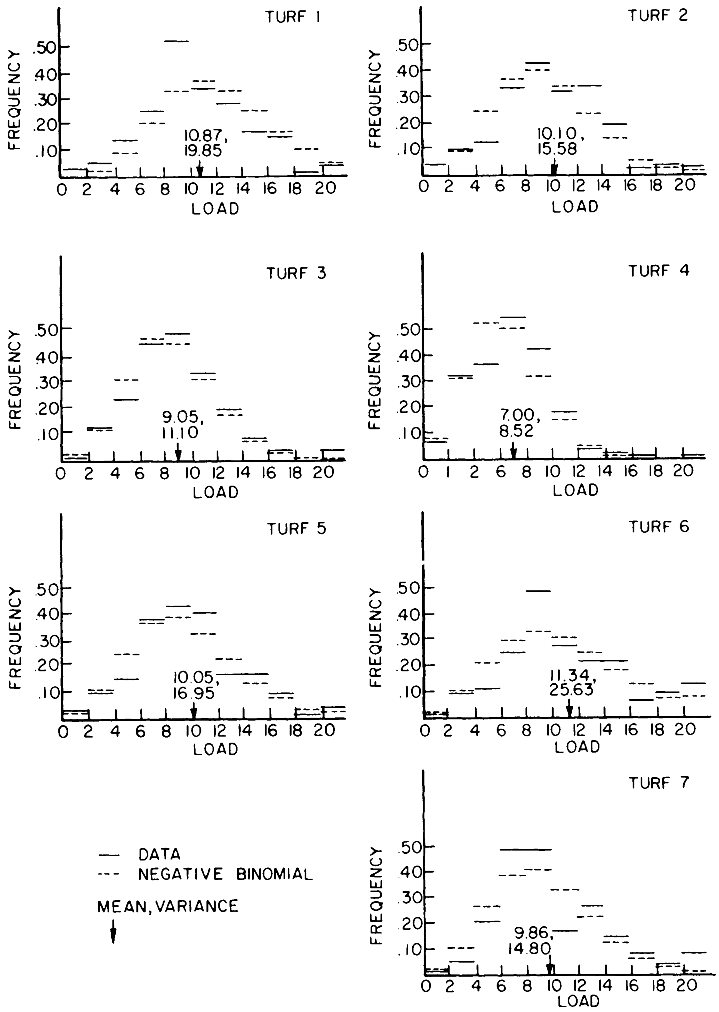

Figure 10. Frequency of daily completed workload in hours.

only one location and they could have been influenced by a seasonal or Hawthorne effect. However, preliminary experience seems to indicate that this system is both workable and desirable, leading to increases in employee satisfaction and productivity and decreases in vehicle mileage.

While our discussion has taken place in the context of telephone repair-

TABLE II
CHARACTERISTICS OF TURFS

Turf No.	Daily Work Completed (Field Data)						Statistics Predicted by Model*							
	Mean (hours)			Variance (hours²)			Var (s^*)	P_1R	$E(\phi(b)-E(s^*))$	$P_2\theta$	$E(y)$	Var(y)	$E(y+z)$	Var($y+z$)
	Instal-lation	Repair	Total	Instal-lation	Repair	Total	Hours²	Hours	Hours	Hours	Hours	Hours²	Hours	Hours²
1	6.43	4.44	10.87	15.74	37.59	19.85	17.92	0.19	0.35	3.40	3.79	15.02	10.21	30.61
2	6.47	3.63	10.10	10.00	38.88	15.58	15.44	0.13	0.52	2.76	2.74	9.44	9.27	19.43
3	5.15	3.90	9.05	**10.03**	21.48	11.10	14.76	0.36	0.54	1.94	2.65	9.27	7.80	19.30
4†	3.71	3.29	7.00	6.41	9.37	8.52	9.87	0.86	0.83	**0.69**	1.68	5.78	5.39	12.19
5	5.75	4.30	10.05	10.91	25.63	16.95	16.33	0.22	0.42	2.65	3.20	11.65	9.01	22.54
6	6.86	4.47	11.34	20.74	48.04	25.63	18.60	0.19	0.28	3.80	4.18	18.25	11.03	38.42
7	5.18	4.68	9.86	11.24	16.27	14.80	16.67	0.30	0.37	2.53	3.52	12.72	8.70	23.94
Total	39.55	28.71	68.27	85.07	197.26	112.43		2.25 (4%)	3.31 (6%)	17.77 (32%)	21.82	82.13	61.35	166.43
Average	5.65	4.10	9.75	12.15	28.18	16.06		0.32	0.47	2.54	3.12	11.73	8.76	23.78
Typical turf	5.65	4.10	9.75	12.15	8.20		16.41	0.28	0.46	2.49	3.03	10.98	8.68	23.11
	Input to Model						Output from Model							

* See text for assumptions.
† Turfperson 4 responsible for garage.

persons/installers, it is clear that the same ideas are equally applicable to any situation where there is a pool of people responsible for providing some service throughout a well-defined geographical region.

Note: D. B. Weinberger is now with Goldman, Sachs & Company, New York.

REFERENCES

1. S. Agis, "Work Democracy Tested at Scandinavian Plants," three article series, *New York Times*, November 11–13, 1974.
2. L. E. Björk, "An Experiment in Work Satisfaction," *Scientific American*, pp. 17–23, March 1975.
3. W. Feller, *An Introduction to Probability Theory and its Applications, Vol. II*, pp. 193–197, John Wiley & Sons, New York, 1966.
4. L. E. Ford, Jr., and D. R. Fulkerson, *Flows in Networks*, pp. 162–169, Princeton University Press, Princeton, N.J., 1962.
5. R. N. Ford, "Job Enrichment Lessons from A.T.&T.," *Harvard Business Rev.* **51**, 96–100 (1973).
6. R. S. Garfinkel and G. L. Nemhauser, "Optimal Political Districting by Implicit Enumeration Techniques," *Management Sci.* **16**, 495–508 (1970).
7. J. R. Hackman, "Is Job Enrichment Just a Fad?" *Harvard Business Rev.* **53**, 129–138 (1975).
8. J. G. Harrison, AT&T Unpublished Report, July 30, 1975.
9. F. Herzberg, "One More Time: How Do You Motivate Employees?" *Harvard Business Rev.* **46**, 53–62 (1968).
10. S. W. Hess et al., "Nonpartisan Political Redistricting by Computer," *Opns. Res.* **13**, 998–1006 (1965).
11. L. E. Hitchner, "A Comparative Investigation of the Computational Efficiency of Shortest Path Algorithms," Operations Research Center Report ORC 68-25, University of California, Berkeley, Calif., 1968.