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MITIGATING THE EFFECTS OF MANPOWER REDUCTIONS AT A CENTRAL ISSUE FACILITY BY IMPROVING THE ALLOCATION OF SERVERS: A SIMULATION STUDY

THESIS

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Acknowledgments

The purpose of this study was to assist the leadership of the Central Issue Facility of Fort Campbell, Kentucky in making decisions regarding manpower reductions. We hope that this quantitative treatment given to the CIF will allow for better personnel allocation decisions.

Much has been learned during this research effort. This thesis brought together many of the production management, simulation, behavioral, and statistical theories to which we have been exposed while attending AFIT, and allowed us to put them to practical use. We wish to express our appreciation to Lieutenant Colonel Jacob Simons for keeping us on course, Major Mark Kraus for many long explanations of mathematical concepts and of the subtleties of computer simulation, Major Michael Morabito for our introduction to production and operations management, and Professor Dan Reynolds for forcing us to learn what the Mean Square of Error is all about.

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Chris Wicker and Mike Garrity

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Abstract

The purpose of this research was to determine a preferred server allocation and a preferred customer batch size for processing customers at an Army Central Issue Facility (CIF) under various manpower levels. The CIF is a retail warehouse which issues tactical clothing and equipment to individual soldiers. It is facing potential manpower reductions from the current level of 19 servers. The CIF exhibits flow shop characteristics. An assembly line balancing approach was used with the objective of reducing the customer's average time-in-system. Five server allocation heuristics and three customer batch sizes were examined. The evaluation tool was a computer simulation using data from a time-motion study. Results indicate that customer batch size has a greater effect on a customer's average time-in-system than server allocation heuristic. In this study the lowest customer mean time-in-system (for any given manning level and server allocation) was *always* attained using a customer batch size of seven. Treatments using the CIF's current customer batch size of 21 generated average times-in-system higher than those using a batch size of seven, but both of these batch sizes generated lower average times-in-system than did the batch size of one.

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I. Introduction

Central Issue Facility (CIF) Operations

The Central Issue Facility (CIF) at Fort Campbell, Kentucky is a retail warehouse which issues individual tactical equipment to the 14,000 soldiers at the post. This equipment includes things such as rucksacks, helmets, cold weather gear, and canteens. Soldiers keep the equipment for about three years until they leave the post. Approximately 80 separate items of specialty clothing and field gear are issued to and turned in by approximately 200 soldiers a day, four and a half days each week (Peavy). The CIF performs 17 functions in the categories of receipt, storage, issue, accountability, turn-in, inspection, sorting, and disposal (FM 10-30:1-1).

The CIF issues equipment to new arrivals in the mornings and receives equipment from departing soldiers in the afternoons. All CIF customers follow the same sequential steps when processing. The CIF layout is shown in Figure 1.

The first step is reception/inprocessing. Reception clerks enter data on all of a session's customers into the CIF's computer. The clerks confirm each customer's need (full-issue, partial-issue, full-turn-in, or partial-turn-in), determine the customer's unit, and then provide each customer with a pre-printed item menu. The customers are then briefed on the process and formed into batches of 21 (usually) for processing.

The actual issues and turn-ins occur during the second step. These are conducted at three equipment counters (A,B, and C). Batches of customers process through these counters in a cyclical order (A→B→C, B→C→A, or C→A→B). Each of these equipment counters issues/collects different groups of items. Customers are released from their batches after they finish processing at all three of these counters. They then proceed as individuals to the next step.

Step three is a special issue/turn-in of aviation items at the Flight Cage for those customers who are members of aircrews. Non-aircrew members bypass this step and proceed directly to step four. The workers at the Flight Cage also serve Direct Exchange (DX) customers as needed. These DX customers arrive at an outside window to exchange items which are damaged or were issued in the wrong size. Customers in the CIF are given priority over the DX customers.

The fourth step is outprocessing. During the issue process the customers verify that they received the items listed on their menus (inspection bins are available), sign the menus and depart. Clerks at the Property Book Office (PBO) then enter the equipment transactions into the customers' records. Outprocessing during turn-in consists of the customer verifying that the correct balances are on the property book records, signing the records, and receiving a clearing stamp if all items were turned in or accounted for by adjustment documents.

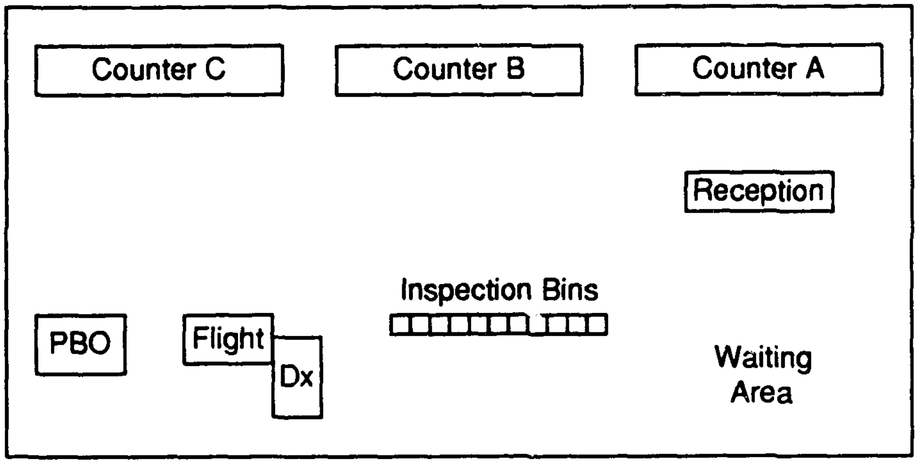


Figure 1. CIF Layout

In this paper, six stations will be referred to:

Station 1 - Reception
Station 2 - Counter A
Station 3 - Counter B
Station 4 - Counter C
Station 5 - Flight Cage/DX
Station 6 - Property Book Office (PBO)

Each of the six stations processes customers at a different rate. These rates are not constant, but stochastic. A station's processing rate can be affected by the number of customers being processed at one time (the batch size) and by the number of servers working. Currently, Station 1 has two servers, Stations 2, 3, and 4 have four servers each, Station 5 has two servers, and Station 6 has three, for a total of nineteen servers among the six stations. The servers at Stations 1, 5, and 6 process customers one-on-one. Additional servers at these stations provide identical parallel services. The servers at Stations 2, 3, and 4 work together (within stations) to process customers in batches.

General Issue

All commanders of Combat Service Support (CSS) units at Fort Campbell were told to increase service efficiency and to plan for personnel cuts.

The authorized manpower (manning level) for the CIF may be reduced in the downsizing process. The cuts may be incremental (one position every few months) or several at a time. If manpower cuts occur, some server positions within the stations will not be filled.

An important factor in manpower reduction decisions is the effect the proposed reduction will have upon a unit's operational capabilities. Usually this is described adjectively ("slight," "crippling," "moderately degrading", etc.) or quantified through gross estimation ("30 percent reduction"). By improving the accuracy of projections the decision process may be improved. A commander with solid capability projections will be better able to assess and articulate the impact of these reductions than a commander with only vague assumptions.

Operational capabilities of the CIF are expressed in terms of the average speed with which customers can be processed (customer service to the individual), and the maximum number of customers processed per day (*customer service to* Fort Campbell).

Research Question

The Support Operations Officer of the 101st Support Group (Corps) is concerned about the effects which decreasing manpower levels at the CIF will have upon the amount of time a customer can expect to spend being processed at the CIF. In formal terms, this time is referred to as a customer's expected processing duration, or average time-in-system.

Because the stations process customers at different rates and these rates are affected by the numbers of servers working at the stations, at reduced manpower levels the allocation of the remaining servers is important. Presumably, at any specific manning level, different allocations of servers would have different effects on the customers' processing durations.

The commander of the 101st Support Group (Corps) wants to examine the effect of reduced manpower levels at the CIF through an Operations Research perspective.

Investigative Questions

The investigative questions this thesis will answer are

1. How can the workers in the CIF be positioned to mitigate the negative effects caused by manpower reductions?

2. What changes in customer processing durations (average time-in-system) can the CIF expect as its manning level decreases?

Improving the efficiency of the CIF may help offset the effects of manpower reductions. The CIF managers are considering other ways to increase efficiency (such as self-service with bar-code scanners at the checkout counters), but this study will focus on the server allocation problem within the current system. Because other CIFs in the Army (such as those at Ft. Drum, NY and Camp Humphreys, Korea) use single customers as the batch size, the effects of decreasing the customer batch size will also be investigated.

Research Goal

Given time limitations and the computational complexity of the problem, the optimal solution of server allocation and batch size may not be determined. The goal of this research is to find a preferred server allocation and batch size for each expected manning level. The preferred solution will be the best of all those considered.

Scope

This study examines average issue and turn-in process durations at the CIF for full-issue/turn-in customers only. The direct exchange process, sorting operation, administration and partial-issue/turn-in processes were considered only to the extent that they directly affected full-issue/turn-in customer processing. Changes in the customer service strategy, such as teaming one server to each customer for all items; going to a self-service approach with bar-code check-out counters; redesigning the layout; or repositioning items in shelves were not examined. CIF production rates (customers per hour) and total time required to process a group of customers were also beyond the scope of this study.

Thesis Overview

Chapter II is a literature review showing the published research relevant to server allocation problems. Chapter III details the methodology chosen to find a solution to the problem. The experimental design, computer simulation, and statistical tests are discussed. Chapter IV presents the output of the simulation and the analysis of that output. Chapter V states conclusions, makes recommendations to the CIF managers, and provides direction for future research in the area of CIF efficiency.

II. Literature Review

Overview

Relevant literature was examined to identify work already performed by others that may be useful to this study. This chapter divides that examination into four areas. First, the CIF problem is formally classified according to categories prevalent in the literature, and literature which directly applies to this problem category is reviewed. Then, representative studies which aid the understanding of the CIF's processes are examined. Next, solution approaches which have been applied to the simpler, deterministic processes are explored, keeping in mind that stochastic processes require more complicated solution approaches. Third, the use of computer simulation to solve complex problems is shown. Finally, heuristic line balancing solutions described in the literature are enumerated.

Classification of Problem

Two main types of production facilities are discussed in the operations research literature: the job shop and the flow shop. A job shop consists of machines (or stations) through which jobs may be routed in any order (Conway, 1967:8). For example, in a job shop with two machines, A and B, there are four possible direct routings: A only, B only, A→B, or B→A. There are also the combinations which arise from a job revisiting machines: A→B→A, B→A→B, etc. A flow shop is a special case of the job shop in which all jobs have the same direct routing (Evans, 1993:585). Because all CIF customers follow the same sequence when processing, the CIF operation is a flow shop. Maximizing flow rate through the CIF is analogous to maximizing the production rate through a flow shop.

In the past, researchers usually considered one of two goals when adjusting the operation of a flow shop. The first goal was to minimize the mean flow time. Flow time is the length of time that a single job takes to flow through all necessary stations and complete processing. The second goal was to minimize the makespan. Makespan for a group of jobs is the time elapsed between starting the first job at the first station and finishing the last job at the last station (Evans, 1993:582). At the CIF a single job is an individual customer and the group of jobs is all of the customers who arrive in a given day for the same type of processing.

When comparing two systems, it is possible for the system which has a lower average flow time to also have a higher makespan. The CIF managers are concerned with customer flow time rather than makespan.

Several variables may be adjusted to reduce mean flow time: the number of work stations; the specific tasks allocated to each work station; the order in which different jobs flow through the shop (sequencing); depth of paralleling of tasks or entire stations (duplication of the production capability of a task or station); the size of job buffers, or queues (temporary holding areas for jobs awaiting processing at the next station); and the size of job batches.

Only two of these variables are applicable to the CIF and of interest to this thesis: paralleling and batch size. The number of CIF stations was fixed at six because of the process design and the facility layout. Changing the tasks assigned to each station is too complicated to do each time the number of servers change. The order in which customers are processed can be controlled by the CIF managers, but because very little predictable differentiation exists among customers, this would have a limited impact on mitigating the effects caused by manpower reductions. Finally, because of space limitations, there is no buffer space available to customers waiting to be processed at the three main counters.

Literature Applicable to Flow Shops

Literature on reducing the cycle time of a flow shop by adjusting the level of paralleling within a fixed number of stations directly applies to this study. Also applicable is research on the allocation of servers in a network with queues. This type of research provides mathematical proof of intuitive concepts regarding the effects of reallocating workers between stations.

Throughput, as used in this study and the research mentioned in this chapter, is the average output rate of a station or process. Vinod and Solberg (1985) mathematically proved that throughput increases when a server is added to a station which exhibits stochastic service rates.

Shanthikumar and Yao (1987) showed that the throughput of a station in a closed queuing network (fixed number of customers; as soon as one is finished processing another arrives at the beginning of the line) is an increasing concave function of the number of parallel servers allocated to the station. This is just an example of the law of diminishing returns. Beyond a certain point, each additional server can contribute less and less to that station's throughput. The authors also mathematically derived a formula to determine the optimal number of servers to allocate to each station in a network. Their method of maximizing the throughput of the network is one of ensuring that the marginal utility of each server at each station is as equal as possible.

As an extension of their earlier work, Shanthikumar and Yao (1988) mathematically showed that throughput can be improved by placing more servers at stations with higher workloads; i.e., balance a network by allocating personnel so that workloads are as equal as possible. They contend that their approach also extends to open queuing networks (the number of customers in the system is not constant).

Cycle time is the "elapsed time between completed units coming off the end of an assembly line" (Adam and Ebert, 1986:347). Ignall (1965:244) found that directly minimizing the cycle time for a given number of stations (by adjusting the task assignments at each station) is much more difficult than simply adjusting the number of stations and their associated tasks in order to meet a given cycle time.

Most of the work published since Ignall's 1965 article focused on fixing the cycle time and then adjusting other parameters in order to meet that time. There is extensive literature on flow shops concerning the effects of allocating tasks among stations, sequencing, paralleling tasks or stations, controlling batch sizes, and scheduling customers for processing. There is also literature on the computational difficulty of obtaining an optimal solution, and on heuristics for obtaining "good" (but not necessarily optimal) solutions to flow shop sequencing and scheduling problems. Even though most of the literature does not apply directly to the CIF problem, many concepts from the literature were adapted to it.

The areas of research which provided the most useful information for this thesis concern assembly lines with stations that have variable task times, computer simulation of those systems, and heuristics which successfully balance stochastic assembly lines. Before discussing this work, however, the foundational concepts will be reviewed.

Foundational Literature

The foundational literature can be broken down into the following general topics: assembly line balancing (ALB), paralleling work stations, batching jobs, and scheduling jobs.

Assembly Line Balancing. A complete manufacturing process is made up of tasks, and these tasks have precedence relationships. The objective of ALB is to "assign tasks to individual work stations along the line in order to minimize labor cost while satisfying precedence constraints and achieving the desired output rate." An assembly line is said to be balanced when "each work center has the same amount of work per operator per unit of time" (Evans, 1993:315-16). This idea of equally loading all work stations to increase efficiency is well established. M. E. Salveson first defined the ALB problem in 1955 (Baybars, 1985:449). Jackson (1956) developed a computing procedure for the ALB problem. Tonge (1960) discussed and defined two classes of the ALB problem, presented heuristics for solving the two classes, and applied them to problems found in industry. These two classes are referred to as Simple Assembly Line Balancing Problems (SALBP) 1 and 2. SALBP-1 is used to minimize the number of work stations while being constrained by precedence relationships and a given production rate. SALBP-2 is used to minimize cycle time while being constrained by a fixed number of work stations and the precedence relationships (Baybars 1986:910-911). Baybars' 1986 article provides a good summary of the significant developments in the ALB field since Ignall's 1965 article.

The main assertion of this literature is that a production line's output is greatest when each station's production rate is equal to the desired system production rate. In that case, each station would have the same utilization rate. This concept is established for assembly lines which have deterministic task durations or stochastic durations with small variances; however, lines which have stochastic processes with wide task time variances may benefit from "unbalancing" their stations (Hillier and Boling 1966:657; Smunt and Perkins 1985:371-372). Unbalancing will be further discussed later in this chapter.

Industry has validated the principles of assembly line balancing. Gunther, Johnson and Peterson interviewed and surveyed practicing industrial engineers from an automobile manufacturer and from several stereo manufacturing firms (1983:210). They assembled a list of eleven goals which represented the engineers' consensus of goals that are important when setting up an assembly line. One of the three most important goals was ensuring "the sum of activity times at a work area does not exceed the cycle time or a percentage of the cycle time."

The SALBP concept is useful for analyzing the CIF. The movement of a server from one station to a second station has the same effect as moving tasks from the second station to the first: both result in higher server utilization at the first station and lower utilization at the second. This leads to the conclusion that moving workers between stations will affect the utilization rates (and production rates) of those stations. Shanthikumar and Yao (1987, 1988) mathematically showed that adding servers to a station will increase that station's throughput. According to ALB theory, regardless of the total number of workers at the CIF, an allocation of those workers which results in equal server utilization rates between the stations (a "balanced" line) will produce the highest throughput, as long as the task times do not show a large variance.

Paralleling tasks or stations. Paralleling is a technique whereby production capabilities for selected tasks or entire work stations are duplicated. In its simplest form, this results in a task being performed simultaneously on two jobs at separate locations. "Multiple [paralleled] stations allow the production rate to be greater than the limitation imposed by the longest work element" (Buxey, 1974:1010). Thus, paralleling should work well at a bottleneck to increase the flow through the system. Reducing a bottleneck may increase the utilization rates of non-bottleneck stations. A concern is that every minute of idle time experienced by a non-paralleled station would be multiplied if that station were paralleled. Killbridge and Wester (1966:255) found that, with careful planning, paralleling provides a case where "non-productive labor should decrease slightly or rise by an amount small enough to be more than compensated for by improved balancing." Horn (1973) showed that it is possible to minimize average flow time by using parallel machines (within the constraints of a fixed total number of machines). Pinto, Dannenbring and Khumawala (1975) showed that paralleling is a way to reduce total costs, and later (1983) showed it as a way to reduce work center times. Buxey

(1974:1011) noted that intermittent losses due to individual variability [stochastic service times] should decrease when paralleling is used.

Paralleling is used at some of the CIF stations, but not at the main issue/turn-in counters. Paralleling will be suggested in Chapter V.

Batching. While production management techniques which are currently gaining popularity (e.g. Just-In-Time manufacturing) strive to reduce lot sizes (Schoenberger, 1982), as long as a set-up time is involved there is an economy of scale to be achieved by having more than one item processed in the same batch. Santos and Magazine (1985) developed analytic and computational procedures to explain why it makes sense to use large batch sizes at bottleneck stations, and small batch sizes at stations with slack time.

Karmarkar (1987:409-17) examined the relationship between batch sizes and total production durations. He demonstrated that, in a situation where a process is made up of a fixed setup duration and a variable process duration, and successive jobs are queued, the minimum average time-in-system is dependent upon the batch size. For a work center with fixed setup durations, small batches cause the load on the work center to increase because the setup task is repeated often, while larger batches result in a higher effective processing rate for the work center because fewer setups are required. Thus, the largest possible batch size will minimize the total worker effort required. This suggests that management must balance the work effort of the employees with the customer service level.

This work on batching suggests that batch size may play a significant role in the efficiency of work stations at the CIF. It is possible that the effects of batch sizing may be as important from an efficiency standpoint as the effects of reallocating personnel.

Job Scheduling. Many researchers have written about the scheduling (also known as dispatching) problem for flow shops. Representative work includes Gupta (1972), Garey and others (1976), Burns and Rooker (1978), Szwarc (1978), Gupta and Reddi

(1978), and Dogramaci and Surkis (1979). Their goal was to manipulate the ordering of jobs into the process, taking advantage of the jobs' individual processing requirements in order to reduce the flow time or the makespan. These studies all used deterministic task times; i.e. the times for processing each job on each machine were known with certainty.

Even though the CIF operations have stochastic task times and the ordering of customers is not one of the items of interest, the work cited above does provide guidance to the CIF problem. Gupta (1972:13) successfully used a heuristic which ensured that the stations at the end of the process were utilized as much as possible. This is analogous to assigning more servers to the front CIF stations in order to minimize slack at the rear stations.

Solution Approaches

Researchers have looked for two types of solutions for assembly line balancing problems. Some have chosen to find optimal solutions while others have chosen to find "good", but not necessarily optimal, solutions. Gupta (1972:12-13) defines a "good" solution as "economically acceptable to management because it is easy to obtain, and is very close to an optimum solution." The course followed depended on the problem complexity and the time and computational power available. Baybars (1985:451) cited Wee and Magazine (1981) as demonstrating that the SALBP-1 and 2 are both *np*-hard. This means that a slight increase in problem complexity causes a tremendous increase in solution difficulty. Finding optimal solutions to ALB problems is a difficult undertaking. Even with the "better" approximate solutions, higher accuracy (closer to the true optimum) comes at an increasing cost in terms of time and computing power (Mastor 1970:728).

Optimal Solutions. Gupta & Dudek (1971) used the brute force method of complete enumeration in order to identify optimal solutions. They had 180 flow shop problems grouped into eight categories. Each problem involved four to six machines. The simplicity of the problems allowed a fast solution to each. The optimal solution for each of the eight categories was determined based on comparisons within the complete solution set. Giffler and Thompson (1960:487) showed that for small size problems (either a low number of machines or a low number of jobs, or both), it is practical to generate the complete set of solutions and then select the optimum by direct inspection.

Linear programming can be used to select an optimal solution as long as the process durations are known and not stochastic. Many authors have used linear programming to solve for minimum flow time or makespan schedules, or for the minimum number of stations needed to meet a specified cycle time. If the problem is simple enough, it may be formulated simply as an assignment problem (Horn, 1973). Many of the linear programming-based solutions for complex problems use branch and bound algorithms to find the optimal solutions (Hoffman 1992; Pinto, Dannenbring and Khumawala, 1975, 1983; Bansal 1977; Reeve and Thomas, 1973). Further examples of the use of linear programming's branch and bound technique can be found in Ignall (1965), Baker (1975), and Johnson (1981). These uses of the assignment problem and the branch and bound technique were possible only because every operation's duration was determined; i.e. there was no uncertainty injected due to stochastic processes.

A variation of linear programming called goal programming has been used to select a solution which minimizes the deviation from conflicting goals (such as minimizing mean flow time and the number of stations at the same time). Gunther, Johnson and Peterson (1983) included behavioral goals (minimize boring tasks for each worker, equalize skill allocations at each station) along with traditional ALB goals (minimize number of work areas) in their study.

A nonlinear programming technique called fractional programming was used by Hoskins and Blom (1983) to find an optimal solution for allocating warehouse personnel.

The size of the operation studied was very similar to the CIF's. Their objective function was the ratio of two linear functions, and deterministic task productivity rates allowed them to use fractional programming.

Approximate Solutions. Approximate (non-optimal) solutions are usually required for complex problems or those with stochastic work element durations. Instead of complete enumeration and selection by inspection or by branch and bound, the set of possible solutions is restricted by the use of heuristics. This restricted set of possible solutions is then evaluated and the "best" chosen. It must be stressed that the best solution of a restricted solution set is not necessarily the optimal solution.

The simplest heuristic used to balance assembly lines is trial and error. Lehman performed a survey (1969) which showed that (at that time) 40 percent of US. companies used this method (and only 15 percent used a computer to aid their decision). The line managers tried new arrangements based on their experiences and intuitions, and then chose the arrangements which yielded the best results.

Gupta and Dudek (1971) chose to solve their larger problems (up to 40 machines in the flow shop) by randomly sampling the solution set through Monte-Carlo simulation. Giffler and Thompson (1960) also used the random sampling approach for large problems.

Helgeson and Birnie (1961) used a technique called "positional weight" to assign values to tasks and then select allocations of tasks which provided the most favorable summation of the assigned values. This greatly reduced the number of possible solutions to be considered.

Moodie and Young (1965) attempted to find improved solutions to the "minimize cycle time" problem for a flow shop by starting with selected allocations of tasks within the fixed number of stations. They then performed a series of single substitutions of tasks between stations in a search for better cycle times. The substitutions continued until no further improvement in the cycle times occurred.

The problem with the use of heuristic solutions is the determination of how good the solution is compared to the optimum. Dogramaci and Surkis (1979) considered this when they evaluated a scheduling heuristic. They explained that the approximation ability of any heuristic is determinable only if it is comparable to a known optimum. Thus, even though a study can find a heuristic-based solution to allocating servers, there is no way of knowing how efficient the solution is in absolute terms unless it can be compared to the actual optimal solution.

Dannenbring (1977) evaluated the effectiveness of four solution improvement heuristics by comparing their results in terms of closeness to the known optimum and the computational effort required. His work showed that using a few wisely selected starting points and improving on them as much as possible generally delivers better results than generating a large number of random starting points and selecting the best of those by inspection. An interesting observation is that the time spent improving the initial starting point choices was two orders of magnitude longer than the time spent making the initial choices themselves (average of 2.13 CPU seconds vs. 0.02 CPU seconds), while the improved accuracy was only two (75 percent vs. 35 percent for small problems) to three (18 percent vs. 5 percent for large problems) times higher. Dannenbring concluded by stating that "it is not unreasonable to expect estimation errors in the range of 10 to 15 percent in practice. In these situations good heuristics offer performance similar to that achievable by an optimizer but at much less cost" (1977:1182).

Solution Approaches to Stochastic Assembly Lines

The optimal solutions described above were possible because of the deterministic nature of the problems' processes. Most of the work done on SALBP-1 and 2 considered only task times which were known with certainty. It was thus possible to create matrices of task times at each machine, and to compute solutions to the various combinations of task-machine sequences. Even though the large number of possible combinations created a very protracted effort, solutions to specific situations were possible. Task durations which exhibit variability, however, add a new dimension of difficulty to the problem.

Few researchers have attempted to mathematically model the stochastic assembly line problem. "Analytical efforts have been hampered by the complexity of the queuing models required for even the simplest of scenarios (a two or three station line)." Past studies usually had to assume that the service durations were exponential or Erlang distributed to be able to find any results at all, yet "the literature and practical experience suggest that these may not be realistic service time distributions" (Smunt and Perkins, 1985:353). The literature we located centered around the relationships between task duration variability, the location of highly variable tasks along the line, buffer space between stations, and output rate (Patterson, 1964; Hillier and Boling 1966; Rao 1975, 1976).

The general conclusion from these studies was that for long assembly lines with task durations that exhibit wide variation, an *unbalanced* line produces better results than a balanced line. This unbalancing may be performed with a "bowl" allocation or with an "inverse bowl" allocation, among others. The bowl phenomenon suggests that output can be increased (compared to a balanced line) by "unbalancing the line with high service times placed at the beginning and end of the line, and low service times in the middle of the line" (Smunt and Perkins 1985:353). The inverse bowl allocation places the station with the lowest capacity at the center of the line, and the stations with the highest capacities at the beginning and end. When slack capacities are low and process fluctuations high, as is the case with the CIF, an inverse bowl strategy may provide better results than a balanced strategy (Fry and Russell, 1993:1111).

Not all of the research led toward unbalancing the line, however. An approach commonly used to balance stochastic lines is to assign tasks to stations up to a set percentage (frequently 90 percent) of the cycle time (Ignall 1965:253). Moodie and Young assigned station capacity to equal that station's mean processing rate minus two standard deviations. They also apportioned the tasks among work stations so that the average times for tasks and the variance summations for tasks were "as nearly equal as possible for all work stations" (1965:27). Reeve's approach was "to rearrange the work elements [re-sequence the tasks among the work stations] such that the probability of one or more stations exceeding the cycle time is minimized" (1973:223).

Two authors tried to simplify the stochastic situation so that deterministic mathematical models could be used. Spicas and Silverman (1976:281) showed that task durations possessing the Poisson, gamma, binomial, negative binomial, chi-square, or normal (truncated at zero) distributions can belong to a class of distributions which can be transformed into simpler deterministic values.

While a mathematical model can produce usable results, that approach uses assumptions which may not be universally applicable. Additionally, mathematical approaches are useful for only simple cases. For the examination of complex cases such as the CIF, researchers have turned to non-mathematical approaches such as computer simulation.

Computer Simulation

Systems with static processes or deterministic task durations may be solved by linear programming methods. Systems which are dynamic or which have stochastic task durations require a different approach. Computer simulation is a valuable tool for studying these types of systems and for evaluating the effects of proposed changes (such as the reallocation of personnel). Additionally, if problem size makes a mathematical solution intractable, then simulation provides a way of generating relevant data from which to draw conclusions.

Simulation was chosen by many researchers as a method to generate data for analysis of a system. Wild and Slack (1973) chose computer simulation as a feasible way to account for variability in task times in their study of paralleling within stations. Smunt and Perkins (1985) used computer simulation because mathematical models were less suitable for studying the effects of varying two independent variables (variance of task time distribution and buffer storage capacity). They also provided a good summary of twelve other computer simulation studies concerning stochastic assembly lines (1985:355-58). Most recently Fry and Russell (1993) compared six different line balancing heuristics via computer simulation. The simulations allowed them to gather data on the effects of changing service capacities and fluctuating process durations.

Heuristics for Improving Throughput

Several station capacity allocation strategies for increasing the throughput of a flow shop have been proposed. Fry and Russell (1993) reviewed the work of several researchers and selected six variations of capacity allocation in a hybrid job shop. This shop had seven sequential work centers (essentially a seven station flow shop configuration), with processing done within each work center by a variable number of machines (in a job shop configuration). The allocations examined were :

1) Balanced - All work centers have equal mean service capacities. Each station should therefore have equal idle time as well.

2) Bowl - The most capacity, and therefore most idle time, is located in the middle of the assembly line.

3) Inverse Bowl - The work centers at the center of the line have the least capacity relative to the stations on the front and back ends of the line.

4) Increasing Linear - Capacity increases linearly along the line. The first work center is the most restrictive upon the system.

5) Segmented - There are two or more increasing linear capacity trends along the line.

6) Step - The first work center has a lower, restrictive capacity, but all other work centers have balanced capacities.

Summary

This literature review helps one understand the different factors which must be considered in analyzing the CIF's operations. General works containing concepts which can be applied to the CIF were reviewed, as were computer simulation studies and research on applicable heuristics for evaluating the process. This review set the stage for the decisions made in the next chapter.

III. Methodology

Overview

To determine preferred allocations of servers and preferred customer batch sizes at the CIF for given manning levels, we designed an experiment which allowed us to predict the average amount of time a customer should need to process through the facility (time-in-system). We chose to employ computer simulation models of the CIF operations to predict the customer time-in-system. Five heuristics were used to allocate servers, and batch sizes were set at minimum, maximum, and intermediate values.

After running the simulations under all conditions of interest, statistical analyses were performed on the results to determine which of the conditions were superior to the others at each of 14 manning levels. Results are presented in tables for use in selecting preferred server allocations and customer batch sizes at each manning level.

Experimental Design

The goal of this experiment was to find a preferred allocation of servers and a preferred customer batch size for each manning level. We did not attempt to determine optimums because to do so would have required an examination of all possible allocations of servers to the six stations at manning levels which vary from a total of nineteen servers down to six, for each of twenty-one batch sizes (over 300 billion possibilities). Additionally, the stochastic nature of the CIF's operations makes any proposed optimal solution questionable. Thus, we decided to seek good solutions rather than optimal ones (Gupta, 1972:12-13). We chose five heuristics to determine server allocation and three batch sizes to apply to each heuristic at all fourteen manning levels. That resulted in 3*5*14 = 210 possible combinations of conditions (treatments).

Manning Levels. All possible manning levels were examined, from the current maximum of nineteen down to the theoretical minimum of six (only one server at each station). An alternative would have been to look at every other manning level and interpolate average customer times-in-system for the missing levels; however, that would have left the allocations of servers (the research goal) unknown. This omission of manning levels would have reduced the manager's ability to predict the impact of personnel reductions and weakened this research effort.

Heuristics. After reviewing the relevant literature, we identified numerous assembly line balancing heuristics which appeared promising to decrease the mean flow time through flow shops similar to the CIF, and thus reduce the average customer time-in-system. The literature specifically mentioned six heuristics, from which we chose two. To these we added three more which we defined using principles followed by other authors (Evans, 1993:315; Buxey, 1974:1010).

Fry and Russell (1993) found that the best allocation heuristic in their hybrid job shop study depended on the levels of two factors: excess capacity (sum of stations' idle time) and process fluctuation (variability in the processing rates within the individual stations). For conditions with high excess capacity, a balanced allocation heuristic provided the best overall results. When the overall excess capacity was low and the process fluctuations were high, an inverse bowl heuristic dominated.

The CIF has relatively high process fluctuations (comparable in magnitude to those in Fry and Russell's study), but its excess capacity is unknown. If the excess capacity is high, then according to Fry and Russell's research a balanced heuristic should provide the best results. If the excess capacity is low, then an inverse bowl allocation heuristic should perform best. For these reasons, the Balance and Inverse Bowl heuristics were chosen for this study.

Stochastic assembly lines can be balanced by using the means of the individual process durations (Spicas and Silverman, 1976:281). The CIF line was balanced by allocating servers in a way that reduced the variance of the mean production capacities among all six stations. After balancing, the line still had an uneven capacity profile because servers had to be allocated as whole units.

The allocations of servers under the Inverse Bowl heuristic placed more production capacity at each end of the line and less in the center. These allocations were determined as in the first heuristic by using the mean production capacities for each station.

The current CIF manager's recommendations were used for the third heuristic, which we call "Manager." At our request, the Chief of the CIF prepared an allocation plan for each manning level, representing the expert opinion of the resident management.

While allocations under the Balance, Inverse Bowl, and Manager heuristics were determined before the experiment began, the fourth and fifth heuristics required consideration of the effect on average customer time-in-system of the previous level's allocation before deciding which station would receive or lose the next server.

The fourth heuristic, "Utilization-Up," set one server at each station at the minimum manning level of six, and at each incremental manning level added a server to the station with the highest average utilization at the previous level. The new allocation was the starting point for determining which station received the next server. For example, if a system with three stations had the average utilization rates and server allocations as shown in Table 1 at a manning level of ten, then at a manning level of eleven the additional server would be allocated to Station 3 (where the servers are the busiest). The additional server at Station 3 should decrease that station's average utilization rate.

TABLE 1

UTILIZATION-UP ALLOCATION EXAMPLE

	Station 1	Station 2	Station 3	Total
Manning:	4 servers	3 servers	3 servers	10
Utilization:	60%	70%	80%	
Manning:	4 servers	3 servers	4 servers	11

The fifth heuristic, "Utilization-Down," began with the current allocation of 19 servers, and at each lower manning level removed a server from the station which had the lowest average utilization at the previous level. The new allocation was the starting point for determining which station would lose the next server.

The server allocations which resulted from the above heuristics are listed in Appendix A.

We believe that a good solution to the allocation problem exists among these five heuristics. We could have increased our chances of finding a better solution by considering more heuristics, but chose not to for two reasons. First, given the problem size, we believe that an allocation which is close to the true optimum at each manning level is likely to be captured by one of these five heuristics, and consideration of more would not have substantially improved our results. Second, consideration of more heuristics would have increased the experiment size by 39 combinations for each heuristic added (three batch sizes times the thirteen manning levels where more than one allocation is possible). Therefore, we restricted the number of heuristics considered to keep the problem from growing too large.

Batch Size. Under current procedures, soldiers are usually processed in batches of 21. This number was determined due to the physical layout of the building and the size of the equipment carts the soldiers use to move their gear from station to station. The three main service counters are slightly different lengths, and only 21 carts can fit side-by-side in front of the shortest counter.

Batch size selection for a production process can, however, significantly impact the overall production rate (Karmarkar, 1987:413). Therefore, a minimum batch size of one and an intermediate size of seven (the most customers a single server could easily handle) were also examined.

Selection of Solution Method

Experimentation with the CIF itself would have been extremely disruptive to the CIF's operations (Peavy). We did not use an analytical approach because the CIF process is too complex for us to find a solution using equations. Linear programming was not feasible because the allocation of servers requires integer units. Integer programming was also eliminated because it was beyond our ability to master within the time available, especially in light of the need to account for the stochastic nature of the CIF operations. Therefore we turned to simulation, the preferred method in cases such as ours where the systems are so complex that analytical solutions from mathematical models are impossible (Law and Kelton, 1991) or not practical (Wild and Slack, 1973; Smunt and Perkins, 1985; Fry and Russell, 1993).

Assumptions and Conditions

The CIF management provided general assistance in validating the model assumptions. Procedural information was obtained from the Chief of the CIF, Mr. Peavy, and the head of the CIF's Property Book Office, Ms. Earhart. Each of these managers has many years experience at the CIF and is an expert in the field. Manpower efficiency data were provided by the platoon leader of the CIF personnel, Lieutenant Peplowski, who has a degree in systems engineering and a knowledge of the principles of queuing theory, line balancing, and computer simulation.

The following assumptions and conditions were established to simplify the problem:

1. The number of customers processed each day was fixed at 63 for full-issue and 63 for full-turn-in. This number was chosen by averaging the weekly totals of full-issue and full-turn-in customers over a 23 week period and dividing the result by the number of issue/turn-in sessions per week (593.47 customers per week / 9 sessions = 65.94 customers per day). Sixty-three was used instead of 66 because no more than 63 customers can simultaneously use all three main issue/turn-in counters. Additionally, 63 is only 0.114 standard deviations from the mean of the data from the 23 week period.

2. All customers are identical, and no preemption is allowed. There are over 60 different customer menus at the CIF and each generates different levels of server workload. This variation in service durations for customers using different menus was captured in the simulation by drawing process durations from probability distributions. Senior officers normally get individual treatment (preempting other soldiers) which slightly increases the processing durations of the remaining customers. Because this involves a relatively small fraction of all customers and has no significant impact on the processing durations of the others, no customer differentiation was used.

3. All servers are identical, and each server can work at any station. Servers assigned to a station assumed the service duration characteristics of that station. In reality, servers at each station perform different tasks which require different amounts of server time, and variations in individual work rates are very noticeable. These variations were reflected in the standardized process duration distributions for each station, which were then applied to generic servers.

4. The number of partial-turn-in customers was set at 38 per day, and the number of partial-issue customers was set at 16 per day. Six months of historical data revealed the

number of partial-turn-in customers was equal to 60 percent of the number of full-turn-in customers. Furthermore, according to the personnel who in-process customers, partial-turn-ins account for 70 percent of all partial-process customers (Peplowski, 1994). Because 63 full-turn-in customers were used in the model, 38 partial-turn-in customers were used (.60 * 63 ≈ 38). And because 38 is 70 percent of 54, 16 partial-issue customers were used (54 - 38 = 16).

Partial-process customers were included in the simulation only to impact the full-process customers, but their times-in-system were ignored. While not directly modeled, the standardized process duration distributions for Stations 2, 3, and 4 reflect this impact of partial-process customers at those stations. The other stations reflect this partial-process impact directly, except that no partial-issue customers were considered to use the flight cage.

5. <u>The number of customers requiring property book hand receipt adjustments was set at 11 per day, and the number requesting copies of hand receipts was set at 6 per day.</u> Adjustments to property book records through reports of survey, statements of charges, or cash collection vouchers are necessary when soldiers lose items they were issued or when items were damaged beyond fair wear-and-tear. Soldiers who require adjustments usually do so after attempting to turn in all items during the full-turn-in session. They then return as partial-turn-in customers to resolve any discrepancies. The number of soldiers requiring adjustments was equal to 28.66 percent of the number of partial-turn-in customers over the most recent six month period. Because 38 partial-turn-in customers were used in the model, 11 soldiers requiring adjustments were used (.2866 * 38 ≈ 11). According to the senior property book clerk (Wilkinson), 40 percent of those soldiers who require adjustments arrive during the issue sessions (.40 * 11 ≈ 4) and the remaining 60 percent arrive during the turn-in sessions (.60 * 11 ≈ 7).

Some soldiers visit the CIF just to get copies of their hand receipts (showing all items they are responsible for) so they can prepare for turn-in. The senior property book clerk said the number of customers requesting copies of hand receipts is about half the number who require adjustments during turn-in ($7 / 2 \approx 3$), and approximately that same number requested copies of hand receipts during issue sessions (Wilkinson).

6. The process durations for issue and turn-in at Stations 2, 3, and 4 are composed of fixed and variable components. The fixed component for each station is the same for issue as for turn-in. This assumption is detailed later in this chapter under Input Data Preparation.

7. There are diminishing returns when additional servers are added to Stations 2, 3, and 4 during the issue sessions; however, diminishing returns are negligible during turn-in or setup because those processes are individually labor intensive. After conferring with his section leaders and observing the idle time of servers at various levels, Lieutenant Peplowski determined that a diminishing return effect exists during the issue process. A diminishing return effect is a decrease in per-server efficiency as additional servers are added to a station. The diminishing return effect is caused by the servers getting in each other's way in the limited work space, and by occasional duplication of effort. Lieutenant Peplowski agreed with our assumption of no diminishing returns for setup and turn-in at Stations 2, 3, and 4, and all processes at Stations 1, 5, and 6.

8. Standardized process durations (server-minutes per customer) at individual stations are valid across all batch sizes and manning levels. In the absence of further empirical data, standardized process durations were assumed to remain constant as batch sizes and numbers of servers changed.

9. Servers allocated to stations are always available for work. They will not be called away for any reason. In reality, servers may temporarily leave the line for various

reasons during the day. These absences were not included in the model because they are unpredictable, and they are assumed to affect any server allocation equally over time.

Input Data Collection

We visited the CIF on three separate occasions to gather information on its operations and to collect input data for the simulation.

During the first visit we received a detailed orientation of the CIF operations from the Chief of the CIF, Mr. Peavy. The information gained from this orientation was used to prepare the data collection plan for the remaining visits.

The purpose of the second and third visits (five days each) was to collect data on all of the service related activities through time-motion studies. We used notebooks and stopwatches to record starting times, numbers of servers, customer batch sizes, and finishing times for each process. We also talked with the servers to increase our understanding of each process. The observed durations of each process are listed in Appendix B.

We perceived that our method of direct observation and questioning may have affected the process. During the second visit we were in uniform, and soon felt that our presence as officers with notebooks and stopwatches observing lower ranking enlisted personnel probably caused them to alter their performance. This is an effect known as the Hawthorne effect (Emory and Cooper, 1991:410). We constantly stressed that we were measuring and not evaluating, and that they should ignore us and perform their duties as usual.

We wore civilian clothes during the third visit and observed from the background to reduce any Hawthorne effect. In any case, we believe that any effect our presence may have had on the measurements was mitigated by the likelihood that all processes would have been affected identically. Because we were interested in *comparing* performances under various conditions rather than *determining* performance values, this effect was probably negligible.

In order to collect more data during the third visit, we asked the heads of each station to record the numbers of servers, customer batch sizes, process types, and process durations on service logs we provided (a sample is shown in Appendix C). We monitored the stations and spot checked their measurements against our own observations. Their measurements were generally consistent and accurate.

We also measured the time customers used to inspect their gear during issue, and the times-in-system of individual customers during both issue and turn-in sessions.

The conditions observed during data collection were very erratic. As mentioned earlier, servers sometimes left their stations, and server performance varied greatly. This variation occurred not only between servers, but individual server performance also varied with changes in the time of day and the day of the week. All standardized process duration distributions were developed under these erratic conditions so the simulation would reflect actual performance, but the erratic conditions limited the confidence we could have in the data analysis.

Input Data Preparation

The observed measurements were used to establish empirical distributions of the stations' standardized process durations. Empirical distributions were used because theoretical distributions which adequately fit the data could not be found. In situations like this, empirical distributions are recommended (Law and Kelton, 1991:325). The distributions consist of the observed durations converted into standardized process durations which were expressed as server-minutes per customer. During simulation, samples taken from the distributions were converted back into process durations based on customer batch sizes and server allocations specified.

Accurate standardized process durations for the reception desk, flight cage, and PBO were easily determined. Each of these stations utilizes one server to process each customer. Thus, the standardized process duration is the observed process duration for each customer, and can be used for any number of parallel servers or customer batch size (soldiers wait in a single line until a server is available). The standardized process durations were used directly to form the empirical distributions for these stations.

Duration distributions for the three main issue/turn-in counters (Stations 2, 3, and 4) were more difficult to develop. Process durations at these stations include variable components which are dependent upon the numbers of servers and the customer batch sizes. The durations also include fixed components which are independent of these factors. These fixed components account for the time each station leader uses to issue verbal instructions (asking for size needed, telling customers when to pick up items, and telling them when and how to move to the next station), and the time a single soldier requires to receive or turn in items at a station under ideal conditions. The activities included in the fixed components for issue correspond to those for turn-in; the roles of provider and receiver are just reversed. Thus, the fixed components at each station are the same for the issue and turn-in sessions.

The durations of the fixed components were determined from a single staged trial at each station. The issue process was measured under the ideal condition of an attentive customer who immediately executed instructions without dropping any items, interrupting, or otherwise slowing down the process. The durations of the fixed components thus observed were 4.92 minutes for Station 2, 2.50 minutes for Station 3, and 3.25 minutes for Station 4.

Because of the diminishing returns of each additional server at Stations 2, 3, and 4 during the issue sessions, adjusted server numbers were used when calculating corresponding process durations. These adjusted server numbers were based upon diminishing return factors provided by Lieutenant Peplowski. Those factors are 80 percent for the second server (the second server only contributes 80 percent of what the first server can do working alone), 50 percent for the third, and 33 percent for the fourth (Peplowski 1994). Because some of the heuristics added a fifth server to some stations, the diminishing return factor of 25 percent was extrapolated for those cases. Thus, two servers equate to 1.8 adjusted server units, three equate to 2.3 adjusted server units, four equate to 2.633, and five equate to 2.883 adjusted server units.

The number of observations we collected on the issue process at Stations 2, 3, and 4 was insufficient to verify the diminishing return factors provided. We did observe, however, that when only one or two servers were working at an issue counter, they worked much harder than servers at counters where three or four shared the same work.

The standardized process durations for each station were calculated by subtracting the fixed component (Stations 2, 3 and 4 only) from each observation to get the variable time, multiplying this variable time by the adjusted number of servers, and then dividing this product by the number of customers in the batch.

Here is an example of the calculation:

> Nineteen customers received a full issue from three servers at Station 2 in 16 minutes. The fixed time for a full issue at Station 2 is 4.92 minutes. Subtracting the fixed time from the total time leaves 16.0 - 4.92 = 11.08 minutes of variable time. Three servers contributed 2.3 adjusted server

units worth of productivity. The standardized process duration to be included in the distribution is 2.3 servers * 11.08 minutes / 19 customers = 1.34 server-minutes per customer.

All the standardized durations were similarly calculated, except that the fixed times were subtracted only from Stations 2, 3 and 4, and adjusted server units were used only for Stations 2, 3 and 4, and only during issue. During each simulation run, samples were randomly drawn from the standardized process duration distributions. These samples were directly used as process durations for Reception, the Flight Cage/DX, and the PBO. Process durations for Stations 2, 3 and 4 were calculated by multiplying the random samples by the batch sizes specified and dividing the products by the numbers of servers or adjusted numbers of servers as required. The fixed durations were then added to yield the process durations.

The Simulation Models

Separate simulation models were developed for the issue and turn-in sessions because the setup process occurs only during issue. These models were constructed using SLAM II simulation language, version 4.1, developed by Pritsker and Associates. SLAM II is an advanced FORTRAN-based simulation language that is ideal for modeling flow shop operations such as the CIF. We found SLAM II particularly easy to use because of its network symbols which it translates into computer processing input statements. The simulation experiments were run on a Digital Equipment Corporation (DEC) VAX 6420 mainframe computer located at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio, using a DEC VAX FORTRAN version 6.1 compiler. The source code and network diagrams for the simulation models are in Appendices D (issue) and E (turn-in).

Model Verification and Validation. Model verification is the process of ensuring the model performs as intended and contains no programming errors, while validation is the process of ensuring the model accurately represents the real system. Failure to perform both of these processes will cause any conclusions drawn from simulation results to be suspect.

The CIF models were verified by tracing the simulation outputs through the models to ensure expected logic was applied at all decision points. These trace runs were performed using test input conditions with known results. The test runs were performed at many batch sizes including the three used in the actual experiment, and at various server allocations.

Model validation was performed by setting conditions in the models to reflect those observed during our visits to the real CIF, and comparing the simulation results to the observed CIF performance. All these test runs returned values which included the observed measurements within one standard deviation of their means. These results were outstanding given the stochastic nature of the CIF operations, and supported the validity of the models.

Analysis of Output Data

Analysis of the simulation output was performed to determine whether any of the treatment means significantly differed from the others, and what effects the different factors had on the results, either independently or interactively. The goal was to use this information to help determine the preferred combinations of server allocations and batch sizes to use at any prescribed manning level during issue and turn-in sessions.

For both issue and turn-in, 100 runs of each treatment were made, and the results were partitioned into two sets containing 50 observations of each treatment. One hundred runs was expected to be large enough to support any desired statistical tests. The data were partitioned so we could "get a feel" for what the data looked like through exploration of the first set (trial data), and perform appropriate statistical analyses on the second set. If the statistical analyses were performed on the trial data, then "data-snooping" would have become an issue.

The experiment used the three factor, fixed effects model shown in Equation 1 for the statistical analyses. The three factors are manning level, customer batch size, and allocation heuristic. Manning level and batch size are quantitative factors and heuristic is a qualitative factor. Fixed effects models use specifically chosen levels of factors (Neter, Wasserman and Kutner, 1985:523). The factor levels used in this experiment were predetermined and not randomly chosen to represent the total population of possible factor levels.

$$Y_{ijkl} = \mu + \tau_i + \beta_j + \gamma_k + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk} + \varepsilon_{ijkl} \qquad (1)$$

where

Y_{ijkl} = the mean time-in-system of the *l*th observation

μ = the mean overall effect of all factors

τ_i = the effect of the *i*th manning level

β_j = the effect of the *j*th allocation heuristic

γ_k = the effect of the *k*th customer batch size

$(\tau\beta)_{ij}$ = the interaction effect of manning level and heuristic

$(\tau\gamma)_{ik}$ = the interaction effect of manning level and batch size

$(\beta\gamma)_{jk}$ = the interaction effect of heuristic and batch size

$(\tau\beta\gamma)_{ijk}$ = the interaction effect of manning level, heuristic and batch size

ε_{ijkl} = the random error component

for

i = 1, 2, ..., 14
j = 1, 2, 3, 4, 5
k = 1, 2, 3
l = 1, 2, ..., 50

Determining Sample Size. The number of observations used for data analysis may be selected arbitrarily or by design. Because the confidence level is dependent upon the number of observations, arbitrary selection may yield a confidence level that is unsatisfactory. Alternatively, Equation 2 may be used to determine the number of observations needed for a specified confidence level (McClave and Benson, 1991:320).

$$n = (z_{\alpha/2})^2\sigma^2/B^2 \qquad (2)$$

A confidence level of 90 percent ($\alpha = .1$) was used in this experiment. Many experiments use higher confidence levels, but we believe 90 percent is reasonable given the erratic conditions observed during data collection. The variance (σ^2) inserted into Equation 2 to calculate the number of observations needed (n) was obtained from the trial data (the first 50 observations), and the bound (B) was set at 20 minutes (the amount of time significant to a soldier in/out-processing; a period of time less than 20 minutes is too short to accomplish additional in/out-processing tasks outside the CIF). This calculation was performed under all treatments for both the issue and turn-in sessions, and the highest value calculated was 24.3. While 25 observations under each treatment should have been sufficient to represent the mean observations under all conditions with 90 percent confidence, 50 observations were already available and thus used in all analyses.

Statistical Methods. Statistical analyses of the results centered on the use of general analyses of variance (ANOVAs) to determine the effects of all factors, and the Scheffé method to examine all differences in treatment means.

In order to use the ANOVA, the errors must be normally distributed and have equal variances. Normality was tested using the Wilk-Shapiro/Rankit Plot procedure (Statistix, 1992:246-7), although it was assumed by invoking the Central Limit Theorem (McClave and Benson, 1991:289). Also, "moderate departures from normality are of little concern in the fixed effects analysis of variance" (Montgomery, 1991:96).

The assumptions of equal variances were tested using Hartley's test and by inspection of the scatter plots of the residuals versus their fitted values. Hartley's test involves the comparison of the highest variance : lowest variance ratio (H statistic) to the H* test statistic. A variance ratio smaller than H* indicates the assumption of equal variances is satisfied (David, 1952:422-24). When the error variances are unequal, the F test and related analyses are only slightly affected if equal sample sizes are used. Hartley's test was chosen for its simplicity, and is appropriate when sample sizes are equal (Neter, Wasserman and Kutner, 1985:623).

The Scheffé method of multiple comparisons was employed to determine which factor levels generally were significantly superior, and which individual treatments were significantly better than the others. The Scheffé method was selected for these comparisons over the Bonferonni and Tukey methods because it is relatively insensitive to departures from normality and equal variances of error terms (Neter, Wasserman and Kutner, 1985:624). Of particular interest in this experiment were the comparisons of the best results at each manning level to one another. These comparisons were important because if there were no significant differences, the lower manning level would be preferred because the assumption would be that the same performance could be achieved with fewer personnel.

In some cases the data did not satisfy the assumptions of normality and equality of variances, so the Kruskal-Wallis non-parametric test and a visual inspection of the treatment means were used in place of an ANOVA.

The data analyses are detailed in the next chapter. The conclusions and recommendations drawn from the analyses are presented in simple tables in Chapter V.

Summary

This chapter described the steps used to determine preferred server allocations and batch sizes for the CIF at various manning levels. That determination was made with the assistance of computer simulation which estimated the average time a customer would require to complete the issue or turn-in process under various conditions.

Input data for the simulation were collected through a manpower study, and those data were converted into empirical distributions of standardized process durations used to establish process durations for each simulated station.

To draw valid conclusions and make responsible recommendations based on the output data, a statistical analysis plan was developed. The plan outlined the statistical procedures used to support the conclusions and recommendations that are presented in Chapter V.

IV. Results and Analysis

Overview

After Chapter I explained the general situation and defined the investigative questions and Chapter II examined the current literature on relevant topics, Chapter III described a research methodology for approaching the problem of manpower allocation. Chapter IV now presents the results of implementing that methodology.

This chapter is organized in three main sections. The first section describes and summarizes the output data from the computer simulation and makes several observations about that data. The second section shows the statistical analyses of that data which will be used in Chapter V to answer the investigative questions. The last section of this chapter makes note of major trends present in the data.

Output Data Description

Tables 2 and 3 summarize the simulation results for the issue and turn-in processes. The durations shown are the means of 50 observations, with each observation consisting of the mean time-in-system (in minutes) of 63 customers. Casual inspection of the treatment means revealed several things. First, as expected, the treatment means increased as the manning level decreased. This effect was most noticeable at the lower manning levels. Second, the treatment means within each manning level showed variation across heuristics and across batch sizes. Third, when the manning level and heuristic were fixed, large differences occurred among the treatment means of the three batch sizes. The differences among treatment means appeared to be much greater across batch sizes than across allocation heuristics. These differences will be analyzed in detail later in this chapter. It should also be noted that because of the variability of the observations which comprise those treatment means, the perceived differences among treatment means may not be significant.

TABLE 2

MEAN CUSTOMER TIME-IN-SYSTEM (ISSUE)

		Heuristic				
Manning Level	**Batch Size**	**Balance**	**Inverse Bowl**	**Manager**	**Utilize-Up**	**Utilize-Down**
19	1	279.40	248.08	252.87	279.35	252.87
	7	162.18	132.33	133.03	130.73	133.03
	21	180.02	154.50	152.17	148.79	152.17
18	1	279.46	248.08	261.03	279.43	252.87
	7	162.93	132.33	137.93	131.42	133.03
	21	182.21	154.50	160.30	151.08	152.17
17	1	279.46	252.95	261.04	279.45	284.27
	7	162.93	133.69	137.93	162.93	164.22
	21	182.21	155.62	160.14	154.50	152.94
16	1	279.47	252.97	261.10	279.47	284.27
	7	163.53	135.47	142.67	163.53	164.22
	21	185.69	159.58	164.29	185.69	184.25
15	1	284.35	261.11	261.10	279.55	284.33
	7	164.88	138.35	142.67	165.32	164.39
	21	186.73	162.35	164.29	186.73	186.73
14	1	284.36	261.31	261.13	279.55	284.36
	7	166.65	143.25	143.08	165.32	164.88
	21	191.00	173.85	166.71	191.00	186.73
13	1	292.50	261.31	277.86	279.77	284.41
	7	169.70	143.25	151.92	166.65	164.93
	21	193.61	173.85	177.10	193.61	198.95
12	1	292.70	261.35	277.91	279.78	284.63
	7	174.58	146.72	152.04	172.02	171.41
	21	205.13	181.78	176.97	193.61	198.94
11	1	292.75	278.06	277.91	279.82	284.65
	7	178.01	154.27	152.04	174.58	172.35
	21	213.07	187.48	176.97	205.13	201.27

TABLE 2 (Cont)

		Heuristic				
Manning Level	**Batch Size**	**Balance**	**Inverse Bowl**	**Manager**	**Utilize-Up**	**Utilize-Down**
10	1	292.75	278.11	309.28	284.69	284.69
	7	178.01	154.37	183.23	178.01	176.13
	21	213.07	187.59	208.49	213.07	205.20
9	1	309.46	309.49	309.69	292.80	296.46
	7	185.54	185.70	209.95	178.25	178.25
	21	218.77	218.98	221.03	218.77	212.96
8	1	309.89	309.89	309.69	297.95	297.95
	7	185.70	211.33	209.95	185.70	185.70
	21	218.98	234.89	221.03	218.98	218.98
7	1	309.89	363.38	363.18	309.89	309.89
	7	211.33	238.86	237.70	211.33	211.33
	21	234.89	267.33	263.71	234.89	234.89
6	1	363.38	363.38	363.38	363.38	363.38
	7	238.86	238.86	238.86	238.86	238.86
	21	267.33	267.33	267.33	267.33	267.33

Average Standard Deviation within treatment cells, by batch size:

Batch size	Standard Deviation
1	3.1
7	6.65
21	11.88

TABLE 3

MEAN CUSTOMER TIME-IN-SYSTEM (TURN-IN)

		Heuristic				
Manning Level	Batch Size	Balance	Inverse Bowl	Manager	Utilize-Up	Utilize-Down
19	1	226.71	214.64	214.56	226.59	214.56
	7	108.88	96.84	93.96	104.87	93.96
	21	119.12	108.82	104.37	117.71	104.37
18	1	226.85	214.64	224.91	227.07	232.78
	7	111.40	96.91	108.81	107.39	112.18
	21	123.71	109.17	125.78	117.85	122.59
17	1	226.85	214.90	224.91	227.19	232.78
	7	111.48	101.65	108.82	107.91	112.25
	21	123.84	117.97	125.80	123.84	122.73
16	1	232.87	233.12	225.10	227.41	232.79
	7	115.30	119.87	116.39	112.00	112.72
	21	128.09	136.20	137.70	128.09	124.49
15	1	233.12	243.13	225.10	227.50	233.23
	7	120.05	127.15	116.53	117.43	115.77
	21	136.90	144.20	138.28	136.90	129.79
14	1	233.12	243.33	226.15	227.59	233.49
	7	120.53	134.69	127.14	120.53	120.53
	21	138.63	156.11	156.20	138.63	138.63
13	1	243.13	243.33	245.77	228.88	234.37
	7	127.72	134.84	139.37	130.28	123.07
	21	146.50	156.66	171.11	146.50	152.07
12	1	243.33	244.37	245.78	229.74	234.61
	7	135.24	145.45	139.43	135.24	132.53
	21	158.08	174.55	171.26	158.08	158.08
11	1	244.38	264.00	245.78	235.31	235.31
	7	145.87	157.66	139.79	145.87	144.05
	21	175.95	189.49	172.63	175.95	175.95

TABLE 3 (Cont)

Manning Level	Batch Size	Heuristic: Balance	Inverse Bowl	Manager	Utilize-Up	Utilize-Down
10	1	264.01	264.01	264.01	251.58	254.56
	7	158.01	158.01	158.01	158.01	147.84
	21	190.86	190.86	190.86	190.86	181.61
9	1	264.37	268.64	268.64	269.53	269.53
	7	159.68	188.05	188.05	159.68	183.30
	21	196.13	232.33	232.33	196.13	196.13
8	1	268.97	281.88	268.97	272.70	272.70
	7	189.36	222.15	189.36	189.36	189.36
	21	236.74	285.79	236.74	236.74	236.74
7	1	282.17	329.24	325.02	282.17	282.17
	7	223.45	249.94	227.83	223.45	223.45
	21	290.00	324.91	285.51	290.00	290.00
6	1	329.44	329.44	329.44	329.44	329.44
	7	251.18	251.18	251.18	251.18	251.18
	21	329.05	329.05	329.05	329.05	329.05

Average Standard Deviation within treatment cells, by batch size:

Batch size	Standard Deviation
1	4.01
7	12.48
21	29.61

Last, the average variance of the treatment means was highest at a batch size of twenty-one and lowest at a batch size of one. The average of each treatment's standard deviation, grouped by respective batch size, shows that variances increased as the batch sizes increased.

Statistical Analysis of Issue Data

Major differences in the degree of adherence to the assumptions of normality and equal variances exist between the issue and turn-in data. Because of these differences, issue and turn-in data were analyzed separately. The data from the issue simulation were tested to verify that they met the basic assumptions of normality and of equality of variance in the error terms (Neter, Wasserman, and Kutner, 1984:624).

An exploratory three-way ANOVA was performed on the trial data set of 50 observations in each treatment cell and the results are in Table 4.

TABLE 4

EXPLORATORY THREE-WAY ANOVA (ISSUE)

					($H \le H^* \Rightarrow$ Equal Variances)		
	Factor	**df**	***F***	***p***	**Rankit**	***H***	***H****
(6, 7,...,19)	Manning (τ)	13	10100.32	0.0000	0.9464	92.820	4.00
(1, 2, 3, 4, 5)	Heuristic (β)	4	869.37	0.0000			
(1, 7, 21)	Batch (γ)	2	195363.10	0.0000			
	$\tau\beta$	52	257.95	0.0000			
	$\tau\gamma$	26	85.26	0.0000			
	$\beta\gamma$	8	21.83	0.0000			
	$\tau\beta\gamma$	104	26.60	0.0000			
	Error (ε)	10290					

These results indicated the assumption of normality was questionable. The Rankit plot had a Wilk-Shapiro value of approximately 0.9464. A value of 0.95 or greater is generally accepted as indicating normality (Barr, 1993).

The data definitely did not satisfy the assumption of equality of variances. The scatter plot showed large differences between the variances of the different observations (Figure 2). The ratio of largest variance to smallest (*H* statistic) was 92.82 : 1. Even though the ANOVA is robust against unequal variances, we concluded that 93 : 1 was too great a difference to ignore.

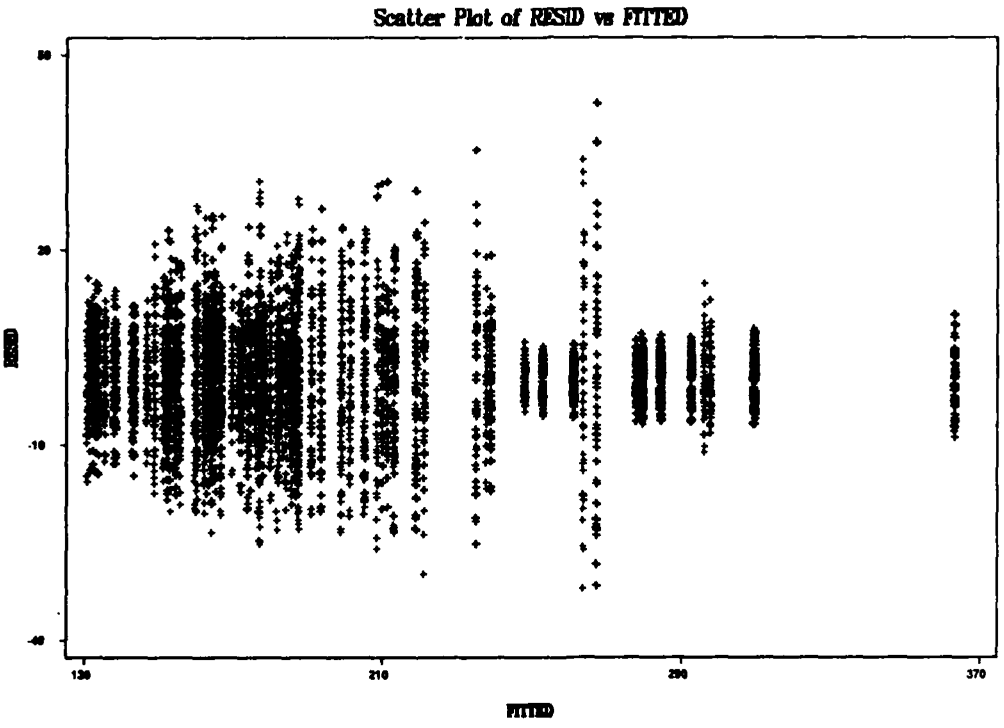


Figure 2. Scatter Plot of Exploratory Data at All Batch Sizes (Issue)

In order to proceed with the analysis we took advantage of a property of the batch size of one. Treatments involving the batch size of one were always the worst among those at any given manning level and heuristic. A batch size of one would never lead to a preferred solution in the CIF's current operating paradigm of serving only one batch at each counter at a time. Therefore, the batch size of one was eliminated from all subsequent analyses.

The analysis continued using the second set of 50 observations in each treatment cell. Another three-way ANOVA was performed for all 14 manning levels, all 5 heuristics, and batch sizes of seven and 21. The results are shown in Table 5.

TABLE 5

THREE-WAY ANOVA FOR RESTRICTED DATA SET (ISSUE)

					($H \le H^* \Rightarrow$ Equal Variances)		
	Factor	**df**	F	p	**Rankit**	H	H^*
(6, 7,...,19)	Manning (τ)	13	5021.01	0.0000	0.9942	12.523	4.00
(1, 2, 3, 4, 5)	Heuristic (β)	4	443.41	0.0000			
(7, 21)	Batch (γ)	1	11114.32	0.0000			
	$\tau\beta$	52	116.66	0.0000			
	$\tau\gamma$	13	46.85	0.0000			
	$\beta\gamma$	4	19.61	0.0000			
	$\tau\beta\gamma$	52	10.73	0.0000			
	Error (ε)	6860					

The results of this ANOVA showed that the restricted data set met the assumption of normality (Rankit $\approx$ 0.9942). The H statistic was examined to check for equality of variances. It had improved to 12.523 : 1, but was still too high to give us confidence that the treatments had equal variances across all factor levels ($H^* \approx 4$). The scatter plot of residuals against their fitted values showed adequate dispersion about the mean (Figure 3), indicating that the variances were roughly equivalent. Because the general ANOVA is robust against unequal variances when the treatment sample sizes are equal (Neter, Wasserman, and Kutner, 1984:624), the results of this ANOVA were accepted as valid.

The high *F* statistics and low *p* values showed that, overall, batch size had the strongest effect on treatment mean times, followed by manning level, heuristic, and the manning-heuristic interaction. Even though all other terms showed significance, they were overwhelmed by the strength of these four and so were relatively insignificant in the three-way ANOVA.

The significant *F* for the manning-heuristic interaction prevents comparisons of means at this level, so each manning level was examined individually.

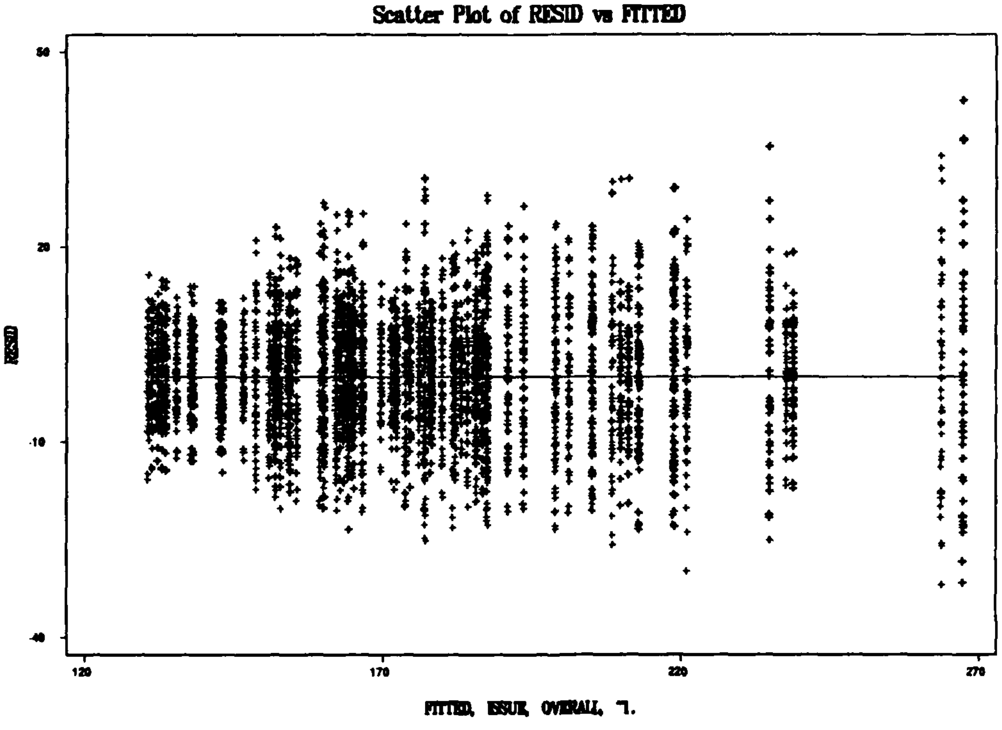


Figure 3. Scatter Plot of Restricted (Batch Size of 21 and 7 only) Data Set (Issue)

Analysis of Batch Size and Heuristic Independent of Manning Level. Parametric two-way ANOVAs were performed at each manning level to analyze the effects of heuristic and batch size. The ANOVAs are summarized in Table 6. Analysis of the residuals of these parametric ANOVAs validated the assumptions of normality and of equality of variances within manning levels.

TABLE 6

TWO-WAY ANOVA FOR RESTRICTED DATA SET (ISSUE)

					($H \leq H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	F	p	**Rankit**	H	H^*
19	Heuristic (β)	4	234.76	0.0000	0.9922	2.526	9.91
	Batch (γ)	1	640.03	0.0000			
	$\beta\gamma$	4	1.03	0.3910			
	Error (ε)	490					
18	Heuristic (β)	4	239.93	0.0000	0.9943	3.639	9.91
	Batch (γ)	1	737.92	0.0000			
	$\beta\gamma$	4	0.91	0.4620			
	Error (ε)	490					
17	Heuristic (β)	4	154.56	0.0000	0.9953	3.567	9.91
	Batch (γ)	1	127.47	0.0000			
	$\beta\gamma$	4	96.95	0.0000			
	Error (ε)	490					
16	Heuristic (β)	4	226.58	0.0000	0.9953	4.337	9.91
	Batch (γ)	1	775.84	0.0000			
	$\beta\gamma$	4	0.68	0.6082			
	Error (ε)	490					
15	Heuristic (β)	4	227.07	0.0000	0.9955	4.337	9.91
	Batch (γ)	1	814.94	0.0000			
	$\beta\gamma$	4	0.36	0.8413			
	Error (ε)	490					

TABLE 6 (Cont)

					($H \leq H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	***F***	***p***	**Rankit**	***H***	***H****
14	Heuristic (β)	4	163.81	0.0000	0.9955	4.406	9.91
	Batch (γ)	1	974.80	0.0000			
	βγ	4	3.35	0.0102			
	Error (ε)	490					
13	Heuristic (β)	4	137.54	0.0000	0.996	6.061	9.91
	Batch (γ)	1	1119.89	0.0000			
	βγ	4	4.86	0.0008			
	Error (ε)	490					
12	Heuristic (β)	4	169.73	0.0000	0.9964	6.539	9.91
	Batch (γ)	1	1133.86	0.0000			
	βγ	4	7.78	0.0000			
	Error (ε)	490					
11	Heuristic (β)	4	201.53	0.0000	0.996	6.539	9.91
	Batch (γ)	1	1348.36	0.0000			
	βγ	4	4.46	0.0016			
	Error (ε)	490					
10	Heuristic (β)	4	131.31	0.0000	0.9919	6.504	9.91
	Batch (γ)	1	1426.67	0.0000			
	βγ	4	5.25	0.0004			
	Error (ε)	490					
9	Heuristic (β)	4	61.52	0.0000	0.9931	5.234	9.91
	Batch (γ)	1	1239.41	0.0000			
	βγ	4	33.85	0.0000			
	Error (ε)	490					
8	Heuristic (β)	4	87.52	0.0000	0.9921	6.514	9.91
	Batch (γ)	1	846.00	0.0000			
	βγ	4	22.41	0.0000			
	Error (ε)	490					

TABLE 6 (Cont)

					($H \leq H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	F	p	**Rankit**	H	H^*
7	Heuristic (β)	4	160.97	0.0000	0.9899	5.452	9.91
	Batch (γ)	1	505.69	0.0000			
	$\beta\gamma$	4	0.78	0.5432			
	Error (ε)	490					
6	Heuristic (β)	4	0.00	1.0000	0.9798	5.334	9.91
	Batch (γ)	1	514.76	0.0000			
	$\beta\gamma$	4	0.00	1.0000			
	Error (ε)	490					

Batch Size. Comparisons of the two-way ANOVAs revealed a consistent effect of batch size. At all manning levels but 17, batch size had the strongest effect on the mean time-in-system, followed by heuristic. Except for manning level 17, the effect of batch size was three to five times larger than that of heuristic. These two factors were reversed in importance at manning level 17, however, where the effect of heuristic was 21 percent larger than that of batch size. In all cases, Scheffé pairwise comparisons of means (Appendix F) showed that a batch size of seven was significantly better than a batch size of 21.

Heuristic. At any combination of manning level and batch size, a single heuristic may not have been clearly best. Usually two or three which were statistically equivalent provided better results than the others. A summary of the Scheffé comparisons showing rankings of all heuristics at each of the manning levels, and across all manning levels, is in Table 7. These rankings are presented by batch size, as well as across the results from both batch sizes combined. The Scheffé comparisons used to build this table are in Appendix G.

TABLE 7

SCHEFFÉ RANKINGS BY HEURISTIC (ISSUE)

	Manning Level														
Heuristic	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**Overall**
Batch Size = 7															
Balance	5	5	4	4	4	4	4	4	4	3	3.5	2	2	3	5
Inverse Bowl	2.5	2	1	1	1	1.5	1	1	1.5	1	3.5	4.5	4.5	3	1
Manager	2.5	4	2	2	2	1.5	2	2	1.5	5	5	4.5	4.5	3	3
Utilization-Up	2.5	2	4	4	4	4	4	4	4	3	1.5	2	2	3	3
Utilization-Down	2.5	2	4	4	4	4	4	4	4	3	1.5	2	2	3	3
Batch Size = 21															
Balance	5	5	5	4	4	4	4	5	5	3.5	3.5	2.5	2	3	5
Inverse Bowl	2.5	2	2	1.5	1.5	2	1	1.5	2	1	3.5	5	4.5	3	1.5
Manager	2.5	4	4	1.5	1.5	1	1.5	1.5	1	3.5	3.5	2.5	4.5	3	1.5
Utilization-Up	2.5	2	2	4	4	4	4	3.5	3.5	3.5	3.5	2.5	2	3	3.5
Utilization-Down	2.5	2	2	4	4	4	4	3.5	3.5	3.5	1	2.5	2	3	3.5
Combined Batch Sizes															
Balance	5	5	5	4	4	4	4	5	5	3.5	2.5	2	2	3	5
Inverse Bowl	2.5	2	1	1	1.5	1.5	1	1.5	2	1	2.5	5	4.5	3	1.5
Manager	2.5	4	2	2	1.5	1.5	2	1.5	1	3.5	5	4	4.5	3	1.5
Utilization-Up	2.5	2	3.5	4	4	4	4	3.5	3.5	3.5	2.5	2	2	3	3.5
Utilization-Down	2.5	2	3.5	4	4	4	4	3.5	3.5	3.5	2.5	2	2	3	3.5

The overall means for the Manager, Utilization-Down, and Utilization-Up heuristics at a batch size of seven are not equal, but are determined to be statistically equivalent by the Scheffé method. Therefore, instead of being ranked second, third, and fourth, they are all assigned the average of these ranks - third place.

The Inverse Bowl heuristic produced allocations that were among the best at manning levels above nine. Below the manning level of ten, other heuristics were significantly better. This is probably because the Inverse Bowl heuristic allocates two servers to the PBO at the lower manning levels while the other heuristics allocate only one server to the PBO (see Appendix A). During issue the PBO does not affect customer time-in-system, so at low manning levels the use of more than one server at the PBO rather than another station will usually increase the average time-in-system.

Manning Level. Many times the best treatment at one manning level was not significantly different from the best treatment at another manning level. Scheffé comparisons of the lowest mean times-in-system at each manning level demonstrate that there are 10 groups in which the best mean times-in system are not significantly different (Figure 4). A high F statistic (1329) and low p value (0.0000) indicate that there is a statistical difference between the 10 groups. The low H statistic indicates that variances are equal enough among the 14 treatments for this test to be statistically valid.

```
ONE-WAY AOV FOR TIME BY TEST
SOURCE    DF        SS          MS         F       P
------- ----   ---------  ---------  ------  ------
BETWEEN   13   7.050E+05    54234.0 1329.23  0.0000
WITHIN   686     27989.6    40.8012
TOTAL    699   7.330E+05

                    CHI-SQ    DF       P
BARTLETT'S TEST OF  ------  ------  ------
   EQUAL VARIANCES   33.34    13    0.0015

COCHRAN'S Q                    0.1340
LARGEST VAR / SMALLEST VAR     2.8912 (H statistic)

COMPONENT OF VARIANCE FOR BETWEEN GROUPS    1083.86
EFFECTIVE CELL SIZE                            50.0

SCHEFFE PAIRWISE COMPARISONS OF MEANS OF TIME BY TEST

 LOWEST                HOMOGENEOUS
TREATMENT      MEAN    GROUPS
---------  ----------  -----------
 6-Util-Dn    238.86    I
 7-Util-Dn    211.33   .. I
 8-Util-Dn    185.70   .... I
 9-Util-Dn    178.25   ...... I
10-Inv Bwl    154.37   ........ I
11-Manager    152.04   ........ I I
12-Inv Bwl    146.72   .......... I I
13-Inv Bwl    143.25   ............ I I
14-Manager    143.08   ............ I I
15-Inv Bwl    138.35   .............. I I
16-Inv Bwl    135.47   ................ I I
17-Inv Bwl    133.69   ................ I I
18-Util-Up    131.42   .................. I
19-Util-Up    130.73   .................. I

THERE ARE 10 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                1.734   REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON      6.0662
STANDARD ERROR FOR COMPARISON      1.2775
```

Figure 4. Comparison of Lowest Mean Times-In-System

Statistical Analysis of Turn-In Data

An exploratory three-way ANOVA was also performed on a trial set of output data (50 observations within each treatment cell) from the turn-in simulation. The results of this exploratory ANOVA (Table 8) eliminated the use of a three factorial parametric ANOVA to draw conclusions across all manning levels. Not only were the differences in variances very high ($H \approx 1430 : 1$), but the data also did not exhibit sufficient normality (Rankit ≈ 0.7826).

TABLE 8

EXPLORATORY THREE-WAY ANOVA (TURN-IN)

					($H \leq H^* \Rightarrow$ Equal Variances)		
	Factor	**df**	F	p	**Rankit**	H	H^*
(6, 7,...,19)	Manning (τ)	13	4787.94	0.0000	0.7826	1430.00	4.00
(1, 2, 3, 4, 5)	Heuristic (β)	4	98.59	0.0000			
(1, 7, 21)	Batch (γ)	2	27936.00	0.0000			
	$\tau\beta$	52	21.32	0.0000			
	$\tau\gamma$	26	208.58	0.0000			
	$\beta\gamma$	8	5.83	0.0000			
	$\tau\beta\gamma$	104	4.29	0.0000			
	Error (ε)	10290					

Eliminating the batch size of one (it was again dominated by the other two batch sizes) helped somewhat (Table 9) but did not correct the problems (Rankit ≈ .8522).

TABLE 9

THREE-WAY ANOVA FOR RESTRICTED DATA SET (TURN-IN)

					($H \le H^* \Rightarrow$ Equal Variances)		
	Factor	**df**	***F***	***p***	**Rankit**	***H***	***H******
(6, 7,...,19)	Manning (τ)	13	2483.79	0.0000	.8522	161.00	4.00
(1, 2, 3, 4, 5)	Heuristic (β)	4	46.03	0.0000			
(7, 21)	Batch (γ)	1	2581.99	0.0000			
	$\tau\beta$	52	9.89	0.0000			
	$\tau\gamma$	13	79.56	0.0000			
	$\beta\gamma$	4	3.06	0.0157			
	$\tau\beta\gamma$	52	0.87	0.7277			
	Error (ε)	6860					

The analysis of subsequent parametric two-way ANOVAs at each manning level (Table 10) showed that their results could not be used to support statistically based conclusions.

TABLE 10

TWO-WAY ANOVA FOR RESTRICTED DATA SET (TURN-IN)

					($H \le H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	***F***	***p***	**Rankit**	***H***	***H******
19	Heuristic (β)	4	38.35	0.0000	0.9189	8.25	9.91
	Batch (γ)	1	124.19	0.0000			
	$\beta\gamma$	4	0.27	0.8965			
	Error (ε)	490					
18	Heuristic (β)	4	25.54	0.0000	0.9124	10.24	9.91
	Batch (γ)	1	122.45	0.0000			
	$\beta\gamma$	4	1.12	0.3455			
	Error (ε)	490					

TABLE 10 (Cont)

					($H \leq H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	***F***	***p***	**Rankit**	***H***	***H******
17	Heuristic (β)	4	6.02	0.0000	0.9019	10.47	9.91
	Batch (γ)	1	141.02	0.0000			
	βγ	4	1.09	0..3589			
	Error (ε)	490					
16	Heuristic (β)	4	9.46	0.0000	0.9194	10.77	9.91
	Batch (γ)	1	162.38	0.0000			
	βγ	4	1.85	0.1164			
	Error (ε)	490					
15	Heuristic (β)	4	9.31	0.0000	0.9092	10.18	9.91
	Batch (γ)	1	169.96	0.0000			
	βγ	4	0.91	0.4579			
	Error (ε)	490					
14	Heuristic (β)	4	17.90	0.0000	0.8848	14.570	9.91
	Batch (γ)	1	163.29	0.0000			
	βγ	4	1.68	0.1515			
	Error (ε)	490					
13	Heuristic (β)	4	19.69	0.0000	.9215	12.750	9.91
	Batch (γ)	1	224.40	0.0000			
	βγ	4	3.58	0.0070			
	Error (ε)	490					
12	Heuristic (β)	4	10.98	0.0000	0.9104	12.570	9.91
	Batch (γ)	1	225.89	0.0000			
	βγ	4	1.02	0.3995			
	Error (ε)	490					
11	Heuristic (β)	4	7.40	0.0000	0.887	7.866	9.91
	Batch (γ)	1	209.75	0.0000			
	βγ	4	0.06	0.9895			
	Error (ε)	490					

TABLE 10 (Cont)

					($H \leq H^* \Rightarrow$ Equal Variances)		
Manning	**Factor**	**df**	***F***	***p***	**Rankit**	***H***	***H****
10	Heuristic (β)	4	3.48	0.0083	0.8984	7.203	9.91
	Batch (γ)	1	251.39	0.0000			
	βγ	4	0.01	0.9992			
	Error (ε)	490					
9	Heuristic (β)	4	40.12	0.0000	0.9100	8.542	9.91
	Batch (γ)	1	230.52	0.0000			
	βγ	4	6.33	0.0001			
	Error (ε)	490					
8	Heuristic (β)	4	28.31	0.0000	0.9254	14.580	9.91
	Batch (γ)	1	270.85	0.0000			
	βγ	4	1.12	0.3475			
	Error (ε)	490					
7	Heuristic (β)	4	8.35	0.0000	0.8951	18.800	9.91
	Batch (γ)	1	244.40	0.0000			
	βγ	4	0.41	0.8010			
	Error (ε)	490					
6	Heuristic (β)	4	0.00	1.0000	0.8999	6.3131	9.91
	Batch (γ)	1	364.49	0.0000			
	βγ	4	0.00	1.0000			
	Error (ε)	490					

Analysis of the residuals from these exploratory two and three-way ANOVAs revealed that the distributions of the residuals around the means were severely skewed. The Scatter Plot from the exploratory three-way ANOVA at all batch sizes (Figure 5) shows an example of this skewness. It became obvious that any conclusions based on parametric analysis would not be supportable.

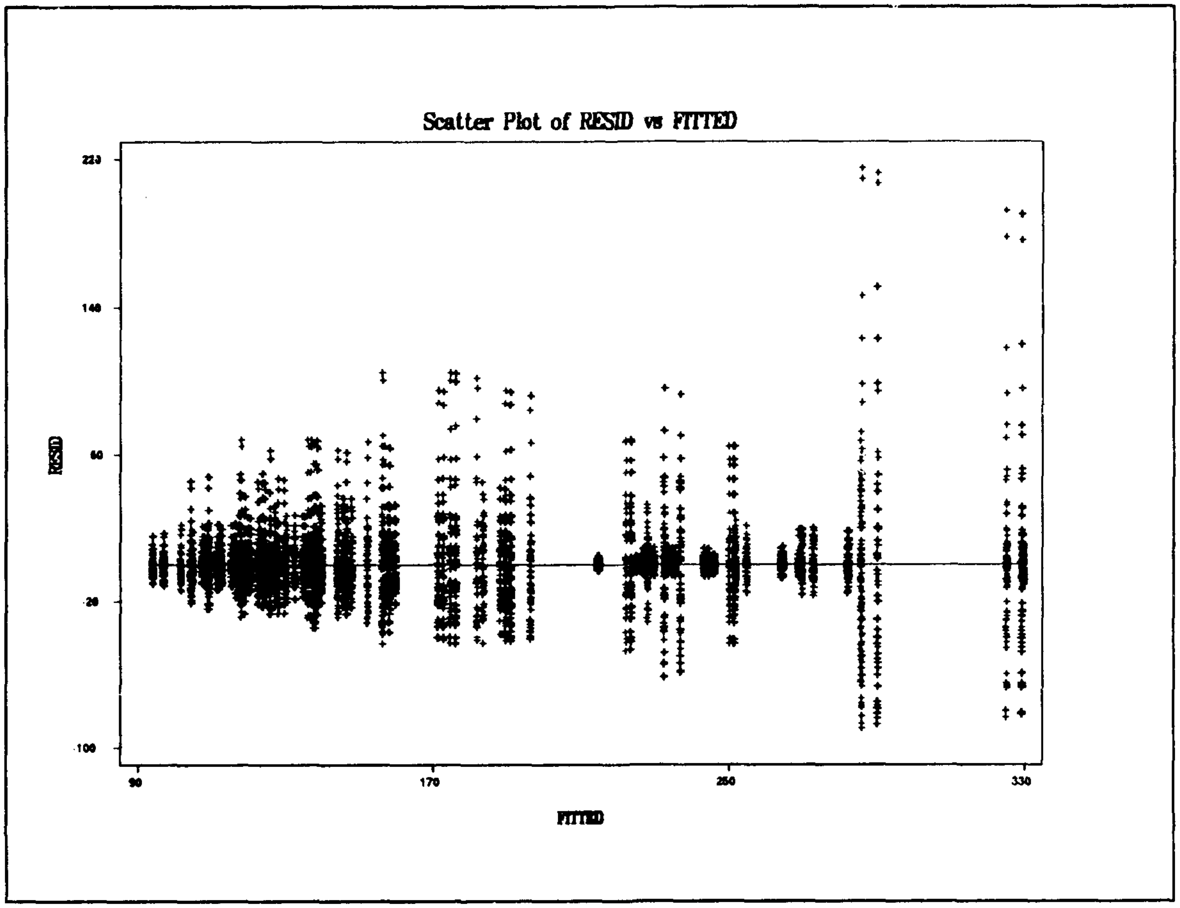


Figure 5. Scatter Plot From Exploratory Three-Way ANOVA (Turn-In)

Analysis of Batch Size and Heuristic Independent of Manning Level. For the reasons cited above the turn-in simulation data were analyzed non-parametrically using visual inspection of the treatment means and the Kruskal-Wallis one-way non-parametric ANOVA. The second data set of 50 observations per treatment was used. Each manning level was examined separately.

Batch Size. Visual inspection of the means displayed in Table 3 showed that again, regardless of manning level or heuristic, a batch size of seven produced better results than did a batch size of 21. For manning levels 19 and 18, though, the best heuristics at a batch size of 21 were better than the worst heuristics at a batch size of seven.

Heuristic. The data indicate that there was an interaction between batch size and heuristic. The performance ranking of the heuristics within a manning level was dependent upon the batch size. For instance, at manning level 13 and a batch size of seven, Utilization-Up results in a higher mean time-in-system (130.28) than does Utilization-Down (123.07). This is reversed when the batch size is 21. In this case Utilization-Up results in a mean time-in-system (146.5) which is lower than that resulting from the Utilization-Down heuristic (152.07).

Because the turn-in data were not normally distributed, parametric methods of ranking and grouping data, such as the Scheffé comparisons, could not be used. Therefore the non-parametric Kruskal-Wallis procedure was used to find the mean ranks of the heuristics at all manning levels and batch sizes (Table 11). The Kruskal-Wallis procedure does not group treatment means as the Scheffé method does, but a visual inspection of the means in Table 3 was used to group those treatments with lower mean times-in-system. These groupings will be presented in Chapter V.

TABLE 11

KRUSKAL-WALLIS RANKING (TURN-IN)

HEURISTIC	MANNING LEVEL 19	18	17	16	15	14	13	12	11	10	9	8	7
Batch Size = 7													
Balance	202.4	161.2	155.3	128.8	131[illegible]	[illegible]	[illegible]6	112.3	121.6	137.7	67.4	108.0	106.8
Inverse Bowl	102.4	40.9	63.7	165.6	188.0	[illegible]	1[illegible].2	172.3	185.6	137.7	170.0	195.5	182.4
Manager	74.6	134.5	126.7	137.7	106.6	141.9	176.8	137.7	89.0	137.7	170.0	108.0	124.7
Utilize-Up	173.6	122.0	118.4	94.8	106.0	98.0	122.2	112.3	121.6	137.7	67.4	108.0	106.8
Utilize-Down	74.6	168.8	163.4	100.6	95.1	98.0	69.7	92.9	109.7	76.5	152.6	108.0	106.8
KW Stat	133.2	99.5	59.3	31.8	53.6	66.2	68.0	35.9	50.0	28.7	109.4	58.6	41.0
p Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Batch Size = 21													
Balance	169.8	145.5	132.6	116.8	121.4	103.7	99.5	111.1	118.5	131.4	96.4	114.0	114.3
Inverse Bowl	115.7	77.4	98.4	143.3	154.3	165.8	138.1	150.0	158.3	131.4	169.1	171.5	164.1
Manager	92.3	147.8	136.4	152.0	131.6	150.7	170.1	144.1	113.8	131.4	169.1	114.0	120.6
Utilize-Up	157.5	115.6	132.6	116.8	121.4	103.7	99.5	111.1	118.5	131.4	96.4	114.0	114.3
Utilize-Down	92.3	141.3	127.9	98.6	98.8	103.7	120.3	111.1	118.5	101.8	96.4	114.0	114.3
KW Stat	50.6	34.1	09.3	18.1	15.4	35.2	33.7	15.0	13.0	06.7	60.6	25.3	18.1
p Value	0.000	0.000	0.053	0.001	0.004	0.000	0.000	0.005	0.011	0.152	0.000	0.000	0.001

Manning Level. A Kruskal-Wallis ANOVA was performed on the turn-in treatments which had the lowest mean times-in-system at each manning level (Figure 6). The results showed that there is a very strong difference between at least two of the treatments. The high KW statistic (648) and its low p value(0.0000) support this difference.

```
KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV FOR TIME BY TEST

 LOWEST        MEAN    SAMPLE
TREATMENT      RANK     SIZE
---------     ------   ------
 6-Util-Up    664.6      50
 7-Util-Up    628.5      50
 8-Util-Up    576.8      50
 9-Util-Up    510.9      50
10-Util-Dn    461.3      50
11-Manager    419.8      50
12-Util-Dn    376.2      50
13-Util-Dn    303.8      50
14-Util-Dn    278.9      50
15-Util-Dn    235.6      50
16-Util-Up    200.7      50
17-Inv Bwl    117.0      50
18-Inv Bwl     78.2      50
19-Manager     54.8      50
TOTAL         350.5     700

KRUSKAL-WALLIS STATISTIC                         647.6877
P-VALUE, USING CHI-SQUARED APPROXIMATION          0.0000

PARAMETRIC AOV APPLIED TO RANKS

SOURCE     DF        SS          MS          F        P
-------   ----   ---------   ---------   ------   ------
BETWEEN    13    2.649E+07   2.037E+06   666.08   0.0000
WITHIN    686    2.098E+06     3058.66
TOTAL     699    2.858E+07

TOTAL NUMBER OF VALUES THAT WERE TIED   42
MAX. DIFF. ALLOWED BETWEEN TIES     0.00001

CASES INCLUDED 700    MISSING CASES 0
```

Figure 6. Kruskal-Wallis Comparison of Lowest Mean Times-In-System (Turn-in)

Major Trends

Under all conditions, batch size had the biggest effect in determining the mean time-in-system. The treatments which used a batch size of seven were better overall than treatments which used a batch size of 21. Tables 2 and 3 show that for any heuristic a batch size of seven almost always produced lower mean times-in-system than did a batch size of 21. Only in two cases out of 210 treatments did a treatment with a batch size of 21 outperform a treatment with a batch size of seven at the same manning level and heuristic.

The effects of the heuristics were much more similar to each other. The performance of any given heuristic was not consistently good or bad. During issue, allocations using the Inverse Bowl heuristic were among the best most frequently, but also were among the best the least number of times during turn-in. Allocations using the other heuristics did not perform as well during issue, or as poorly during turn-in.

Summary

This chapter presented the results obtained by using the methodology described in Chapter III. It showed evidence which suggests that the customer batch size has a greater effect on customer mean time-in-system than does server allocation heuristic.

Chapter V will draw conclusions from these results, answer the two investigative questions, and present recommendations for the CIF managers and future researchers.

V. Conclusions and Recommendations

Overview

This study began by asking the following two investigative questions:

1. How can the workers in the CIF be positioned to mitigate the negative effects caused by manpower reductions?

2. What changes in customer processing durations (average time-in-system) can the CIF expect as its manning level decreases?

Data was gathered through observation of operations at the CIF and used in a computer simulation of those operations. The output of that simulation was analyzed to draw the conclusions and make the recommendations in this chapter.

Summary of Results

Few generalizations can be made from the results presented in the last chapter. The goal of this study was to determine a preferred allocation of servers and a preferred batch size for each expected manning level. This goal focuses on a specific solution for each manning level rather than generalizations. Those solutions are shown in Tables 12 - 15. The solutions shown in these tables are those whose results are not significantly different from one another within manning levels and within batch sizes. Table 12 shows the preferred server allocations for issue sessions using customer batch sizes of seven. As explained below, the preferred solution always resulted from a batch size of seven. Table 13 shows preferred allocations for issue sessions using customer batch sizes of twenty-one. Tables 14 and 15 show preferred server allocations for turn-in sessions using customer batch sizes of seven and twenty-one respectively.

The preferred server allocations are listed in the far right columns of Tables 12 - 15 as the number of servers to be assigned to Stations 1 - 6 in order. Thus, a listing of 2 5 2 4 2 4 means that two servers should be assigned to Station 1 (Reception), five servers to Station 2 (Counter A), two servers to Station 3 (Counter B), four servers to Station 4 (Counter C), two servers to Station 5 (Flight/DX), and four servers to Station 6 (PBO).

TABLE 12

PREFERRED SERVER ALLOCATIONS FOR CUSTOMER BATCH SIZE OF 7 (ISSUE)

Manning	Groups	Heuristic	Mean T-I-S	Allocation
19	I	Inverse Bowl	132.33	2 5 2 4 2 4
		Manager	133.03	2 4 4 4 2 3
		Utilization-Up	130.73	2 5 3 5 2 2
		Utilization-Down	133.03	2 4 4 4 2 3
18	I	Inverse Bowl	132.33	2 5 2 4 2 3
		Utilization-Up	131.42	2 5 2 5 2 2
		Utilization-Down	133.03	2 4 4 4 2 2
17	I I	Inverse Bowl	133.69	2 4 2 4 2 3
16	I I	Inverse Bowl	135.47	2 4 2 3 2 3
15	I I	Inverse Bowl	138.35	2 3 2 3 2 3
14	. I I	Inverse Bowl	143.25	2 3 1 3 2 3
		Manager	143.08	2 3 2 2 2 3
13	. I I	Inverse Bowl	143.25	2 3 1 3 2 2
12	. . I I	Inverse Bowl	146.72	2 3 1 2 2 2
11	. . . I I	Inverse Bowl	154.27	2 2 1 2 2 2
		Manager	152.04	2 2 2 2 1 2
10	 I	Inverse Bowl	154.37	2 2 1 2 1 2
9	 I	Utilization-Up	178.25	1 3 1 2 1 1
		Utilization-Down	178.25	1 3 2 1 1 1
8	 I	Balance	185.70	1 2 1 2 1 1
		Utilization-Up	185.70	1 3 1 1 1 1
		Utilization-Down	185.70	1 2 1 2 1 1
7	 I	Balance	211.33	1 2 1 1 1 1
		Utilization-Up	211.33	1 2 1 1 1 1
		Utilization-Down	211.33	1 2 1 1 1 1

TABLE 13

PREFERRED SERVER ALLOCATIONS FOR CUSTOMER BATCH SIZE OF 21 (ISSUE)

Manning	Groups								Heuristic	Mean T-I-S	Allocation
19	I								Inverse Bowl	154.50	2 5 2 4 2 4
									Manager	152.17	2 4 4 4 2 3
									Utilization-Up	148.79	2 5 3 5 2 2
									Utilization-Down	152.17	2 4 4 4 2 3
18	I	I							Inverse Bowl	154.50	2 5 2 4 2 3
									Utilization-Up	151.08	2 5 2 5 2 2
									Utilization-Down	152.17	2 4 4 4 2 2
17	I	I							Inverse Bowl	155.62	2 4 2 4 2 3
									Utilization-Up	154.50	2 5 2 4 2 2
									Utilization-Down	152.94	2 4 3 4 2 2
16	I	I	I						Inverse Bowl	159.54	2 4 2 3 2 3
									Manager	164.29	2 3 3 2 2 4
15		I	I	I					Inverse Bowl	162.35	2 3 2 3 2 3
									Manager	164.29	2 3 3 2 2 3
14	.		I	I	I				Manager	166.71	2 3 2 2 2 3
13	.	.		I	I				Inverse Bowl	173.85	2 3 1 3 2 2
									Manager	177.10	2 2 2 2 2 3
12	.	.	.		I	I			Inverse Bowl	181.78	2 3 1 2 2 2
									Manager	176.97	2 2 2 2 1 3
11	.	.	.		I	I			Manager	176.97	2 2 2 2 1 2
10	.	.	.	.	.	I			Inverse Bowl	187.59	2 2 1 2 1 2
9	.	.	.	.	.	.	I		Utilization-Down	212.96	1 3 1 2 1 1
8	.	.	.	.	.	.	I		Balance	218.98	1 2 1 2 1 1
									Manager	221.03	1 2 2 1 1 1
									Utilization-Up	218.98	1 2 1 2 1 1
									Utilization-Down	218.98	1 2 1 2 1 1
7	.	.	.	.	.	.	.	I	Balance	234.89	1 2 1 1 1 1
									Utilization-Up	234.89	1 2 1 1 1 1
									Utilization-Down	234.89	1 2 1 1 1 1

TABLE 14

PREFERRED SERVER ALLOCATIONS FOR CUSTOMER BATCH SIZE OF 7 (TURN-IN)

Manning	Groups	Heuristic	Mean T-I-S	Allocation
19	I	Inverse Bowl	96.84	2 4 4 3 1 4
		Manager	93.96	2 4 4 4 2 3
		Utilization-Down	93.96	2 4 4 4 2 3
18	I	Inverse Bowl	96.91	2 4 4 3 1 4
17	I I	Inverse Bowl	101.65	2 4 3 3 1 4
16	I I	Utilization-Up	112.00	1 5 4 3 1 2
		Utilization-Down	112.72	1 4 4 4 1 2
15	. I	Manager	116.53	2 3 3 2 2 3
		Utilization-Up	117.43	1 5 3 3 1 2
		Utilization-Down	115.77	1 4 4 3 1 2
14	. I I	Balance	120.53	1 4 3 3 1 2
		Utilization-Up	120.53	1 4 3 3 1 2
		Utilization-Down	120.53	1 4 3 3 1 2
13	. I I	Utilization-Down	123.07	1 4 3 3 1 1
12	. . I I	Balance	135.24	1 3 3 2 1 2
		Utilization-Up	135.24	1 3 3 2 1 2
		Utilization-Down	132.53	1 4 3 2 1 1
11	. . . I I	Manager	139.79	2 2 2 2 1 2
10	. . . . I I	Utilization-Down	147.84	1 3 2 2 1 1
9	 I	Balance	159.68	1 2 2 2 1 1
		Utilization-Up	159.68	1 2 2 2 1 1
8	 I	Balance	189.36	1 2 2 1 1 1
		Manager	189.36	1 2 2 1 1 1
		Utilization-Up	189.36	1 2 2 1 1 1
		Utilization-Down	189.36	1 2 2 1 1 1
7	 I	Balance	223.45	1 2 1 1 1 1
		Manager	227.83	1 1 2 1 1 1
		Utilization-Up	223.45	1 2 1 1 1 1
		Utilization-Down	223.45	1 2 1 1 1 1

TABLE 15

PREFERRED SERVER ALLOCATIONS FOR CUSTOMER BATCH SIZE OF 21 (TURN-IN)

Manning	Groups	Heuristic	Mean T-I-S	Allocation
19	I	Inverse Bowl	108.42	2 4 4 3 1 5
		Manager	104.37	2 4 4 4 2 3
		Utilization-Down	104.37	2 4 4 4 2 3
18	I	Inverse Bowl	109.17	2 4 4 3 1 4
17	I	Inverse Bowl	117.97	2 4 3 3 1 4
16	I	Balance	128.09	1 4 4 3 1 3
		Utilization-Up	128.09	1 4 4 3 1 3
		Utilization-Down	124.49	1 4 4 4 1 2
15	I	Utilization-Down	129.79	1 4 4 3 1 2
14	. I	Balance	138.63	1 4 3 3 1 2
		Utilization-Up	138.63	1 4 3 3 1 2
		Utilization-Down	138.63	1 4 3 3 1 2
13	. . I	Balance	146.50	1 3 3 3 1 2
		Utilization-Up	146.50	1 3 3 3 1 2
12	. . . I	Balance	158.08	1 3 3 2 1 2
		Utilization-Up	158.08	1 3 3 2 1 2
		Utilization-Down	158.08	1 3 3 2 1 2
11	 I	Balance	175.95	1 3 2 2 1 2
		Manager	172.63	2 2 2 2 1 2
		Utilization-Up	175.95	1 3 2 2 1 2
		Utilization-Down	175.95	1 3 2 2 1 2
10	 I	Utilization-Down	181.61	1 3 2 2 1 1
9	 I	Balance	196.13	1 2 2 2 1 1
		Utilization-Up	196.13	1 2 2 2 1 1
		Utilization-Down	196.13	1 2 2 2 1 1
8	 I	Balance	236.74	1 2 2 1 1 1
		Manager	236.74	1 2 2 1 1 1
		Utilization-Up	236.74	1 2 2 1 1 1
		Utilization-Down	236.74	1 2 2 1 1 1
7	 I	Balance	290.00	1 2 1 1 1 1
		Manager	285.51	1 1 2 1 1 1
		Utilization-Up	290.00	1 2 1 1 1 1
		Utilization-Down	290.00	1 2 1 1 1 1

Visual comparisons of the mean times-in-system (T-I-S) in the columns to the left of the preferred allocations show the changes in average customer time-in-system that can be expected as manning level decreases. Thus, both investigative questions are answered by Tables 12 - 15.

Manning level. Intuitively one can generalize that, up to a point (of negative returns), additional manpower will improve a labor intensive process. The data support that generalization, but the comparisons of the best observed treatment means at each manning level show that there is no significant difference in customer mean time-in-system between some manning levels. Specifically, under the assumptions of this study, the best combination of server allocation and customer batch size at a manning level of 19 will result in a mean time-in-system which is not significantly different from that at a manning level of 18 or 17 (or 16 for issue only). Tables 12 - 15 show which manning levels have the best observed treatment means that are not significantly different. In the column labeled "Groups," an "I" at a manning level will be vertically aligned with the "I" from any other manning level that is not significantly different. This suggests that, when the preferred allocation at a given manning level is not significantly different from a lower manning level, the CIF manager could take some servers off the line with no significant impact on customer time-in-system.

Batch Size. The data showed that customer batch size clearly affects the customer mean time-in-system more than the allocation of servers under the assumptions in this study. They also show that, under these assumptions, customer batch sizes of seven produce better results than batch sizes of one or twenty-one. This suggests that the best batch size under any circumstance may be much less than the batch size of 21 currently employed by the CIF.

Heuristic. The heuristics used in this study are simply tools for generating proposed server allocations. No heuristic dominated the others overall, although the Utilization-Down heuristic provided the largest number of preferred allocations and the Balance heuristic provided the smallest number of preferred allocations. The only conclusion that can be drawn from this is that the Utilization-Down heuristic should be considered when attempting to solve manpower allocation problems similar to this one.

Recommendations to Management

During the course of this study we gained insight about the CIF operations. This insight and the analysis of data presented in the last chapter led to the following recommendations to management:

1. Implement an allocation strategy listed in Tables 12 - 15. The data suggest that the manpower allocations shown in these tables will result in the lowest (compared to all conditions studied) mean times-in-system at the stated manning levels and batch sizes. When more than one allocation is shown at a manning level, or when two or more manning levels are grouped together, no significant difference in results should occur from using any of those allocations. This suggests that reductions in manpower may have no significant impact on customer process durations at some initial manning levels.

Also, because preferred allocations may differ between issue and turn-in at a specific manning level and batch size, different allocations should be implemented for the two sessions.

2. Use a batch size of seven. The results of this study suggest that a customer batch size of seven will almost always result in a lower mean time-in-system than a batch size of one or twenty-one, regardless of how workers are allocated.

The third recommendation was not based on this study but rather on our observation of the CIF in action and our knowledge of queuing theory.

3. Stagger customer arrivals. We observed staggered arrivals only occasionally during issue sessions, and never during turn-in sessions. When more than 63 customers arrived at once, three customer batches were served while the remaining customers waited for stations 2, 3, and 4. During this time the Reception clerks were also idle. This idle time of both customers and servers would be avoided if arrivals were staggered by the amount of time (dependent on batch size) needed to process three batches through stations 2, 3, and 4. Also, to avoid the need to repeat (or give at all) the briefing, it could be written on a handout (with diagram) and given to the soldiers before they arrive to the CIF.

Suggestions for Future Research

This study was limited in scope by design, but throughout this process the relevance of several issues became apparent. The following suggestions are offered to aid/initiate future research:

1. Explore other customer batch sizes. Exploratory simulation performed by modifying the batch size of a small sample of the preferred allocations generated in this study suggested the best customer batch size for the CIF may be between nine and fifteen. Models similar (or identical) to those used in this study could be employed to determine whether customer process durations can be improved through the use of other batch sizes.

2. Parallel Stations 2, 3, and 4. If smaller batch sizes (less than 11) are used, two or more batches can fit at Stations 2, 3, and 4 and be served by two sets of servers simultaneously. This procedure may reduce or possibly eliminate any bottlenecks at these stations (Buxey, 1974:1010).

3. Thoroughly test the diminishing return factors used in this study. Although the model used in this study appears to accurately represent the operations of the CIF, validation involved relatively few actual observations. While it is possible the diminishing return factors used here are accurate, they do appear to be rather severe. Because some degree of synergism is common when two or more people work together, the rapid decline in successive server effectiveness may be exaggerated.

4. *Look at other measures of effectiveness.* This study dealt with the average customer's time-in system, but similar studies focusing on the total time required to process groups of various sizes may be useful for establishing operating hours and scheduling employees.

5. *Emphasize experimental design.* Problems with non-normality of data and non-equality of error variances hindered this research. Similar problems may be avoided through greater emphasis on experimental design and the use of variance reduction techniques and other methods.

Appendix A: Server Allocations

BALANCE - ISSUE

Manning	RECP	A	B	C	FLT/DX	PBO
6	1	1	1	1	1	1
7	1	2	1	1	1	1
8	1	2	1	2	1	1
9	1	2	1	2	2	1
10	1	3	1	2	2	1
11	1	3	1	2	2	2
12	1	3	1	3	2	2
13	1	3	2	3	2	2
14	1	4	2	3	2	2
15	1	4	2	4	2	2
16	1	5	2	4	2	2
17	1	5	2	5	2	2
18	1	5	2	5	2	3
19	1	5	3	5	2	3

INVERSE BOWL - ISSUE

Manning	RECP	A	B	C	FLT/DX	PBO
6	1	1	1	1	1	1
7	1	1	1	1	1	2
8	1	2	1	1	1	2
9	1	2	1	2	1	2
10	2	2	1	2	1	2
11	2	2	1	2	2	2
12	2	3	1	2	2	2
13	2	3	1	3	2	2
14	2	3	1	3	2	3
15	2	3	2	3	2	3
16	2	4	2	3	2	3
17	2	4	2	4	2	3
18	2	5	2	4	2	3
19	2	5	2	4	2	4

MANAGER - ISSUE/TURN-IN

Manning	RECP	A	B	C	FLT/DX	PBO
6	1	1	1	1	1	1
7	1	1	2	1	1	1
8	1	2	2	1	1	1
9	1	2	2	1	1	2
10	1	2	2	2	1	2
11	2	2	2	2	1	2
12	2	2	2	2	1	3
13	2	2	2	2	2	3
14	2	3	2	2	2	3
15	2	3	3	2	2	3
16	2	3	3	2	2	4
17	2	3	3	3	2	4
18	2	3	3	3	3	4
19	2	4	4	4	2	3

	UTILIZATION-UP - ISSUE						
Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	6	1	1	1	1	1	1
7		1	1	1	1	1	1
1		1	1	1	1	1	1
21	7	1	2	1	1	1	1
7		1	2	1	1	1	1
1		1	2	1	1	1	1
21	8	1	2	1	2	1	1
7		1	3	1	1	1	1
1		1	3	1	1	1	1
21	9	1	2	1	2	2	1
7		1	3	1	2	1	1
1		1	3	1	2	1	1
21	10	1	3	1	2	2	1
7		1	3	1	2	2	1
1		1	4	1	2	1	1
21	11	1	3	1	3	2	1
7		1	3	1	3	2	1
1		1	5	1	2	1	1
21	12	1	3	2	3	2	1
7		1	4	1	3	2	1
1		1	5	1	3	1	1
21	13	1	3	2	3	2	2
7		1	4	2	3	2	1
1		1	5	1	4	1	1

UTILIZATION-UP - ISSUE (Cont)

Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	14	1	4	2	3	2	2
7		1	5	2	3	2	1
1		1	5	2	4	1	1
21	15	1	4	2	4	2	2
7		1	5	2	3	2	2
1		1	5	2	5	1	1
21	16	1	5	2	4	2	2
7		1	5	2	4	2	2
1		1	5	3	5	1	1
21	17	2	5	2	4	2	2
7		1	5	2	5	2	2
1		1	5	4	5	1	1
21	18	2	5	2	5	2	2
7		2	5	2	5	2	2
1		1	5	5	5	1	1
21	19	2	5	3	5	2	2
7		2	5	3	5	2	2
1		1	5	5	5	2	1

Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
		UTILIZATION-DOWN - ISSUE					
21	6	1	1	1	1	1	1
7		1	1	1	1	1	1
1		1	1	1	1	1	1
21	7	1	2	1	1	1	1
7		1	2	1	1	1	1
1		1	2	1	1	1	1
21	8	1	2	1	2	1	1
7		1	2	1	2	1	1
1		1	3	1	1	1	1
21	9	1	3	1	2	1	1
7		1	3	1	2	1	1
1		1	4	1	1	1	1
21	10	1	3	1	3	1	1
7		1	4	1	2	1	1
1		1	4	1	2	1	1
21	11	1	4	1	3	1	1
7		1	4	1	3	1	1
1		1	4	1	3	1	1
21	12	1	4	1	4	1	1
7		1	4	1	4	1	1
1		1	4	1	4	1	1
21	13	1	4	1	4	2	1
7		1	4	2	4	1	1
1		1	4	2	4	1	1

	UTILIZATION-DOWN - ISSUE (Cont)						
Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	14	1	4	2	4	2	1
7		1	4	2	4	2	1
1		1	4	3	4	1	1
21	15	1	4	2	4	2	2
7		1	4	3	4	2	1
1		1	4	4	4	1	1
21	16	1	4	3	4	2	2
7		1	4	4	4	2	1
1		1	4	4	4	2	1
21	17	2	4	3	4	2	2
7		1	4	4	4	2	2
1		1	4	4	4	2	2
21	18	2	4	4	4	2	2
7		2	4	4	4	2	2
1		2	4	4	4	2	2
21	19	2	4	4	4	2	3
7		2	4	4	4	2	3
1		2	4	4	4	2	3

BALANCE - TURN-IN

Manning	RECP	A	B	C	FLT/DX	PBO
6	1	1	1	1	1	1
7	1	2	1	1	1	1
8	1	2	2	1	1	1
9	1	2	2	2	1	1
10	1	2	2	2	1	2
11	1	3	2	2	1	2
12	1	3	3	2	1	2
13	1	3	3	3	1	2
14	1	4	3	3	1	2
15	1	4	3	3	1	3
16	1	4	4	3	1	3
17	1	5	4	3	1	3
18	1	5	4	3	2	3
19	1	5	5	3	2	3

INVERSE BOWL - TURN-IN

Manning	RECP	A	B	C	FLT/DX	PBO
6	1	1	1	1	1	1
7	1	1	1	1	1	2
8	1	2	1	1	1	2
9	1	2	2	1	1	2
10	1	2	2	2	1	2
11	1	2	2	2	1	3
12	1	3	2	2	1	3
13	1	3	3	2	1	3
14	1	3	3	2	1	4
15	1	3	3	3	1	4
16	1	4	3	3	1	4
17	2	4	3	3	1	4
18	2	4	4	3	1	4
19	2	4	4	3	1	5

	UTILIZATION-UP - TURN-IN						
Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	6	1	1	1	1	1	1
7		1	1	1	1	1	1
1		1	1	1	1	1	1
21	7	1	2	1	1	1	1
7		1	2	1	1	1	1
1		1	2	1	1	1	1
21	8	1	2	2	1	1	1
7		1	2	2	1	1	1
1		1	3	1	1	1	1
21	9	1	2	2	2	1	1
7		1	2	2	2	1	1
1		1	4	1	1	1	1
21	10	1	2	2	2	1	2
7		1	2	2	2	1	2
1		1	4	2	1	1	1
21	11	1	3	2	2	1	2
7		1	3	2	2	1	2
1		1	4	2	2	1	1
21	12	1	3	3	2	1	2
7		1	3	3	2	1	2
1		1	5	2	2	1	1
21	13	1	3	3	3	1	2
7		1	4	3	2	1	2
1		1	5	2	3	1	1

UTILIZATION-UP - TURN-IN (Cont)

Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	14	1	4	3	3	1	2
7		1	4	3	3	1	2
1		1	5	3	3	1	1
21	15	1	4	3	3	1	3
7		1	5	3	3	1	2
1		1	5	3	4	1	1
21	16	1	4	4	3	1	3
7		1	5	4	3	1	2
1		1	5	3	5	1	1
21	17	1	5	4	3	1	3
7		1	5	4	4	1	2
1		1	5	4	5	1	1
21	18	1	5	4	4	1	3
7		1	5	4	4	1	3
1		1	5	5	5	1	1
21	19	1	5	4	4	2	3
7		1	5	5	4	1	3
1		1	5	5	5	1	2

	UTILIZATION-DOWN - TURN-IN						
Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	6	1	1	1	1	1	1
7		1	1	1	1	1	1
1		1	1	1	1	1	1
21	7	1	2	1	1	1	1
7		1	2	1	1	1	1
1		1	2	1	1	1	1
21	8	1	2	2	1	1	1
7		1	2	2	1	1	1
1		1	3	1	1	1	1
21	9	1	2	2	2	1	1
7		1	3	2	1	1	1
1		1	4	1	1	1	1
21	10	1	3	2	2	1	1
7		1	3	2	2	1	1
1		1	4	1	2	1	1
21	11	1	3	2	2	1	2
7		1	4	2	2	1	1
1		1	4	2	2	1	1
21	12	1	3	3	2	1	2
7		1	4	3	2	1	1
1		1	4	2	3	1	1
21	13	1	4	3	2	1	2
7		1	4	3	3	1	1
1		1	4	2	4	1	1

UTILIZATION-DOWN - TURN-IN (Cont)

Batch Size	Manning	RECP	A	B	C	FLT/DX	PBO
21	14	1	4	3	3	1	2
7		1	4	3	3	1	2
1		1	4	3	4	1	1
21	15	1	4	4	3	1	2
7		1	4	4	3	1	2
1		1	4	4	4	1	1
21	16	1	4	4	4	1	2
7		1	4	4	4	1	2
1		1	4	4	4	1	2
21	17	1	4	4	4	1	3
7		1	4	4	4	1	3
1		1	4	4	4	1	3
21	18	1	4	4	4	2	3
7		1	4	4	4	2	3
1		1	4	4	4	2	3
21	19	2	4	4	4	2	3
7		2	4	4	4	2	3
1		2	4	4	4	2	3

Appendix B: Observed Durations

Note: All times given are in minutes

Issue Process

Time to process full issue customers at Reception (Station 1)

0.65	0.67	0.82	0.82	0.87	1.00
1.05	1.07	1.08	1.10	1.13	1.25
1.42	1.70				

Counter A (Station 2) set-up data

NUMBER SERVERS	NUMBER SLOTS	SETUP TIME	SETUP RATE
3	17	11.82	2.0859
2	21	22.00	2.0952
2	21	22.00	2.0952
5	21	8.97	2.1357
2.5	9	8.00	2.2222
4	21	12.90	2.4571
2.2	21	25.00	2.6190

NOTE: Rate = (servers * set time)/(slots)

Counter B (Station 3) set-up data

NUMBER SERVERS	NUMBER SLOTS	SETUP TIME	SETUP RATE
1	7	5.53	0.7900
2	21	8.57	0.8162
2	17	7.00	0.8235
3	21	7.25	1.0357
2.45	21	11.05	1.2892

NOTE: Rate = (servers * set time)/(slots)

Counter C (Station 4) set-up data

NUMBER SERVERS	NUMBER SLOTS	SETUP TIME	SETUP RATE
1	14	7.88	0.5629
1	5	5.00	1.0000
1	7	13.00	1.8571
2.5	21	16.50	1.9643
2	6	6.00	2.0000
2	23	27.00	2.3478
2	21	25.00	2.3810
2	9	11.00	2.4444
4	21	15.00	2.8571
2	16	23.00	2.8750
2	8	12.00	3.0000
2	21	32.50	3.0952
2	5	8.00	3.2000
2.79	21	24.28	3.2258
4	18	15.00	3.3333

NOTE: Rate = (servers * set time)/(slots)

Counter A (Station 2) issue data

NUMBER SERVER	ADJUST SERVER	CUST	ISSUE TIME	ADJUSTED TIME	RATE	ADJUSTED RATE
1	1.0	5	6.81	1.89	1.3620	0.3780
3	2.3	21	13.00	8.08	1.8571	0.8850
3	2.3	21	13.83	8.91	1.9751	0.9754
2	1.8	9	10.00	5.08	2.2222	1.0160
3	2.3	17	15.10	10.18	2.6647	1.3773
3	2.3	17	17.00	12.08	3.0000	1.6444
2	1.8	18	22.00	17.08	2.4444	1.7080
2	1.8	9	15.00	10.08	3.3333	2.0160
2	1.8	21	31.00	26.08	2.9524	2.2354
2	1.8	9	18.00	13.08	4.0000	2.6160

Note: Adjusted Time = (Issue Time - 4.92 minutes)

Adjusted Rate = (Adj Server * Adj Time) / Cust

Counter B (Station 3) issue data

NUMBER SERVER	ADJUST SERVER	CUST	ISSUE TIME	ADJUSTED TIME	ISSUE RATE	ADJUSTED RATE
1	1.0	17	9.00	6.50	0.5294	0.3824
1	1.0	9	6.00	3.50	0.6667	0.3889
1	1.0	21	12.00	9.50	0.5714	0.4524
1	1.0	9	7.00	4.50	0.7778	0.5000
1	1.0	9	7.45	4.95	0.8278	0.5500
2	1.8	21	11.96	9.46	1.1390	0.8109
3	2.3	23	13.07	10.57	1.7048	1.0570
3	2.3	7	6.38	3.88	2.7343	1.2749
2	1.8	5	7.14	4.64	2.8560	1.6704

Note: Adjusted Time = (Issue Time - 2.5 minutes)
Adjusted Rate = (Adj Server * Adj Time) / Cust

Counter C (Station 4) issue data

NUMBER SERVER	ADJUST SERVER	CUST	ISSUE TIME	ADJUSTED TIME	RATE	ADJUSTED RATE
2	1.8	5	4.00	0.75	1.6000	0.2700
2	1.8	2	9.00	5.75	0.8571	0.4929
2	1.8	16	8.00	4.75	1.0000	0.5344
2	1.8	9	6.00	2.75	1.3333	0.5500
1	1.0	6	7.00	3.75	1.1667	0.6250
1	1.0	8	9.21	5.96	1.1509	0.7446
2	1.8	11	8.00	4.75	1.4545	0.7773
3	2.3	21	10.57	7.32	1.5100	0.8017
3	2.3	21	11.00	7.75	1.5714	0.8488
2	1.8	23	15.00	11.75	1.3043	0.9196
2	1.8	21	14.00	10.75	1.3333	0.9214
1	1.0	7	14.50	11.25	2.0719	1.6076
2	1.8	5	8.13	4.88	3.2520	1.7568

Note: Adjusted Time = (Issue Time - 3.25 minutes)
Adjusted Rate = (Adj Server * Adj Time) / Cust

Flight Cage (Station 5) issue durations

1.12	1.48	2.23	3.58	3.87	4.08
6.40	6.40	6.40	6.40	6.40	7.50

Time at bins for a customer to inspect issued equipment

0	0	0	0	3	5
7	9	10	10	12	12
14	14	14.5	15	15	15
16	18	18	18	19	19
20	20	20	20	20	20
22	22	24.9	25	25	26
27	27	29	29.7	30	30
31	31	32	33	34	36
36	37	38.1	39	42	43.2
44	48	59.7			

Time for Property Book Office (Station 6) clerks to input issue item data into a customer's account

0.22	0.42	0.42	0.57	0.58	0.67
0.68	0.70	0.77	0.78	0.78	0.82
0.85	0.87	0.87	0.88	0.88	0.92
0.95	0.97	0.97	0.98	0.98	1.00
1.00	1.00	1.03	1.03	1.07	

Turn-In Process

Time to process partial issue, full turn-in, and partial turn-in customers at Reception (Station 1)

0.24	0.27	0.27	0.30	0.30	0.32
0.33	0.33	0.33	0.33	0.33	0.33
0.33	0.35	0.37	0.37	0.37	0.37
0.38	0.40	0.40	0.40	0.42	0.43
0.43	0.45	0.45	0.45	0.47	0.48
0.48	0.48	0.48	0.48	0.48	0.50
0.50	0.50	0.50	0.52	0.55	0.55
0.55	0.57	0.58	0.60	0.60	0.60
0.60	0.62	0.62	0.63	0.67	0.67
0.72	0.73	0.80	0.80	0.82	0.82
0.88	0.88	0.97	0.98	1.05	1.17
1.35	1.35	1.78			

Counter A (Station 2) turn-in data

NUMBER SERVERS	NUMBER CUST	TURN-IN TIME	ADJUSTED TIME	RATE	ADJUSTED RATE
1	1	7.00	2.08	7.0000	2.0800
1	8	22.00	17.08	2.7500	2.1350
2	8	14.00	9.08	3.5000	2.2700
1	8	24.00	19.08	3.0000	2.3850
1	2	10.00	5.08	5.0000	2.5400
3	21	30.00	25.08	4.2857	3.5829
4	20	23.04	18.12	4.6080	3.6240
2	16	35.00	30.08	4.3750	3.7600
3	23	36.00	31.08	4.6957	4.0539
2	17	42.00	37.08	4.9412	4.3624
3	17	30.00	25.08	5.2941	4.4259
3	20	35.00	30.08	5.2500	4.5120
2	4	15.00	10.08	7.5000	5.0400
4	18	26.83	21.91	6.7083	5.4783
4	23	36.75	31.83	6.3913	5.5357
2	4	14.00	9.08	9.6250	6.2425

NOTE: Adjusted time = (Turn-in time - 4.92 minutes)
Adjusted rate = (servers * adjusted time) / (customers)

Counter B (Station 3) turn-in data

NUMBER SERVERS	NUMBER CUST	TURN-IN TIME	ADJUSTED TIME	RATE	ADJUSTED RATE
1	21	30.00	27.50	1.4286	1.3095
1	4	8.00	5.50	2.0000	1.3750
2	17	17.00	14.50	2.0000	1.7059
1	1	4.50	2.00	4.5000	2.0000
2	18	25.45	22.95	2.8278	2.5500
1	4	15.00	12.50	3.7500	3.1250
2	14	25.00	22.50	3.5714	3.2143
3	21	26.00	23.50	3.7143	3.3571
1	2	10.00	7.50	5.0000	3.7500
3	21	29.00	26.50	4.1429	3.7857
3	23	35.41	32.91	4.6187	4.2926
1	1	7.00	4.50	7.0000	4.5000
1	1	8.00	5.50	8.0000	5.5000
1	1	9.00	6.50	9.0000	6.5000
1	1	15.00	12.50	15.0000	12.500

NOTE: Adjusted time = (turn-in time - 2.5 minutes)
Adjusted rate = (servers * adjusted time)/(customers)

Counter C (Station 4) turn-in data

NUMBER SERVERS	NUMBER CUST	TURNIN TIME	ADJUSTED TIME	RATE	ADJUSTED RATE
2	21	12.00	8.75	1.1429	0.8333
2	21	12.00	8.75	1.1429	0.8333
3	21	11.00	7.75	1.5714	1.1071
2	10	10.00	6.75	2.0000	1.3500
1	4	9.00	5.75	2.2500	1.4375
1	4	10.00	6.75	2.5000	1.6875
2	21	25.00	21.75	2.3810	2.0714
3	21	18.00	14.75	2.5714	2.1071
2	16	24.00	20.75	3.0000	2.5938
1	1	6.00	2.75	6.0000	2.7500
1	1	6.00	2.75	6.0000	2.7500
3	21	23.00	19.75	3.2857	2.8214
3	8	11.00	7.75	4.1250	2.9063
2	21	35.00	31.75	3.3333	3.0238
2	18	33.00	29.75	3.9967	3.6031
4	18	23.60	20.35	5.2444	4.5222
1	1	8.00	4.75	8.0000	4.7500
4	23	36.74	33.49	6.3896	5.8243
4	20	32.50	29.25	6.5000	5.8500
1	1	10.00	6.75	10.0000	6.7500

NOTE: Adjusted time = (turn-in time - 3.25 minutes)
Adjusted rate = (servers * adjusted time)/(customers)

Flight Cage (Station 5) turn-in durations

0.78	1.22	1.47	1.53	1.77	1.88
2.07	2.28	2.28	2.53	3.25	4.03
4.08	4.50	5.33	6.33		

Time for the Property Book Office (Station 6) to change customer balances after a full or partial turn-in or a partial issue

0.18	0.37	0.40	0.40	0.42	0.53
0.58	0.63	0.63	0.65	0.72	0.73
0.77	0.78	0.82	0.83	0.83	0.87
0.95	0.97	1.00	1.00	1.05	1.07
1.08	1.08	1.25	1.28	1.38	1.42
1.43	1.50	1.52	1.57	2.25	2.60
3.42	3.82	4.72	5.33	5.35	

Continuous Processes

Time for Property Book Office (Station 6) to provide a customer with a copy of current hand receipt

1.33	1.66	2.00	2.00	2.27	3.00
3.00	4.00	8.00	8.00	11.00	

Time for Property Book Office (Station 6) to make an administrative adjustment to a hand receipt balance

2.02	3.53	4.00	4.00	4.35	4.53
4.83	5.03	5.58	5.68	5.83	6.58
6.82	7.00	7.25	8.00	8.10	8.50
8.70	10.57	11.25	15.00		

NOTE: Adjustments include reports of surveys, statements of charges, and cash collection vouchers.

Time duration to service a DX customer (Station 5)

0.10	0.13	0.23	0.23	0.37	0.43
0.48	0.48	0.72	0.73	0.77	0.85
0.95	0.97	0.97	0.98	1.00	1.15
1.23	1.27	1.28	1.40	1.43	1.43
1.45	1.50	1.52	1.58	1.58	1.73
1.75	1.83	1.98	1.98	2.09	2.10
2.15	2.17	2.32	2.33	2.35	2.48
2.52	2.55	2.60	2.65	2.67	2.72
3.03	3.05	3.07	3.08	3.22	3.98
4.15	4.20	4.30	4.65	4.72	4.92
5.15	5.47	5.83	6.32	7.15	7.32
7.38	8.22	8.45	10.77		

Historical work load data, first 23 weeks of FY 94

Numbers and categories of CIF's customers

WEEK #	ISSUE CUST	TURNIN CUST	TOTAL CUST	PARTIAL CUST	PBO WORK
1	110	370	480	115	94
2	61	182	243	70	52
3	165	437	602	387	67
4	152	499	651	444	76
5	150	388	538	554	66
6	261	678*	939	1339*	170
7	167	320	487	630*	69
8	108	503	611	248	50
9	320	653*	973	553	63
10	220	562	782	530	90
11	126	508	634	315	79
12	30	147	177	230	24
13	272	280	552	1377*	68
14	216	366	582	671*	71
15	81	132	213	121	41
16	139	338	477	501	76
17	167	394	561	869*	76
18	105	262	367	193	60
19	132	478	610	593	58
20	192	472	664	941*	100
21	182	986*	1168	413	107
22	103	515	618	356	97
23	159	562	721	397	84

NOTE: * indicates that the figures for the numbers of customers are abnormally high due to unusual circumstances.

PBO WORK includes all administrative adjustment and hand receipt procedures.

Number of DX customers per working day

27	30	34	34	34	35
35	39	39	39	39	40
40	42	43	46	48	49
49	50	50	50	50	51
51	52	52	52	52	54
54	55	55	55	56	56
57	58	58	60	61	61
61	61	62	62	62	62
62	62	63	63	63	65
65	66	68	69	69	69
69	70	71	73	74	75
76	78	80	81	81	84
84	85	86	90	94	95
98	105	107	111	117	119
124	131				

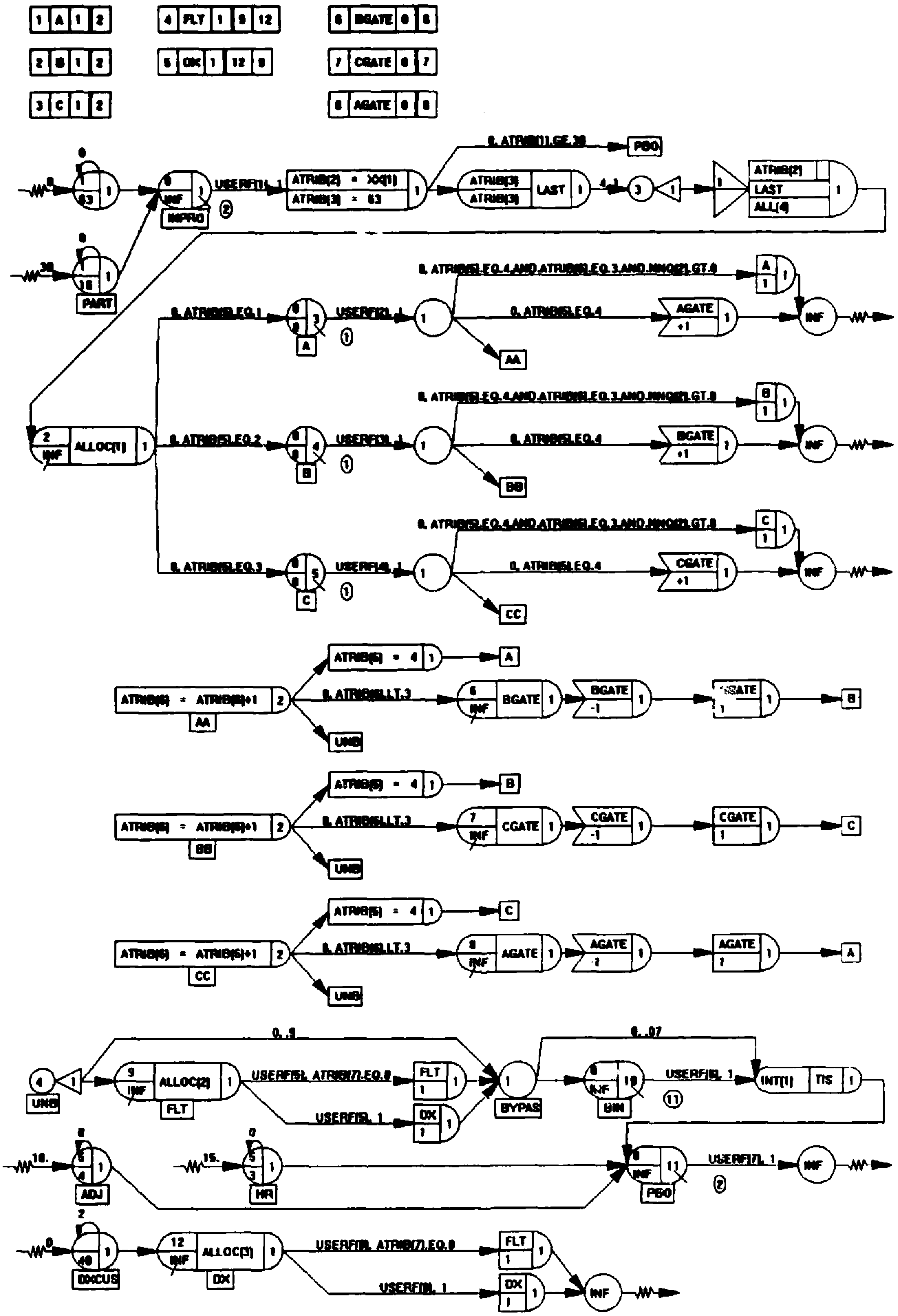
Appendix C: Sample Process Duration Log

Station ____________ **Date** ____________

# Servers	# Customers	Time	Notes

Name ____________

Appendix D: SLAM Network and Source Code (Issue)


1 A 1 2
2 B 1 2
3 C 1 2
4 FLT 1 9 12
5 DX 1 12 9
6 BGATE 0 6
7 CGATE 0 7
8 AGATE 0 8
0, ATRIB(1).GE.30
PBO
USERF(1), 1
ATRIB(2) = XX(1)
ATRIB(3) = 63
ATRIB(3)
ATRIB(3)
LAST
4, 1
3
ATRIB(2)
LAST
ALL(4)
INF
INPRO
②
63
PART
0, ATRIB(5).EQ.1
0, ATRIB(5).EQ.2
0, ATRIB(5).EQ.3
A
B
C
USERF(2), 1
USERF(3), 1
USERF(4), 1
①
0, ATRIB(5).EQ.4.AND.ATRIB(6).EQ.3.AND.NNQ(2).GT.0
0, ATRIB(5).EQ.4
AGATE
BGATE
CGATE
+1
INF
AA
BB
CC
ALLOC(1)
ATRIB(6) = ATRIB(6)+1
ATRIB(5) = 4
0, ATRIB(6).LT.3
UNB
-1
0, .9
0, .07
ALLOC(2)
FLT
USERF(5), ATRIB(7).EQ.0
USERF(5), 1
DX
BYPAS
BIN
USERF(6), 1
⑪
INT(1)
TIS
10.
15.
ADJ
HR
USERF(7), 1
PBO
ALLOC(3)
DXCUS
USERF(8), ATRIB(7).EQ.0
USERF(8), 1
12
40

SLAM Code for the Issue Model

```
GEN,MIKE AND CHRIS,THESIS,8/12/1994,100,N,N,Y/Y,N,Y/S,72;
LIMITS,12,8,200;
INTLC,XX(1)=7,XX(2)=2.883,XX(3)=1.8,XX(4)=2.633,XX(5)=5,
XX(6)=2,XX(7)=4,XX(8)=2,XX(9)=19;
INITIALIZE,,,N;
NETWORK;
       RESOURCE/1,A,2;
       RESOURCE/2,B,2;
       RESOURCE/3,C,2;
       RESOURCE/4,FLT,9,12;
       RESOURCE/5,DX(1),12,9;
       RESOURCE/6,BGATE(0),6;
       RESOURCE/7,CGATE(0),7;
       RESOURCE/8,AGATE(0),8;
;
       CREATE,0,,1,63,1;
       ACTIVITY;
INPRO  QUEUE(1),,,;
       ACTIVITY(2)/1,USERF(1);
       ASSIGN,ATRIB(2)=XX(1),ATRIB(3)=63,1;
       ACTIVITY,,ATRIB(1).GE.30,PBO;
       ACTIVITY;
       ACCUMULATE,ATRIB(3),ATRIB(3),,1;
       ACTIVITY,4;
       UNBATCH,3,1;
       ACTIVITY;
       BATCH,1,ATRIB(2),,,ALL(4),1;
       ACTIVITY;
       AWAIT(2),ALLOC(1),,1;
       ACTIVITY,,ATRIB(5).EQ.1;
       ACTIVITY,,ATRIB(5).EQ.2,B;
       ACTIVITY,,ATRIB(5).EQ.3,C;
A      QUEUE(3),,0,;
       ACTIVITY(1)/2,USERF(2);
       GOON,1;
       ACTIVITY,,ATRIB(5).EQ.4.AND.ATRIB(6).EQ.3.AND.
         NNQ(2).GT.0;
       ACTIVITY,,ATRIB(5).EQ.4,ZAAP;
       ACTIVITY,,,AA;
       FREE,A,1;
       ACTIVITY;
ZAAO   TERMINATE;
ZAAP   ALTER,AGATE,+1,1;
       ACTIVITY,,,ZAAO;
B      QUEUE(4),,0,;
```

```
        ACTIVITY(1)/3,USERF(3);
        GOON,1;
        ACTIVITY,,ATRIB(5).EQ.4.AND.ATRIB(6).EQ.3.AND.
          NNQ(2).GT.0;
        ACTIVITY,,ATRIB(5).EQ.4,ZAAR;
        ACTIVITY,,,BB;
        FREE,B,1;
        ACTIVITY;
ZAAQ    TERMINATE;
ZAAR    ALTER,BGATE,+1,1;
        ACTIVITY,,,ZAAQ;
C       QUEUE(5),,0,;
        ACTIVITY(1)/4,USERF(4);
        GOON,1;
        ACTIVITY,,ATRIB(5).EQ.4.AND.ATRIB(6).EQ.3.AND.
          NNQ(2).GT.0;
        ACTIVITY,,ATRIB(5).EQ.4,ZAAT;
        ACTIVITY,,,CC;
        FREE,C,1;
        ACTIVITY;
ZAAS    TERMINATE;
ZAAT    ALTER,CGATE,+1,1;
        ACTIVITY,,,ZAAS;
;
PART    CREATE,0,30,1,16,1;
        ACTIVITY,,,INPR;
;
AA      ASSIGN,ATRIB(6)=ATRIB(6)+1,2;
        ACTIVITY;
        ACTIVITY,,ATRIB(6).LT.3,ZAAU;
        ACTIVITY,,,UNB;
        ASSIGN,ATRIB(5)=4,1;
        ACTIVITY,,,A;
ZAAU    AWAIT(6),BGATE,,1;
        ACTIVITY;
        ALTER,BGATE,-1,1;
        ACTIVITY;
        FREE,BGATE,1;
        ACTIVITY,,,B;
;
BB      ASSIGN,ATRIB(6)=ATRIB(6)+1,2;
        ACTIVITY;
        ACTIVITY,,ATRIB(6).LT.3,ZAAV;
        ACTIVITY,,,UNB;
        ASSIGN,ATRIB(5)=4,1;
        ACTIVITY,,,B;
ZAAV    AWAIT(7),CGATE,,1;
        ACTIVITY;
        ALTER,CGATE,-1,1;
```

```
       ACTIVITY;
       FREE,CGATE,1;
       ACTIVITY,,C;
;
CC     ASSIGN,ATRIB(6)=ATRIB(6)+1,2;
       ACTIVITY;
       ACTIVITY,,ATRIB(6).LT.3,ZAAW;
       ACTIVITY,,UNB;
       ASSIGN,ATRIB(5)=4,1;
       ACTIVITY,,C;
ZAAW   AWAIT(8),AGATE,,1;
       ACTIVITY;
       ALTER,AGATE,-1,1;
       ACTIVITY;
       FREE,AGATE,1;
       ACTIVITY,,A;
;
UNB    UNBATCH,4,1;
       ACTIVITY,,.9;
       ACTIVITY,,FLT;
BYPAS  GOON,1;
       ACTIVITY,,.07;
       ACTIVITY,,BIN;
ZAAX   COLCT,INT(1),TIS,,1;
       ACTIVITY;
PBO    QUEUE(11),,,;
       ACTIVITY(4),USERF(7);
       TERMINATE;
BIN    QUEUE(10),,,;
       ACTIVITY(11),USERF(6),,ZAAX;
FLT    AWAIT(9),ALLOC(2),,1;
       ACTIVITY,USERF(5),ATRIB(7).EQ.0;
       ACTIVITY,USERF(5),,ZAAY;
       FREE,FLT,1;
       ACTIVITY,,BYPA;
ZAAY   FREE,DX,1;
       ACTIVITY,,BYPA;
;
HR     CREATE,0,15,5,3,1;
       ACTIVITY,,PBO;
;
ADJ    CREATE,0,10,5,4,1;
       ACTIVITY,,PBO;
;
DXCUS  CREATE,2,,,48,1;
       ACTIVITY;
DX     AWAIT(12),ALLOC(3),,1;
       ACTIVITY,USERF(8),ATRIB(7).EQ.0;
       ACTIVITY,USERF(8),,ZABA;
```

```
       FREE,FLT,1;
       ACTIVITY;
ZAAZ   TERMINATE;
ZABA   FREE,DX,1;
       ACTIVITY,,,ZAAZ;
       END;
FIN;
```

FORTRAN Code for the Issue Model

```
      PROGRAM MAIN
      DIMENSION NSET(50000)
      PARAMETER  (MEQT=100,  MSCND=25,  MENTR=25, MRSC=75,
     1 MARR=50, 1 MGAT=25,   MHIST=50,  MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      PARAMETER (MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT),DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
      COMMON QSET(50000)
      EQUIVALENCE (NSET(1),QSET(1))
      OPEN (1,FILE='GLM94S:[MGARRITY]IRESULTS.DAT',
     1 STATUS='OLD', ACCESS='APPEND')
      NNSET=50000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      CLOSE (1)
      STOP
      END
C
C
      SUBROUTINE ALLOC(IFN,IFLAG)
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, 1 MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
      IFLAG = 0
      GO TO (1,2,3),IFN
C     SEND BATCHES TO COUNTERS A,B,C AS AVAILABLE
1     IF (NNQ(2).GT.0) THEN
        IF (NNRSC(1).LE.0.AND.NNRSC(2).LE.0.AND.
     1    NNRSC(3).LE.0) THEN
          GO TO 101
        ELSE IF (NNRSC(1).GT.0) THEN
          CALL SEIZE(1,1)
          ATRIB(5) = 1
        ELSE IF (NNRSC(2).GT.0) THEN
          CALL SEIZE(2,1)
```

```
          ATRIB(5) = 2
        ELSE
          CALL SEIZE(3,1)
          ATRIB(5) = 3
        ENDIF
        IFLAG = 1
      ENDIF
101   RETURN
C
C
C    FLIGHT CUSTOMERS USE FLIGHT/DX SERVERS WHEN AVAILABLE
2     IF (NNQ(9).GT.0) THEN
        IF (NNRSC(4).LE.0.AND.NNRSC(5).LE.0) THEN
          GO TO 201
        ELSE IF (NNRSC(4).GT.0) THEN
          CALL SEIZE(4,1)
        ELSE
          CALL SEIZE(5,1)
          ATRIB(7) = 1
        ENDIF
        IFLAG = 1
      ENDIF
201   RETURN
C
C
C    DX CUSTOMERS USE DX/FLIGHT SERVERS WHEN AVAILABLE
3     IF (NNQ(12).GT.0) THEN
        IF (NNRSC(4).LE.0.AND.NNRSC(5).LE.0) THEN
          GO TO 301
        ELSE IF (NNRSC(5).GT.0) THEN
          CALL SEIZE(5,1)
          ATRIB(7) = 1
        ELSE
          CALL SEIZE(4,1)
        ENDIF
        IFLAG = 1
      ENDIF
301   RETURN
      END
C
C
      FUNCTION USERF(IFN)
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      PARAMETER (MVARP1=MVARP+1)
```

```
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
      COMMON QSET(15000)
      COMMON/UCOM1/RDUR(13,16,2)
      R=DRAND(IFN)
      IF (ATRIB(5).LT.4) THEN
C       ESTABLISH NON-SETUP DURATION
        I=2
50      CONTINUE
        IF (I.LE.16) THEN
          IF (R.LE.RDUR(IFN,I,1)) THEN
            S=RDUR(IFN,I-1,2)+(RDUR(IFN,I,2)-
     1         RDUR(IFN,I-1,2))*((R-RDUR(IFN,I-1,1))/
     2         (RDUR(IFN,I,1)-RDUR(IFN,I-1,1)))
              IF (IFN.EQ.2) THEN
                USERF=4.92+S*XX(1)/XX(IFN)
              ELSE IF (IFN.EQ.3) THEN
                USERF=2.50+S*XX(1)/XX(IFN)
              ELSE IF (IFN.EQ.4) THEN
                USERF=3.25+S*XX(1)/XX(IFN)
              ELSE
                USERF=S
              ENDIF
            I=99
          ENDIF
          I=I+1
          GO TO 50
        ENDIF
      ELSE IF (ATRIB(5).EQ.4) THEN
C       ESTABLISH SETUP DURATION
        I=2
100     CONTINUE
        IF (I.LE.16) THEN
          IF (R.LE.RDUR(IFN+7,I,1)) THEN
            S=RDUR(IFN+7,I-1,2)+(RDUR(IFN+7,I,2)-
     1         RDUR(IFN+7,I-1,2))*((R-RDUR(IFN+7,I-1,1))/
               (RDUR(IFN+7,I,1)-RDUR(IFN+7,I-1,1)))
            USERF=S*XX(1)/XX(IFN+3)
            I=99
          ENDIF
        I=I+1
        GO TO 100
        ENDIF
      ELSE IF (ATRIB(5).EQ.10) THEN
C       ESTABLISH DURATION FOR ADJUSTMENTS AT PBO
        I=2
150     CONTINUE
        IF (I.LE.16) THEN
```

```
          IF (R.LE.RDUR(12,I,1)) THEN
            USERF=RDUR(12,I-1,2)+(RDUR(12,I,2)-
     1         RDUR(12,I-1,2))*((R-RDUR(12,I-1,1))/
     2         (RDUR(12,I,1)-RDUR(12,I-1,1)))
            I=99
          ENDIF
        I=I+1
        GO TO 150
        ENDIF
      ELSE IF (ATRIB(5).EQ.15) THEN
C       ESTABLISH DURATION FOR HAND RECEIPTS AT PBO
        I=2
200     CONTINUE
        IF (I.LE.16) THEN
          IF (R.LE.RDUR(13,I,1)) THEN
            USERF=RDUR(13,I-1,2)+(RDUR(13,I,2)-
     1         RDUR(13,I-1,2))*((R-RDUR(13,I-1,1))/
     2         (RDUR(13,I,1)-RDUR(13,I-1,1)))
            I=99
          ENDIF
        I=I+1
        GO TO 200
        ENDIF
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE OTPUT
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
C       SET UP OUTPUT FOR ANALYSIS
      IF (XX(9).LT.20) THEN
        WRITE(1,1000) XX(9), XX(8), XX(1), CCAVG(1)
1000    FORMAT(' ',F8.0,F8.0,F8.0,F10.2)
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE INTLC
      COMMON/UCOM1/RDUR(13,16,2)
C       PREPARE DISTRIBUTION FOR INPROCESSING DURATION
```

```
      RDUR(1,1,1)=0.00
      RDUR(1,2,1)=1./14.
      RDUR(1,3,1)=2./14.
      RDUR(1,4,1)=4./14.
      RDUR(1,5,1)=5./14.
      RDUR(1,6,1)=6./14.
      RDUR(1,7,1)=7./14.
      RDUR(1,8,1)=8./14.
      RDUR(1,9,1)=9./14.
      RDUR(1,10,1)=10./14.
      RDUR(1,11,1)=11./14.
      RDUR(1,12,1)=12./14.
      RDUR(1,13,1)=13./14.
      RDUR(1,14,1)=1.00
      RDUR(1,15,1)=1.00
      RDUR(1,16,1)=1.00
      RDUR(1,1,2)=.64
      RDUR(1,2,2)=.65
      RDUR(1,3,2)=.67
      RDUR(1,4,2)=.82
      RDUR(1,5,2)=.87
      RDUR(1,6,2)=1.00
      RDUR(1,7,2)=1.05
      RDUR(1,8,2)=1.07
      RDUR(1,9,2)=1.08
      RDUR(1,10,2)=1.10
      RDUR(1,11,2)=1.13
      RDUR(1,12,2)=1.25
      RDUR(1,13,2)=1.42
      RDUR(1,14,2)=1.84
      RDUR(1,15,2)=9999.
      RDUR(1,16,2)=9999.
C       PREPARE DISTRIBUTION FOR STATION A SERVICE DURATION
      RDUR(2,1,1)=0.00
      RDUR(2,2,1)=.10
      RDUR(2,3,1)=.20
      RDUR(2,4,1)=.30
      RDUR(2,5,1)=.40
      RDUR(2,6,1)=.50
      RDUR(2,7,1)=.60
      RDUR(2,8,1)=.70
      RDUR(2,9,1)=.80
      RDUR(2,10,1)=.90
      RDUR(2,11,1)=1.00
      RDUR(2,12,1)=1.00
      RDUR(2,13,1)=1.00
      RDUR(2,14,1)=1.00
      RDUR(2,15,1)=1.00
      RDUR(2,16,1)=1.00
```

```
      RDUR(2,1,2)=.1245
      RDUR(2,2,2)=.3780
      RDUR(2,3,2)=.8850
      RDUR(2,4,2)=.9754
      RDUR(2,5,2)=1.0160
      RDUR(2,6,2)=1.3773
      RDUR(2,7,2)=1.6344
      RDUR(2,8,2)=1.7080
      RDUR(2,9,2)=2.0160
      RDUR(2,10,2)=2.2354
      RDUR(2,11,2)=2.8063
      RDUR(2,12,2)=9999.
      RDUR(2,13,2)=9999.
      RDUR(2,14,2)=9999.
      RDUR(2,15,2)=9999.
      RDUR(2,16,2)=9999.
C       PREPARE DISTRIBUTION FOR STATION B SERVICE DURATION
      RDUR(3,1,1)=0.00
      RDUR(3,2,1)=.1111
      RDUR(3,3,1)=.2222
      RDUR(3,4,1)=.3333
      RDUR(3,5,1)=.4444
      RDUR(3,6,1)=.5556
      RDUR(3,7,1)=.6667
      RDUR(3,8,1)=.7778
      RDUR(3,9,1)=.8889
      RDUR(3,10,1)=1.00
      RDUR(3,11,1)=1.00
      RDUR(3,12,1)=1.00
      RDUR(3,13,1)=1.00
      RDUR(3,14,1)=1.00
      RDUR(3,15,1)=1.00
      RDUR(3,16,1)=1.00
      RDUR(3,1,2)=.3791
      RDUR(3,2,2)=.3824
      RDUR(3,3,2)=.3889
      RDUR(3,4,2)=.4524
      RDUR(3,5,2)=.5000
      RDUR(3,6,2)=.5500
      RDUR(3,7,2)=.8109
      RDUR(3,8,2)=1.0570
      RDUR(3,9,2)=1.2749
      RDUR(3,10,2)=1.8681
      RDUR(3,11,2)=9999.
      RDUR(3,12,2)=9999.
      RDUR(3,13,2)=9999.
      RDUR(3,14,2)=9999.
      RDUR(3,15,2)=9999.
      RDUR(3,16,2)=9999.
```

```
C        PREPARE DISTRIBUTION FOR STATION C SERVICE DURATION
      RDUR(4,1,1)=0.00
      RDUR(4,2,1)=1./13.
      RDUR(4,3,1)=2./13.
      RDUR(4,4,1)=3./13.
      RDUR(4,5,1)=4./13.
      RDUR(4,6,1)=5./13.
      RDUR(4,7,1)=6./13.
      RDUR(4,8,1)=7./13.
      RDUR(4,9,1)=8./13.
      RDUR(4,10,1)=9./13.
      RDUR(4,11,1)=10./13.
      RDUR(4,12,1)=11./13.
      RDUR(4,13,1)=12/13.
      RDUR(4,14,1)=1.00
      RDUR(4,15,1)=1.00
      RDUR(4,16,1)=1.00
      RDUR(4,1,2)=.1586
      RDUR(4,2,2)=.2700
      RDUR(4,3,2)=.4929
      RDUR(4,4,2)=.5344
      RDUR(4,5,2)=.5500
      RDUR(4,6,2)=.6250
      RDUR(4,7,2)=.7446
      RDUR(4,8,2)=.7773
      RDUR(4,9,2)=.8017
      RDUR(4,10,2)=.8488
      RDUR(4,11,2)=.9196
      RDUR(4,12,2)=.9214
      RDUR(4,13,2)=1.6076
      RDUR(4,14,2)=1.8314
      RDUR(4,15,2)=9999.
      RDUR(4,16,2)=9999.
C        PREPARE DISTRIBUTION FOR FLIGHT DURATION
      RDUR(5,1,1)=0.00
      RDUR(5,2,1)=1./12.
      RDUR(5,3,1)=2./12.
      RDUR(5,4,1)=3./12.
      RDUR(5,5,1)=4./12.
      RDUR(5,6,1)=5./12.
      RDUR(5,7,1)=6./12.
      RDUR(5,8,1)=11./12.
      RDUR(5,9,1)=1.00
      RDUR(5,10,1)=1.00
      RDUR(5,11,1)=1.00
      RDUR(5,12,1)=1.00
      RDUR(5,13,1)=1.00
      RDUR(5,14,1)=1.00
      RDUR(5,15,1)=1.00
```

```
      RDUR(5,16,1)=1.00
      RDUR(5,1,2)=.9600
      RDUR(5,2,2)=1.12
      RDUR(5,3,2)=1.48
      RDUR(5,4,2)=2.23
      RDUR(5,5,2)=3.58
      RDUR(5,6,2)=3.87
      RDUR(5,7,2)=4.08
      RDUR(5,8,2)=6.40
      RDUR(5,9,2)=8.05
      RDUR(5,10,2)=9999.
      RDUR(5,11,2)=9999.
      RDUR(5,12,2)=9999.
      RDUR(5,13,2)=9999.
      RDUR(5,14,2)=9999.
      RDUR(5,15,2)=9999.
      RDUR(5,16,2)=9999.
C       PREPARE DISTRIBUTION FOR CHECK DURATION
      RDUR(6,1,1)=0.00
      RDUR(6,2,1)=3./54.
      RDUR(6,3,1)=5./54.
      RDUR(6,4,1)=9./54.
      RDUR(6,5,1)=16./54.
      RDUR(6,6,1)=27./54.
      RDUR(6,7,1)=32./54.
      RDUR(6,8,1)=36./54.
      RDUR(6,9,1)=42./54.
      RDUR(6,10,1)=46./54.
      RDUR(6,11,1)=49./54.
      RDUR(6,12,1)=52./54.
      RDUR(6,13,1)=53./54.
      RDUR(6,14,1)=53./54.
      RDUR(6,15,1)=53./54.
      RDUR(6,16,1)=1.00
      RDUR(6,1,2)=2.0000
      RDUR(6,2,2)=5.8667
      RDUR(6,3,2)=9.7333
      RDUR(6,4,2)=13.6000
      RDUR(6,5,2)=17.4667
      RDUR(6,6,2)=21.3333
      RDUR(6,7,2)=25.2000
      RDUR(6,8,2)=29.0666
      RDUR(6,9,2)=32.9333
      RDUR(6,10,2)=36.8000
      RDUR(6,11,2)=40.6666
      RDUR(6,12,2)=44.5333
      RDUR(6,13,2)=48.4000
      RDUR(6,14,2)=52.2666
      RDUR(6,15,2)=56.1333
```

```
      RDUR(6,16,2)=66.000
C       PREPARE DISTRIBUTION FOR PBO DURATION
      RDUR(7,1,1)=0.00
      RDUR(7,2,1)=0.00
      RDUR(7,3,1)=1./29.
      RDUR(7,4,1)=1./29.
      RDUR(7,5,1)=1./29.
      RDUR(7,6,1)=3./29.
      RDUR(7,7,1)=3./29.
      RDUR(7,8,1)=4./29.
      RDUR(7,9,1)=5./29.
      RDUR(7,10,1)=8./29.
      RDUR(7,11,1)=8./29.
      RDUR(7,12,1)=12./29.
      RDUR(7,13,1)=17./29.
      RDUR(7,14,1)=19./29.
      RDUR(7,15,1)=26./29.
      RDUR(7,16,1)=1.00
      RDUR(7,1,2)=.1200
      RDUR(7,2,2)=.1847
      RDUR(7,3,2)=.2493
      RDUR(7,4,2)=.3140
      RDUR(7,5,2)=.3787
      RDUR(7,6,2)=.4433
      RDUR(7,7,2)=.5080
      RDUR(7,8,2)=.5727
      RDUR(7,9,2)=.6373
      RDUR(7,10,2)=.7020
      RDUR(7,11,2)=.7667
      RDUR(7,12,2)=.8313
      RDUR(7,13,2)=.8960
      RDUR(7,14,2)=.9607
      RDUR(7,15,2)=1.0253
      RDUR(7,16,2)=1.0900
C       PREPARE DISTRIBUTION FOR DX DURATION
      RDUR(8,1,1)=0.00
      RDUR(8,2,1)=12./70.
      RDUR(8,3,1)=29./70.
      RDUR(8,4,1)=41./70.
      RDUR(8,5,1)=53./70.
      RDUR(8,6,1)=54./70.
      RDUR(8,7,1)=59./70.
      RDUR(8,8,1)=62./70.
      RDUR(8,9,1)=64./70.
      RDUR(8,10,1)=65./70.
      RDUR(8,11,1)=67./70.
      RDUR(8,12,1)=69./70.
      RDUR(8,13,1)=69./70.
      RDUR(8,14,1)=69./70.
```

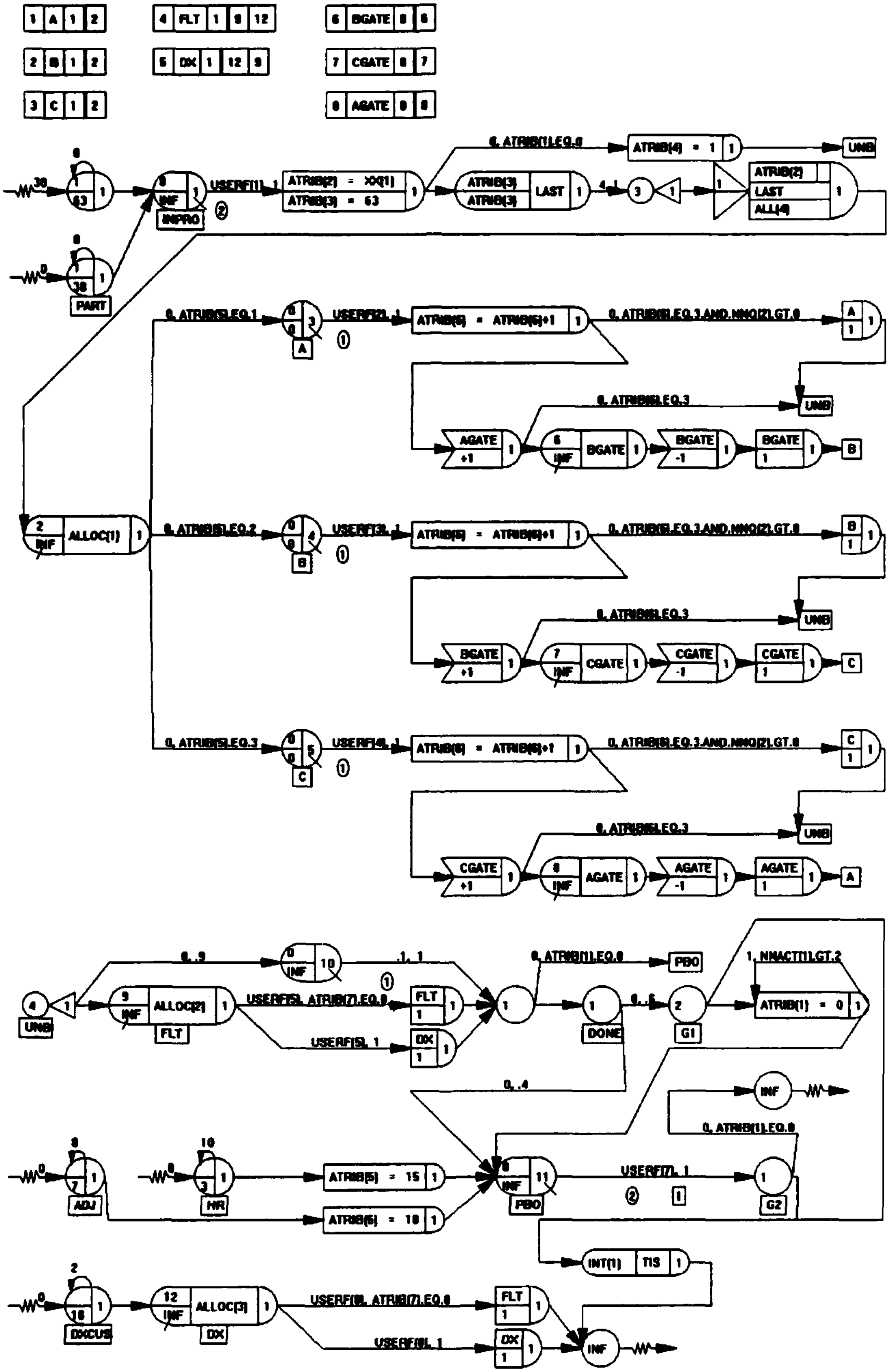
```
      RDUR(8,15,1)=1.00
      RDUR(8,16,1)=1.00
      RDUR(8,1,2)=.0850
      RDUR(8,2,2)=.8747
      RDUR(8,3,2)=1.6643
      RDUR(8,4,2)=2.4540
      RDUR(8,5,2)=3.2437
      RDUR(8,6,2)=4.0433
      RDUR(8,7,2)=4.8230
      RDUR(8,8,2)=5.6127
      RDUR(8,9,2)=6.4023
      RDUR(8,10,2)=7.1920
      RDUR(8,11,2)=7.9817
      RDUR(8,12,2)=8.7713
      RDUR(8,13,2)=9.5610
      RDUR(8,14,2)=10.3507
      RDUR(8,15,2)=11.1403
      RDUR(8,16,2)=11.9300
C       PREPARE DISTRIBUTION FOR STATION A SETUP DURATION
      RDUR(9,1,1)=0.00
      RDUR(9,2,1)=1./7.
      RDUR(9,3,1)=3./7.
      RDUR(9,4,1)=4./7.
      RDUR(9,5,1)=5./7.
      RDUR(9,6,1)=6./7.
      RDUR(9,7,1)=1.00
      RDUR(9,8,1)=1.00
      RDUR(9,9,1)=1.00
      RDUR(9,10,1)=1.00
      RDUR(9,11,1)=1.00
      RDUR(9,12,1)=1.00
      RDUR(9,13,1)=1.00
      RDUR(9,14,1)=1.00
      RDUR(9,15,1)=1.00
      RDUR(9,16,1)=1.00
      RDUR(9,1,2)=2.0813
      RDUR(9,2,2)=2.0859
      RDUR(9,3,2)=2.0952
      RDUR(9,4,2)=2.1357
      RDUR(9,5,2)=2.2222
      RDUR(9,6,2)=2.4571
      RDUR(9,7,2)=2.7000
      RDUR(9,8,2)=9999.
      RDUR(9,9,2)=9999.
      RDUR(9,10,2)=9999.
      RDUR(9,11,2)=9999.
      RDUR(9,12,2)=9999.
      RDUR(9,13,2)=9999.
      RDUR(9,14,2)=9999.
```

```
      RDUR(9,15,2)=9999.
      RDUR(9,16,2)=9999.
C       PREPARE DISTRIBUTION FOR STATION B SETUP DURATION
      RDUR(10,1,1)=0.00
      RDUR(10,2,1)=1./5.
      RDUR(10,3,1)=2./5.
      RDUR(10,4,1)=3./5.
      RDUR(10,5,1)=4./5.
      RDUR(10,6,1)=1.00
      RDUR(10,7,1)=1.00
      RDUR(10,8,1)=1.00
      RDUR(10,9,1)=1.00
      RDUR(10,10,1)=1.00
      RDUR(10,11,1)=1.00
      RDUR(10,12,1)=1.00
      RDUR(10,13,1)=1.00
      RDUR(10,14,1)=1.00
      RDUR(10,15,1)=1.00
      RDUR(10,16,1)=1.00
      RDUR(10,1,2)=.7769
      RDUR(10,2,2)=.7900
      RDUR(10,3,2)=.8162
      RDUR(10,4,2)=.8235
      RDUR(10,5,2)=1.0357
      RDUR(10,6,2)=1.4160
      RDUR(10,7,2)=9999.
      RDUR(10,8,2)=9999.
      RDUR(10,9,2)=9999.
      RDUR(10,10,2)=9999.
      RDUR(10,11,2)=9999.
      RDUR(10,12,2)=9999.
      RDUR(10,13,2)=9999.
      RDUR(10,14,2)=9999.
      RDUR(10,15,2)=9999.
      RDUR(10,16,2)=9999.
C       PREPARE DISTRIBUTION FOR STATION C SETUP DURATION
      RDUR(11,1,1)=0.00
      RDUR(11,2,1)=1./15.
      RDUR(11,3,1)=2./15.
      RDUR(11,4,1)=3./15.
      RDUR(11,5,1)=4./15.
      RDUR(11,6,1)=5./15.
      RDUR(11,7,1)=6./15.
      RDUR(11,8,1)=7./15.
      RDUR(11,9,1)=8./15.
      RDUR(11,10,1)=9./15.
      RDUR(11,11,1)=10./15.
      RDUR(11,12,1)=11./15.
      RDUR(11,13,1)=12./15.
```

```
      RDUR(11,14,1)=13./15.
      RDUR(11,15,1)=14./15.
      RDUR(11,16,1)=1.00
      RDUR(11,1,2)=.3444
      RDUR(11,2,2)=.5629
      RDUR(11,3,2)=1.0000
      RDUR(11,4,2)=1.8571
      RDUR(11,5,2)=1.9643
      RDUR(11,6,2)=2.0000
      RDUR(11,7,2)=2.3478
      RDUR(11,8,2)=2.3810
      RDUR(11,9,2)=2.4444
      RDUR(11,10,2)=2.8571
      RDUR(11,11,2)=2.8750
      RDUR(11,12,2)=3.0000
      RDUR(11,13,2)=3.0952
      RDUR(11,14,2)=3.2000
      RDUR(11,15,2)=3.2258
      RDUR(11,16,2)=3.3871
C       PREPARE DISTRIBUTION FOR PBO ADJUSTMENT DURATION
      RDUR(12,1,1)=0.00
      RDUR(12,2,1)=1./22.
      RDUR(12,3,1)=1./22.
      RDUR(12,4,1)=5./22.
      RDUR(12,5,1)=8./22.
      RDUR(12,6,1)=11./22.
      RDUR(12,7,1)=15./22.
      RDUR(12,8,1)=18./22.
      RDUR(12,9,1)=19./22.
      RDUR(12,10,1)=20./22.
      RDUR(12,11,1)=21./22.
      RDUR(12,12,1)=21./22.
      RDUR(12,13,1)=21./22.
      RDUR(12,14,1)=21./22.
      RDUR(12,15,1)=21./22.
      RDUR(12,16,1)=1.00
      RDUR(12,1,2)=1.27
      RDUR(12,2,2)=2.31
      RDUR(12,3,2)=3.35
      RDUR(12,4,2)=4.39
      RDUR(12,5,2)=5.43
      RDUR(12,6,2)=6.47
      RDUR(12,7,2)=7.51
      RDUR(12,8,2)=8.55
      RDUR(12,9,2)=9.59
      RDUR(12,10,2)=10.63
      RDUR(12,11,2)=11.67
      RDUR(12,12,2)=12.70
      RDUR(12,13,2)=13.74
```

```
      RDUR(12,14,2)=14.78
      RDUR(12,15,2)=15.82
      RDUR(12,16,2)=16.87
C       PREPARE DISTRIBUTION FOR PBO HAND RECEIPT DURATION
      RDUR(13,1,1)=0.00
      RDUR(13,2,1)=1./11.
      RDUR(13,3,1)=2./11.
      RDUR(13,4,1)=4./11.
      RDUR(13,5,1)=5./11.
      RDUR(13,6,1)=7./11.
      RDUR(13,7,1)=8./11.
      RDUR(13,8,1)=10./11
      RDUR(13,9,1)=1.00
      RDUR(13,10,1)=1.00
      RDUR(13,11,1)=1.00
      RDUR(13,12,1)=1.00
      RDUR(13,13,1)=1.00
      RDUR(13,14,1)=1.00
      RDUR(13,15,1)=1.00
      RDUR(13,16,1)=1.00
      RDUR(13,1,2)=1.16
      RDUR(13,2,2)=1.33
      RDUR(13,3,2)=1.66
      RDUR(13,4,2)=2.00
      RDUR(13,5,2)=2.27
      RDUR(13,6,2)=3.00
      RDUR(13,7,2)=4.00
      RDUR(13,8,2)=8.00
      RDUR(13,9,2)=12.50
      RDUR(13,10,2)=9999.
      RDUR(13,11,2)=9999.
      RDUR(13,12,2)=9999.
      RDUR(13,13,2)=9999.
      RDUR(13,14,2)=9999.
      RDUR(13,15,2)=9999.
      RDUR(13,16,2)=9999.
      RETURN
      END
```

Appendix E: SLAM Network and Source Code (Turn-in)



1 A 1 2
2 B 1 2
3 C 1 2
4 FLT 1 9 12
5 DX 1 12 9
6 BGATE 0 6
7 CGATE 0 7
8 AGATE 0 8
38
63
0
1
INF
INPRO
USERF(1), 1
②
ATRIB(2) = XX(1)
ATRIB(3) = 63
0, ATRIB(1).EQ.0
ATRIB(4) = 1
UNB
ATRIB(3)
ATRIB(3)
LAST
4, 1
3
ATRIB(2)
LAST
ALL(4)
PART
0, ATRIB(5).EQ.1
USERF(2), 1
①
A
ATRIB(6) = ATRIB(6)+1
0, ATRIB(6).EQ.3.AND.NNQ(2).GT.0
0, ATRIB(6).EQ.3
AGATE
+1
6
BGATE
-1
B
2
ALLOC(1)
0, ATRIB(5).EQ.2
4
USERF(3), 1
7
CGATE
C
0, ATRIB(5).EQ.3
5
USERF(4), 1
8
0, .9
10
.1, 1
0, ATRIB(1).EQ.0
PBO
1, NNACT(1).GT.2
4
UNB
9
ALLOC(2)
USERF(5), ATRIB(7).EQ.0
FLT
USERF(5), 1
DX
0, .6
DONE
G1
ATRIB(1) = 0
0, .4
ADJ
HR
ATRIB(5) = 15
ATRIB(5) = 18
11
USERF(7), 1
G2
INT(1)
TIS
DXCUS
16
12
ALLOC(3)
USERF(8), ATRIB(7).EQ.0
USERF(8), 1

SLAM Code for the Turn-In Model

```
GEN,MIKE AND CHRIS,THESIS,8/17/1994,100,N,N,Y/Y,N,Y/S,72;
LIMITS,12,7,200;
INTLC,XX(1)=9,XX(2)=4,XX(3)=4,XX(4)=4,XX(8)=5,XX(9)=19;
INITIALIZE,,,Y;
NETWORK;
       RESOURCE/1,A,2;
       RESOURCE/2,B,2;
       RESOURCE/3,C,2;
       RESOURCE/4,FLT,9,12;
       RESOURCE/5,DX(1),12,9;
       RESOURCE/6,BGATE(0),6;
       RESOURCE/7,CGATE(0),7;
       RESOURCE/8,AGATE(0),8;
;
       CREATE,0,30,1,63,1;
       ACTIVITY;
INPRO  QUEUE(1),,,;
       ACTIVITY(2),USERF(1);
       ASSIGN,ATRIB(2)=XX(1),ATRIB(3)=63,1;
       ACTIVITY,,ATRIB(1).EQ.0;
       ACTIVITY,,,ZAAO;
       ASSIGN,ATRIB(4)=1,1;
       ACTIVITY,,,UNB;
ZAAO   ACCUMULATE,ATRIB(3),ATRIB(3),,1;
       ACTIVITY,4;
       UNBATCH,3,1;
       ACTIVITY;
       BATCH,1,ATRIB(2),,,ALL(4),1;
       ACTIVITY;
       AWAIT(2),ALLOC(1),,1;
       ACTIVITY,,ATRIB(5).EQ.1;
       ACTIVITY,,ATRIB(5).EQ.2,B;
       ACTIVITY,,ATRIB(5).EQ.3,C;
A      QUEUE(3),,0,;
       ACTIVITY(1),USERF(2);
       ASSIGN,ATRIB(6)=ATRIB(6)+1,1;
       ACTIVITY,,ATRIB(6).EQ.3.AND.NNQ(2).GT.0;
       ACTIVITY,,,ZAAL;
       FREE,A,1;
       ACTIVITY,,,UNB;
ZAAL   ALTER,AGATE,+1,1;
       ACTIVITY,,ATRIB(6).EQ.3,UNB;
       ACTIVITY;
       AWAIT(6),BGATE,,1;
       ACTIVITY;
       ALTER,BGATE,-1,1;
       ACTIVITY;
```

```
        FREE,BGATE,1;
        ACTIVITY,,,B;
B       QUEUE(4),,0,;
        ACTIVITY(1),USERF(3);
        ASSIGN,ATRIB(6)=ATRIB(6)+1,1;
        ACTIVITY,,ATRIB(6).EQ.3.AND.NNQ(2).GT.0;
        ACTIVITY,,,ZAAM;
        FREE,B,1;
        ACTIVITY,,,UNB;
ZAAM    ALTER,BGATE,+1,1;
        ACTIVITY,,ATRIB(6).EQ.3,UNB;
        ACTIVITY;
        AWAIT(7),CGATE,,1;
        ACTIVITY;
        ALTER,CGATE,-1,1;
        ACTIVITY;
        FREE,CGATE,1;
        ACTIVITY,,,C;
C       QUEUE(5),,0,;
        ACTIVITY(1),USERF(4);
        ASSIGN,ATRIB(6)=ATRIB(6)+1,1;
        ACTIVITY,,ATRIB(6).EQ.3.AND.NNQ(2).GT.0;
        ACTIVITY,,,ZAAN;
        FREE,C,1;
        ACTIVITY,,,UNB;
ZAAN    ALTER,CGATE,+1,1;
        ACTIVITY,,ATRIB(6).EQ.3,UNB;
        ACTIVITY;
        AWAIT(8),AGATE,,1;
        ACTIVITY;
        ALTER,AGATE,-1,1;
        ACTIVITY;
        FREE,AGATE,1;
        ACTIVITY,,,A;
;
PART    CREATE,0,,1,38,1;
        ACTIVITY,,,INPR;
;
UNB     UNBATCH,4,1;
        ACTIVITY,,.9;
        ACTIVITY,,,FLT;
        QUEUE(10),,,;
        ACTIVITY(1),.1;
ZAAR    GOON,1;
        ACTIVITY,,ATRIB(1).EQ.0,PBO;
        ACTIVITY;
DONE    GOON,1;
        ACTIVITY,,.6;
        ACTIVITY,,.4,PBO;
G1      GOON,2;
```

```
      ACTIVITY;
      ACTIVITY,,,ZAAP;
ZAAQ  COLCT,INT(1),TIS,,1;
      ACTIVITY;
ZAAT  TERMINATE;
ZAAP  ASSIGN,ATRIB(1)=0,1;
      ACTIVITY,2,NNACT(1).GT.3,ZAAP;
      ACTIVITY;
PBO   QUEUE(11),,,;
      ACTIVITY(3)/1,USERF(7);
G2    GOON,1;
      ACTIVITY,,ATRIB(1).EQ.0;
      ACTIVITY,,,ZAAQ;
      TERMINATE;
FLT   AWAIT(9),ALLOC(2),,1;
      ACTIVITY,USERF(5),ATRIB(7).EQ.0;
      ACTIVITY,USERF(5),,ZAAS;
      FREE,FLT,1;
      ACTIVITY,,,ZAAR;
ZAAS  FREE,DX,1;
      ACTIVITY,,,ZAAR;
;
HR    CREATE,10,,,3,1;
      ACTIVITY;
      ASSIGN,ATRIB(5)=15,1;
      ACTIVITY,,,PBO;
;
ADJ   CREATE,8,,,7,1;
      ACTIVITY;
      ASSIGN,ATRIB(5)=10,1;
      ACTIVITY,,,PBO;
;
DXCUS CREATE,2,,,16,1;
      ACTIVITY;
DX    AWAIT(12),ALLOC(3),,1;
      ACTIVITY,USERF(8),ATRIB(7).EQ.0;
      ACTIVITY,USERF(8),,ZAAU;
      FREE,FLT,1;
      ACTIVITY,,,ZAAT;
ZAAU  FREE,DX,1;
      ACTIVITY,,,ZAAT;
      END;
FIN;
```

FORTRAN Code for the Turn-In Model

```
      PROGRAM MAIN
      DIMENSION NSET(50000)
      PARAMETER  (MEQT=100,  MSCND=25,  MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100,  MNODE=500, MITYP=50,
     4 MMXXV=100)
      PARAMETER (MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
      COMMON QSET(50000)
      EQUIVALENCE (NSET(1),QSET(1))
      OPEN (1,FILE='GLM94S:[MGARRITY]TR.DAT',STATUS='OLD',
     1 ACCESS='APPEND')
      NNSET=50000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      CLOSE (1)
      STOP
      END
C
C
      SUBROUTINE ALLOC(IFN,IFLAG)
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
      IFLAG = 0
      GO TO (1,2,3),IFN
C    SEND BATCHES TO COUNTERS A,B,C AS AVAILABLE
1     IF (NNQ(2).GT.0) THEN
        IF (NNRSC(1).LE.0.AND.NNRSC(2).LE.0.AND.
     2         NNRSC(3).LE.0) THEN
          GO TO 101
        ELSE IF (NNRSC(1).GT.0) THEN
          CALL SEIZE(1,1)
          ATRIB(5) = 1
        ELSE IF (NNRSC(2).GT.0) THEN
          CALL SEIZE(2,1)
```

```
          ATRIB(5) = 2
        ELSE
          CALL SEIZE(3,1)
          ATRIB(5) = 3
        ENDIF
        IFLAG = 1
      ENDIF
101   RETURN
C
C
C    FLIGHT CUSTOMERS USE FLIGHT/DX SERVERS WHEN AVAILABLE
2     IF (NNQ(9).GT.0) THEN
        IF (NNRSC(4).LE.0.AND.NNRSC(5).LE.0) THEN
          GO TO 201
        ELSE IF (NNRSC(4).GT.0) THEN
          CALL SEIZE(4,1)
        ELSE
          CALL SEIZE(5,1)
          ATRIB(7) = 1
        ENDIF
        IFLAG = 1
      ENDIF
201   RETURN
C
C
C    DX CUSTOMERS USE DX/FLIGHT SERVERS WHEN AVAILABLE
3     IF (NNQ(12).GT.0) THEN
        IF (NNRSC(4).LE.0.AND.NNRSC(5).LE.0) THEN
          GO TO 301
        ELSE IF (NNRSC(5).GT.0) THEN
          CALL SEIZE(5,1)
          ATRIB(7) = 1
        ELSE
          CALL SEIZE(4,1)
        ENDIF
        IFLAG = 1
      ENDIF
301   RETURN
      END
C
C
      FUNCTION USERF(IFN)
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      PARAMETER (MVARP1=MVARP+1)
```

```
       COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
      1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
      2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
       COMMON QSET(15000)
       COMMON/UCOM1/RDUR(13,16,2)
       R=DRAND(IFN)
       IF (ATRIB(5).LT.4) THEN
C        ESTABLISH A B C DURATION
         I=2
50       CONTINUE
         IF (I.LE.16) THEN
           IF (R.LE.RDUR(IFN,I,1)) THEN
             S=RDUR(IFN,I-1,2)+(RDUR(IFN,I,2)-RDUR(IFN,I-
      1         1,2))*((R-RDUR(IFN,I-1,1))/(RDUR(IFN,I,1)-
      2         RDUR(IFN,I-1,1)))
               IF (IFN.EQ.2) THEN
                 USERF=4.92+S*XX(1)/XX(2)
               ELSE IF (IFN.EQ.3) THEN
                 USERF=2.50+S*XX(1)/XX(3)
               ELSE IF (IFN.EQ.4) THEN
                 USERF=3.25+S*XX(1)/XX(4)
               ELSE
                 USERF=S
               ENDIF
             I=99
           ENDIF
           I=I+1
           GO TO 50
         ENDIF
       ELSE IF (ATRIB(5).EQ.10) THEN
C        ESTABLISH DURATION FOR ADJUSTMENTS AT PBO
         I=2
150      CONTINUE
         IF (I.LE.16) THEN
           IF (R.LE.RDUR(12,I,1)) THEN
             USERF=RDUR(12,I-1,2)+(RDUR(12,I,2)-RDUR(12,I-
      1         1,2))*((R-RDUR(12,I-1,1))/(RDUR(12,I,1)-
      2         RDUR(12,I-1,1)))
             I=99
           ENDIF
         I=I+1
         GO TO 150
         ENDIF
       ELSE IF (ATRIB(5).EQ.15) THEN
C        ESTABLISH DURATION FOR HAND RECEIPTS AT PBO
         I=2
200      CONTINUE
         IF (I.LE.16) THEN
           IF (R.LE.RDUR(13,I,1)) THEN
```

```
            USERF=RDUR(13,I-1,2)+(RDUR(13,I,2)-RDUR(13,I-
     1         1,2))*((R-RDUR(13,I-1,1))/(RDUR(13,I,1)-
     2         RDUR(13,I-1,1)))
            I=99
          ENDIF
        I=I+1
        GO TO 200
        ENDIF
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE OTPUT
      PARAMETER  (MEQT=100, MSCND=25, MENTR=25, MRSC=75,
     1 MARR=50, MGAT=25, MHIST=50, MCELS=500, MCLCT=50,
     2 MSTAT=50, MEQV=100, MATRB=100, MFILS=100, MPLOT=10,
     3 MVARP=10, MSTRM=10, MACT=100, MNODE=500, MITYP=50,
     4 MMXXV=100)
      COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW,
     1 II, MFA, MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2 NTAPE, SS(MEQT), SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
C       SET UP OUTPUT FOR ANALYSIS
      IF (XX(9).LT.20) THEN
        WRITE(1,1000) XX(9), XX(8), XX(1), CCAVG(1),CCSTD(1)
1000    FORMAT(' ',F8.0,F8.0,F8.0,F10.2,F10.2)
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE INTLC
      COMMON/UCOM1/RDUR(13,16,2)
C       PREPARE DISTRIBUTION FOR INPROCESSING DURATION
      RDUR(1,1,1)=0.00
      RDUR(1,2,1)=7./34.
      RDUR(1,3,1)=14./34.
      RDUR(1,4,1)=24./34.
      RDUR(1,5,1)=26./34.
      RDUR(1,6,1)=31./34.
      RDUR(1,7,1)=31./34.
      RDUR(1,8,1)=31./34.
      RDUR(1,9,1)=31./34.
      RDUR(1,10,1)=31./34.
      RDUR(1,11,1)=33./34.
      RDUR(1,12,1)=33./34.
      RDUR(1,13,1)=33./34.
      RDUR(1,14,1)=33./34
      RDUR(1,15,1)=33./34
      RDUR(1,16,1)=1.00
```

```
      RDUR(1,1,2)=.240
      RDUR(1,2,2)=.357
      RDUR(1,3,2)=.474
      RDUR(1,4,2)=.591
      RDUR(1,5,2)=.708
      RDUR(1,6,2)=.825
      RDUR(1,7,2)=.942
      RDUR(1,8,2)=1.059
      RDUR(1,9,2)=1.176
      RDUR(1,10,2)=1.293
      RDUR(1,11,2)=1.410
      RDUR(1,12,2)=1.527
      RDUR(1,13,2)=1.644
      RDUR(1,14,2)=1.761
      RDUR(1,15,2)=1.878
      RDUR(1,16,2)=1.995
C       PREPARE DISTRIBUTION FOR STATION A SERVICE DURATION
      RDUR(2,1,1)=0.00
      RDUR(2,2,1)=2./16.
      RDUR(2,3,1)=3./16.
      RDUR(2,4,1)=4./16.
      RDUR(2,5,1)=5./16.
      RDUR(2,6,1)=6./16.
      RDUR(2,7,1)=7./16.
      RDUR(2,8,1)=8./16.
      RDUR(2,9,1)=9./16.
      RDUR(2,10,1)=10./16.
      RDUR(2,11,1)=11./16.
      RDUR(2,12,1)=12./16.
      RDUR(2,13,1)=13./16.
      RDUR(2,14,1)=14./16.
      RDUR(2,15,1)=15./16.
      RDUR(2,16,1)=1.00
      RDUR(2,1,2)=2.0530
      RDUR(2,2,2)=2.1350
      RDUR(2,3,2)=2.2700
      RDUR(2,4,2)=2.3850
      RDUR(2,5,2)=2.5400
      RDUR(2,6,2)=3.5829
      RDUR(2,7,2)=3.6240
      RDUR(2,8,2)=3.7600
      RDUR(2,9,2)=4.0539
      RDUR(2,10,2)=4.3624
      RDUR(2,11,2)=4.4259
      RDUR(2,12,2)=4.5120
      RDUR(2,13,2)=5.0400
      RDUR(2,14,2)=5.4783
      RDUR(2,15,2)=5.5357
      RDUR(2,16,2)=6.5959
C       PREPARE DISTRIBUTION FOR STATION B SERVICE DURATION
```

```
      RDUR(3,1,1)=0.00
      RDUR(3,2,1)=1./15.
      RDUR(3,3,1)=2./15.
      RDUR(3,4,1)=3./15.
      RDUR(3,5,1)=4./15.
      RDUR(3,6,1)=5./15.
      RDUR(3,7,1)=6./15.
      RDUR(3,8,1)=7./15.
      RDUR(3,9,1)=8./15.
      RDUR(3,10,1)=9./15.
      RDUR(3,11,1)=10./15.
      RDUR(3,12,1)=11./15.
      RDUR(3,13,1)=12./15.
      RDUR(3,14,1)=13./15
      RDUR(3,15,1)=14./15.
      RDUR(3,16,1)=1.00
      RDUR(3,1,2)=1.2768
      RDUR(3,2,2)=1.3095
      RDUR(3,3,2)=1.3750
      RDUR(3,4,2)=1.7059
      RDUR(3,5,2)=2.0000
      RDUR(3,6,2)=2.5500
      RDUR(3,7,2)=3.1250
      RDUR(3,8,2)=3.2143
      RDUR(3,9,2)=3.3571
      RDUR(3,10,2)=3.7500
      RDUR(3,11,2)=3.7857
      RDUR(3,12,2)=4.2926
      RDUR(3,13,2)=4.5000
      RDUR(3,14,2)=5.5000
      RDUR(3,15,2)=6.5000
      RDUR(3,16,2)=15.5000
C       PREPARE DISTRIBUTION FOR STATION C SERVICE DURATION
      RDUR(4,1,1)=0.00
      RDUR(4,2,1)=2./20.
      RDUR(4,3,1)=3./20.
      RDUR(4,4,1)=4./20.
      RDUR(4,5,1)=5./20.
      RDUR(4,6,1)=6./20.
      RDUR(4,7,1)=8./20.
      RDUR(4,8,1)=9./20.
      RDUR(4,9,1)=12./20
      RDUR(4,10,1)=13./20.
      RDUR(4,11,1)=14./20.
      RDUR(4,12,1)=15./20.
      RDUR(4,13,1)=16./20.
      RDUR(4,14,1)=17./20.
      RDUR(4,15,1)=19./20.
      RDUR(4,16,1)=1.00
      RDUR(4,1,2)=.5595
```

```
      RDUR(4,2,2)=.8333
      RDUR(4,3,2)=1.1071
      RDUR(4,4,2)=1.3500
      RDUR(4,5,2)=1.4375
      RDUR(4,6,2)=1.6875
      RDUR(4,7,2)=2.1071
      RDUR(4,8,2)=2.5938
      RDUR(4,9,2)=2.8214
      RDUR(4,10,2)=2.9063
      RDUR(4,11,2)=3.0238
      RDUR(4,12,2)=3.6031
      RDUR(4,13,2)=4.5222
      RDUR(4,14,2)=4.7500
      RDUR(4,15,2)=5.8500
      RDUR(4,16,2)=7.2000
C       PREPARE DISTRIBUTION FOR FLIGHT DURATION
      RDUR(5,1,1)=0.00
      RDUR(5,2,1)=1./16.
      RDUR(5,3,1)=2./16.
      RDUR(5,4,1)=3./16.
      RDUR(5,5,1)=4./16.
      RDUR(5,6,1)=5./16.
      RDUR(5,7,1)=6./16.
      RDUR(5,8,1)=7./16.
      RDUR(5,9,1)=9./16.
      RDUR(5,10,1)=10./16.
      RDUR(5,11,1)=11./16.
      RDUR(5,12,1)=12./16.
      RDUR(5,13,1)=13./16.
      RDUR(5,14,1)=14./16.
      RDUR(5,15,1)=15./16.
      RDUR(5,16,1)=1.00
      RDUR(5,1,2)=.56
      RDUR(5,2,2)=.78
      RDUR(5,3,2)=1.22
      RDUR(5,4,2)=1.47
      RDUR(5,5,2)=1.53
      RDUR(5,6,2)=1.77
      RDUR(5,7,2)=1.88
      RDUR(5,8,2)=2.07
      RDUR(5,9,2)=2.28
      RDUR(5,10,2)=2.53
      RDUR(5,11,2)=3.25
      RDUR(5,12,2)=4.03
      RDUR(5,13,2)=4.08
      RDUR(5,14,2)=4.50
      RDUR(5,15,2)=5.33
      RDUR(5,16,2)=6.83
C       PREPARE DISTRIBUTION FOR PBO DURATION
      RDUR(7,1,1)=0.00
```

```
      RDUR(7,2,1)=1./24.
      RDUR(7,3,1)=2./24.
      RDUR(7,4,1)=3./24.
      RDUR(7,5,1)=4./24.
      RDUR(7,6,1)=5./24.
      RDUR(7,7,1)=6./24.
      RDUR(7,8,1)=8./24.
      RDUR(7,9,1)=12./24.
      RDUR(7,10,1)=14./24.
      RDUR(7,11,1)=17./24.
      RDUR(7,12,1)=18./24.
      RDUR(7,13,1)=19./24.
      RDUR(7,14,1)=21./24.
      RDUR(7,15,1)=22./24.
      RDUR(7,16,1)=1.00
      RDUR(7,1,2)=.09
      RDUR(7,2,2)=.18
      RDUR(7,3,2)=.37
      RDUR(7,4,2)=.42
      RDUR(7,5,2)=.53
      RDUR(7,6,2)=.58
      RDUR(7,7,2)=.72
      RDUR(7,8,2)=.78
      RDUR(7,9,2)=.87
      RDUR(7,10,2)=.97
      RDUR(7,11,2)=1.08
      RDUR(7,12,2)=1.28
      RDUR(7,13,2)=1.38
      RDUR(7,14,2)=1.52
      RDUR(7,15,2)=1.57
      RDUR(7,16,2)=5.36
C        PREPARE DISTRIBUTION FOR DX DURATION
      RDUR(8,1,1)=0.00
      RDUR(8,2,1)=12./70.
      RDUR(8,3,1)=29./70.
      RDUR(8,4,1)=41./70.
      RDUR(8,5,1)=53./70.
      RDUR(8,6,1)=54./70.
      RDUR(8,7,1)=59./70.
      RDUR(8,8,1)=62./70.
      RDUR(8,9,1)=64./70.
      RDUR(8,10,1)=65./70.
      RDUR(8,11,1)=67./70.
      RDUR(8,12,1)=69./70.
      RDUR(8,13,1)=69./70.
      RDUR(8,14,1)=69./70.
      RDUR(8,15,1)=1.00
      RDUR(8,16,1)=1.00
      RDUR(8,1,2)=.0850
      RDUR(8,2,2)=.8747
```

```
      RDUR(8,3,2)=1.6643
      RDUR(8,4,2)=2.4540
      RDUR(8,5,2)=3.2437
      RDUR(8,6,2)=4.0433
      RDUR(8,7,2)=4.8230
      RDUR(8,8,2)=5.6127
      RDUR(8,9,2)=6.4023
      RDUR(8,10,2)=7.1920
      RDUR(8,11,2)=7.9817
      RDUR(8,12,2)=8.7713
      RDUR(8,13,2)=9.5610
      RDUR(8,14,2)=10.3507
      RDUR(8,15,2)=11.1403
      RDUR(8,16,2)=11.9300
C       PREPARE DISTRIBUTION FOR PBO ADJUSTMENT DURATION
      RDUR(12,1,1)=0.00
      RDUR(12,2,1)=1./22.
      RDUR(12,3,1)=1./22.
      RDUR(12,4,1)=5./22.
      RDUR(12,5,1)=8./22.
      RDUR(12,6,1)=11./22.
      RDUR(12,7,1)=15./22.
      RDUR(12,8,1)=18./22.
      RDUR(12,9,1)=19./22.
      RDUR(12,10,1)=20./22.
      RDUR(12,11,1)=21./22.
      RDUR(12,12,1)=21./22.
      RDUR(12,13,1)=21./22.
      RDUR(12,14,1)=21./22.
      RDUR(12,15,1)=21./22.
      RDUR(12,16,1)=1.00
      RDUR(12,1,2)=1.27
      RDUR(12,2,2)=2.31
      RDUR(12,3,2)=3.35
      RDUR(12,4,2)=4.39
      RDUR(12,5,2)=5.43
      RDUR(12,6,2)=6.47
      RDUR(12,7,2)=7.51
      RDUR(12,8,2)=8.55
      RDUR(12,9,2)=9.59
      RDUR(12,10,2)=10.63
      RDUR(12,11,2)=11.67
      RDUR(12,12,2)=12.70
      RDUR(12,13,2)=13.74
      RDUR(12,14,2)=14.78
      RDUR(12,15,2)=15.82
      RDUR(12,16,2)=16.87
C       PREPARE DISTRIBUTION FOR PBO HAND RECEIPT DURATION
      RDUR(13,1,1)=0.00
      RDUR(13,2,1)=1./11.
```

```
RDUR(13,3,1)=2./11.
RDUR(13,4,1)=4./11.
RDUR(13,5,1)=5./11.
RDUR(13,6,1)=7./11.
RDUR(13,7,1)=8./11.
RDUR(13,8,1)=10./11
RDUR(13,9,1)=1.00
RDUR(13,10,1)=1.00
RDUR(13,11,1)=1.00
RDUR(13,12,1)=1.00
RDUR(13,13,1)=1.00
RDUR(13,14,1)=1.00
RDUR(13,15,1)=1.00
RDUR(13,16,1)=1.00
RDUR(13,1,2)=1.16
RDUR(13,2,2)=1.33
RDUR(13,3,2)=1.66
RDUR(13,4,2)=2.00
RDUR(13,5,2)=2.27
RDUR(13,6,2)=3.00
RDUR(13,7,2)=4.00
RDUR(13,8,2)=8.00
RDUR(13,9,2)=12.50
RDUR(13,10,2)=9999.
RDUR(13,11,2)=9999.
RDUR(13,12,2)=9999.
RDUR(13,13,2)=9999.
RDUR(13,14,2)=9999.
RDUR(13,15,2)=9999.
RDUR(13,16,2)=9999.
RETURN
END
```

Appendix F: Scheffé Comparisons of Batch Sizes

MANNING LEVEL OF 19

```
     SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                                HOMOGENEOUS
  BATCH        MEAN             GROUPS
---------   ----------      -----------
    21        157.53         I
     7        138.26        .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.4962
STANDARD ERROR FOR COMPARISON    0.7615

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL OF 18

```
     SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                                HOMOGENEOUS
  BATCH        MEAN             GROUPS
---------   ----------      -----------
    21        160.05         I
     7        139.53        .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.4844
STANDARD ERROR FOR COMPARISON    0.7555

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 17

```
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH        MEAN          GROUPS
---------    ----------     -----------
    21         161.08        I
     7         152.34       .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.5213
STANDARD ERROR FOR COMPARISON    0.7742

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 16

```
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH        MEAN          GROUPS
---------    ----------     -----------
    21         175.90        I
     7         153.88       .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.5530
STANDARD ERROR FOR COMPARISON    0.7904

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 15

```
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH        MEAN          GROUPS
---------    ----------     -----------
    21         177.37        I
     7         155.12       .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.5308
STANDARD ERROR FOR COMPARISON    0.7791

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 14

```
        SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
   BATCH        MEAN       GROUPS
 ---------   ----------   -----------
     21        181.86      I
      7        156.63     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.5872
STANDARD ERROR FOR COMPARISON    0.8078

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 13

```
        SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
   BATCH        MEAN       GROUPS
 ---------   ----------   -----------
     21        187.42      I
      7        159.29     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.6518
STANDARD ERROR FOR COMPARISON    0.8406

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 12

```
        SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
   BATCH        MEAN       GROUPS
 ---------   ----------   -----------
     21        191.29      I
      7        163.35     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                  3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON    1.6298
STANDARD ERROR FOR COMPARISON    0.8295

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 11

```
      SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH         MEAN         GROUPS
---------    ----------    -----------
    21         196.79        I
     7         166.25      .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                     3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON       1.6338
STANDARD ERROR FOR COMPARISON       0.8315

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 10

```
      SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH         MEAN         GROUPS
---------    ----------    -----------
    21         205.48        I
     7         173.95      .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                     3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON       1.6403
STANDARD ERROR FOR COMPARISON       0.8348

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 9

```
      SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                             HOMOGENEOUS
  BATCH         MEAN         GROUPS
---------    ----------    -----------
    21         218.10        I
     7         187.54      .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                     3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON       1.7058
STANDARD ERROR FOR COMPARISON       0.8681

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 8

```
     SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
  BATCH        MEAN        GROUPS
---------   ----------   -----------
    21        222.57       I
     7        195.68     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                    3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON      1.8168
STANDARD ERROR FOR COMPARISON      0.9246

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 7

```
     SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
  BATCH        MEAN        GROUPS
---------   ----------   -----------
    21        247.14       I
     7        222.11     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                    3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON      2.1871
STANDARD ERROR FOR COMPARISON      1.1131

ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

MANNING LEVEL = 6

```
     SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY BATCH
                           HOMOGENEOUS
  BATCH        MEAN        GROUPS
---------   ----------   -----------
    21        267.33       I
     7        238.86     .. I

ALL 2 MEANS ARE SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

CRITICAL F VALUE                    3.860    REJECTION LEVEL
0.050
CRITICAL VALUE FOR COMPARISON      2.4653
STANDARD ERROR FOR COMPARISON      1.2547
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

Appendix G: Scheffé Comparisons of Heuristics

MANNING LEVEL OF 19

```
                 COMBINED BATCH SIZES
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN      HOMOGENEOUS GROUPS
---------   ----------   -----------
    1         171.10      I
    2         143.41     .. I
    3         142.60     .. I
    5         142.60     .. I
    4         139.76     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     3.7230
STANDARD ERROR FOR COMPARISON     1.2040
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                   BATCH SIZE = 21
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN     HOMOGENEOUS GROUPS
---------   ----------   -----------
    1         180.02      I
    2         154.50     .. I
    3         152.17     .. I
    5         152.17     .. I
    4         148.79     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      6.1158
STANDARD ERROR FOR COMPARISON      1.9703
```

```
                   BATCH SIZE = 7
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN     HOMOGENEOUS GROUPS
---------   ----------   -----------
    1         162.18      I
    3         133.03     .. I
    5         133.03     .. I
    2         132.33     .. I
    4         130.73     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.2972
STANDARD ERROR FOR COMPARISON      1.3844
```

MANNING LEVEL OF 18

```
                   COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
     1        172.57    I
     3        149.11   .. I
     2        143.41   .... I
     5        142.60   .... I
     4        141.25   .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     3.6936
STANDARD ERROR FOR COMPARISON     1.1945
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                     BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     1        182.21    I
     3        160.30   .. I
     2        154.50   .. I I
     5        152.17   .... I
     4        151.08   .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      6.1099
STANDARD ERROR FOR COMPARISON      1.9685
```

```
                     BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     1        162.93    I
     3        137.93   .. I
     5        133.03   .... I
     2        132.33   .... I
     4        131.42   .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.2022
STANDARD ERROR FOR COMPARISON      1.3538
```

MANNING LEVEL = 17

```
                     COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC     MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        172.57     I
    4        158.72    .. I
    5        158.58    .. I
    3        149.04    .... I
    2        144.66    ...... I

THERE ARE 4 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     3.7853
STANDARD ERROR FOR COMPARISON     1.2242
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                        BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        182.21     I
    3        160.14    .. I
    2        155.62    .. I I
    4        154.50    .. I I
    5        152.94    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      6.1777
STANDARD ERROR FOR COMPARISON      1.9903
```

```
                        BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    5        164.22     I
    1        162.93     I
    4        162.93     I
    3        137.93    .. I
    2        133.69    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.4260
STANDARD ERROR FOR COMPARISON      1.4259
```

MANNING LEVEL = 16

```
                     COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
     1        174.61     I
     4        174.61     I
     5        174.23     I
     3        153.48    .. I
     2        147.52    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     3.8643
STANDARD ERROR FOR COMPARISON     1.2497
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                          BATCH = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     1        185.69     I
     4        185.69     I
     5        184.25     I
     3        164.29    .. I
     2        159.58    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      6.5680
STANDARD ERROR FOR COMPARISON      2.1161
```

```
                       BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     5        164.22     I
     1        163.53     I
     4        163.53     I
     3        142.67    .. I
     2        135.47    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.1293
STANDARD ERROR FOR COMPARISON      1.3304
```

MANNING LEVEL = 15

```
                  COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------   ----------  -----------
     4        176.02     I
     1        175.80     I
     5        175.56     I
     3        153.48    .. I
     2        150.35    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     3.8090
STANDARD ERROR FOR COMPARISON     1.2319
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                    BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     1        186.73     I
     4        186.73     I
     5        186.73     I
     3        164.29    .. I
     2        162.35    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      6.4574
STANDARD ERROR FOR COMPARISON      2.0804
```

```
                    BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     4        165.32     I
     1        164.88     I
     5        164.39     I
     3        142.67    .. I
     2        138.35    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.0967
STANDARD ERROR FOR COMPARISON      1.3198
```

MANNING LEVEL = 14

```
                    COMBINED BATCH SIZES
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------   ----------  -----------
    1         178.82     I
    4         178.16     I
    5         175.80     I
    2         158.55    .. I
    3         154.90    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      3.9493
STANDARD ERROR FOR COMPARISON      1.2772
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                      BATCH SIZE = 21
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
    1         191.00     I
    4         191.00     I
    5         186.73     I
    2         173.85    .. I
    3         166.71    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       6.8547
STANDARD ERROR FOR COMPARISON       2.2084
```

```
                      BATCH SIZE = 7
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
    1         166.65     I
    4         165.32     I
    5         164.88     I
    2         143.25    .. I
    3         143.08    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       3.9849
STANDARD ERROR FOR COMPARISON       1.2838
```

MANNING LEVEL = 13

```
                        COMBINED BATCH SIZES
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN      HOMOGENEOUS GROUPS
---------  ----------  -----------
    5        181.94      I
    1        181.66      I
    4        180.13      I
    3        164.51    .. I
    2        158.55    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.1100
STANDARD ERROR FOR COMPARISON      1.3292
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                          BATCH SIZE = 21
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
    5        198.95      I
    1        193.61      I
    4        193.61      I
    3        177.10    .. I
    2        173.85    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       7.3102
STANDARD ERROR FOR COMPARISON       2.3552
```

```
                          BATCH SIZE = 7
    SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        169.70      I
    4        166.65      I I
    5        164.93    .. I
    3        151.92    .... I
    2        143.25    ...... I

THERE ARE 4 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       3.8273
STANDARD ERROR FOR COMPARISON       1.2330
```

MANNING LEVEL = 12

```
                 COMBINED BATCH SIZES
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC     MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        189.86     I
    5        185.17    .. I
    4        182.82    .. I
    3        164.51    .... I
    2        164.25    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.0555
STANDARD ERROR FOR COMPARISON      1.3116
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                    BATCH SIZE = 21
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        205.13     I
    5        198.94     I I
    4        193.61    .. I
    2        181.78    .... I
    3        176.97    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       7.2735
STANDARD ERROR FOR COMPARISON       2.3434
```

```
                    BATCH SIZE = 7
  SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        174.58     I
    4        172.02     I
    5        171.41     I
    3        152.04    .. I
    2        146.72    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       3.6591
STANDARD ERROR FOR COMPARISON       1.1789
```

MANNING LEVEL = 11

```
                      COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC     MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
     1       195.54     I
     4       189.86    .. I
     5       186.81    .. I
     2       170.88    .... I
     3       164.51    ...... I

THERE ARE 4 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.0653
STANDARD ERROR FOR COMPARISON      1.3148
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                        BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     1       213.07     I
     4       205.13    .. I
     5       201.27    .. I
     2       187.48    .... I
     3       176.97    ...... I

THERE ARE 4 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       7.3387
STANDARD ERROR FOR COMPARISON       2.3644
```

```
                           BATCH = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     1       178.01     I
     4       174.58     I I
     5       172.35    .. I
     2       154.27    .... I
     3       152.04    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON       3.5720
STANDARD ERROR FOR COMPARISON       1.1508
```

MANNING LEVEL = 10

COMBINED BATCH SIZES
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC

```
HEURISTIC     MEAN     HOMOGENEOUS GROUPS
---------  ----------  -----------
    3        195.86     I
    1        195.54     I
    4        195.54     I
    5        190.66     .. I
    2        170.98     .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     4.0815
STANDARD ERROR FOR COMPARISON     1.3200
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

BATCH SIZE = 21
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC

```
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    1        213.07     I
    4        213.07     I
    3        208.49     I I
    5        205.20     .. I
    2        187.59     .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      7.4432
STANDARD ERROR FOR COMPARISON      2.3980
```

BATCH SIZE = 7
SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC

```
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
    3        183.23     I
    1        178.01     .. I
    4        178.01     .. I
    5        176.13     .. I
    2        154.37     .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      3.4272
STANDARD ERROR FOR COMPARISON      1.1041
```

MANNING LEVEL = 9

```
                     COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------   ----------  -----------
     3        215.49     I
     2        202.34    .. I
     1        202.16    .. I
     4        198.51    .. I I
     5        195.61    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     4.2445
STANDARD ERROR FOR COMPARISON     1.3727
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                        BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     3        221.03     I
     2        218.98     I I
     1        218.77     I I
     4        218.77     I I
     5        212.96    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      7.5401
STANDARD ERROR FOR COMPARISON      2.4292
```

```
                        BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     3        209.95     I
     2        185.70    .. I
     1        185.54    .. I
     4        178.25    .... I
     5        178.25    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE             2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      3.9701
STANDARD ERROR FOR COMPARISON      1.2791
```

MANNING LEVEL = 8

```
                    COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN     HOMOGENEOUS GROUPS
---------   ----------  -----------
     2        223.11     I
     3        215.49    .. I
     1        202.34    .... I
     4        202.34    .... I
     5        202.34    .... I

THERE ARE 3 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     4.5206
STANDARD ERROR FOR COMPARISON     1.4620
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                      BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     2        234.89     I
     3        221.03    .. I
     1        218.98    .. I
     4        218.98    .. I
     5        218.98    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      7.9623
STANDARD ERROR FOR COMPARISON      2.5653
```

```
                      BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC       MEAN    HOMOGENEOUS GROUPS
---------   ----------  -----------
     2        211.33     I
     3        209.95     I
     1        185.70    .. I
     4        185.70    .. I
     5        185.70    .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE              2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      4.3559
STANDARD ERROR FOR COMPARISON      1.4033
```

MANNING LEVEL = 7

```
                    COMBINED BATCH SIZES
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC     MEAN     GROUPS
---------  ----------  -----------
     2       253.09     I
     3       250.70     I
     1       223.11     .. I
     4       223.11     .. I
     5       223.11     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON     5.4422
STANDARD ERROR FOR COMPARISON     1.7600
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

```
                    BATCH SIZE = 21
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     2       267.33     I
     3       263.71     I
     1       234.89     .. I
     4       234.89     .. I
     5       234.89     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      9.6026
STANDARD ERROR FOR COMPARISON      3.0937
```

```
                    BATCH SIZE = 7
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC
HEURISTIC      MEAN    HOMOGENEOUS GROUPS
---------  ----------  -----------
     2       238.86     I
     3       237.70     I
     1       211.33     .. I
     4       211.33     .. I
     5       211.33     .. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.
CRITICAL F VALUE            2.408   REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON      5.2123
STANDARD ERROR FOR COMPARISON      1.6793
```

MANNING LEVEL = 6

```
   SCHEFFÉ PAIRWISE COMPARISONS OF MEANS OF TIME BY HEURISTIC

                              HOMOGENEOUS
HEURISTIC        MEAN         GROUPS
---------    ----------    -----------
    1          253.09       I
    2          253.09       I
    3          253.09       I
    4          253.09       I
    5          253.09       I

THERE ARE NO SIGNIFICANT PAIRWISE DIFFERENCES AMONG THE MEANS.
CRITICAL F VALUE            2.390    REJECTION LEVEL    0.050
CRITICAL VALUE FOR COMPARISON        6.1344
STANDARD ERROR FOR COMPARISON        1.9839
ERROR TERM USED: HEURISTIC*BATCH*REP, 490 DF
```

Scheffé comparisons for the batch sizes of 21 and 7 are meaningless because the mean times within each batch size at manning level 6 are the same.

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Vita

Captain Michael K. Garrity was born 12 September 1959 in Manhattan Beach, California. He attended California State University, Long Beach, and was graduated with a Bachelor of Science in Business Administration (Accounting). Upon graduation he was commissioned in the USAF. He served tours of duty as a Budget Officer at Headquarters, Air Training Command, and Headquarters, Air Force Material Command. He entered the Graduate School of Logistics and Acquisition Management, Air Force Institute of Technology in May, 1993 to begin a Logistics career.

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Vita

Captain Christopher J. Wicker was born on 31 October 1960 and grew up on a series of Air Force bases. After graduating from high school in Las Vegas, Nevada he joined the Marine Corps as an infantryman. He graduated from the University of Nevada, Las Vegas in 1985 with a Bachelor of Science in Geology. Upon graduation he received a reserve commission through Army ROTC and went on to serve as a Military Police platoon leader in the Republic of Korea. His next assignment was as a platoon leader in the 101st Airborne Division at Fort Campbell, Kentucky. In 1988 he transferred to the Army's Ordnance branch, and began a career as a maintenance management officer. Captain Wicker was a distinguished graduate of his Officer Advanced Course in 1990. His next assignment was back to Korea where he served as the electronics officer and as the wheeled vehicle officer for the 19th Support Command, Taegu, Korea. He was the action officer on the transfer of M48 series tanks from the National Guard Bureau to the Republic of Korea Army. From August 1991 through December 1992 he was the commander of Headquarters and Headquarters Company, 23d Area Support Group, Pyongtaek, Korea. Following a successful command, Captain Wicker was selected to attend the Air Force Institute of Technology beginning in June 1993. In December of 1993 he married Korean Army Captain Kim Yeon-hui, who finally joined him in America in April of 1994. Captain Wicker's follow-on assignment from AFIT is with the Joint Warfare Center, which has a mission to develop warfare simulation packages and joint theater level war games.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this research was to determine a preferred server allocation and a preferred customer batch size for processing customers at an Army Central Issue Facility (CIF) under various manpower levels. The CIF is a retail warehouse which issues tactical clothing and equipment to individual soldiers. It is facing potential manpower reductionsfrom the current level of 19 servers. The CIF exhibits flow shop characteristics. An assembly line balancing approach was used with the objective of reducing the customer's average time-in-system. Five server allocation heuristics and three customer batch sizes were examined. The evaluation tool was a computer simulation using data from a time-motion study. Results indicate that customer batch size has a greater effect on a customer's average time-in-system than server allocation heuristic. In this study a batch size of seven resulted in lower average times-in-system than did a batch size of one or twenty-one.

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