A SIMULATION OF THE OPERATION OF A LOG LANDING FOR A HELI-STAT AIRSHIP IN OLD-GROWTH TIMBER

by

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A Paper

Submitted To

Forest Engineering Department

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Submitted: June 2, 1982

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Date Paper Presented: June 2, 1982

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ABSTRACT

This paper discusses the development of a computer simulation program for the operation of a log landing for the proposed Heli-stat airship. The first part of the paper describes the time study used to develop production rates for the chasers, buckers, front-end loaders, and skidders to be used on the landing. A time study was performed on a helicopter landing resulting in regression equations or production probability distributions for each of the five job functions on the landing. Because the Heli-stat is capable of delivering a much larger payload than the helicopter that was studied, extrapolations of the time study results were necessary. A mechanical analysis was used to determine the production rate of a large rubber tired skidder used as a swing machine between the dropsite and the bucking chute.

The second part of the paper discusses the features of General Purpose Simulation System (GPSS V) program used to simulate the Heli-stat landing. Queue lengths and equipment utilization rates were used as evaluation criteria in determining the minimum turn times that could be handled by a number of different landing configurations. Different crewing patterns were evaluated for landings with one or two dropsites for old-growth log loads consisting of either bucked logs, tree length logs, or whole trees with tops and limbs. Production rates and production costs based on delay free times were used to compare the various alternatives. The results indicate that tree length logging may have some definite advantages over the other two types because the long, limbed logs can be handled more efficiently

than either the bucked logs or the whole trees. The results also show that a standard helicopter landing configuration increased in both physical dimensions and crew sizes can accommodate Heli-stat turn times of 4.0 to 6.0 minutes.

A primary goal of this project was to develop production equations that could be used in a larger stump-to-cold-deck simulation of the entire Heli-stat yarding cycle. This larger simulation will be performed by the Aerospace Corporation of Los Angeles, California, and will incorporate the landing production rates developed here with yarding and load assembly production rates developed by John Miles and Bruce Hartsough at the University of California at Davis.

TABLE OF CONTENTS

INDEX TO FIGURES

ACKNOWLEDGEMENTS

I would like to thank the following people and organizations for the cooperation and assistance given to me during the course of this project: St. Regis Paper Company, Columbia Helicopters, and Don Hanks, logging boss for the Columbia Helicopter side, who graciously permitted me to perform a time study on their helicopter logging operation in North Bend, Washington in August of 1981. The simulation models were built with the assistance of Jeff Arthur from the Department of Statistics at Oregon State University, and Craig Bodenhausen of the U.S. Forest Service Advanced Logging Systems Group at Oregon State University. Dr. Eldon Olsen of the Department of Forest Engineering at Oregon State University provided valuable assistance on time study procedures and statistical analysis. Finally, Mickey Conan, Logging Engineer for the Umpqua National Forest, provided me with the data sheets from the Diner Creek helicopter study, which were used to validate the production functions.

INTRODUCTION

The objective of this project was to develop a simulation program which could be used to recommend a crewing size and landing configuration for the Heli-stat; a proposed heavy lift logging airship with an estimated payload capacity of roughly eighteen tons. This project is part of a larger project which will simulate the entire stump-to-cold-deck logging operation.

The U.S. Forest Service intends to test the Heli-stat in a logging situation on six timber sales on six different National Forests in California, Washington, Idaho, Montana, and Alaska. Because the Heli-stat is capable of carrying over twice the payload of a conventional Siskorsky S-64E helicopter, the Forest Service felt that the existing guidelines and procedures for helicopter logging would not be adequate for the Heli-stat. They proposed that the entire logging operation be simulated in an attempt to find the optimal load assembly, yarding, and landing procedures for a wide variety of timber types, stand densities, and topography. All reasonable alternatives were to be investigated.

This portion of the project involved the simulation of the landing operations for logging in large, old-growth timber. Bruce Hartsough and John Miles at the School of Agricultural Engineering at the University of California at Davis are responsible for the simulation of load assembly and yarding for the old-growth timber, so I cooperated closely with them. An entirely separate simulation package for small timber is being developed in a similar cooperative effort between the U.S. Forest Service in Missoula, Montana and Montana State University in Bozeman, Montana. Finally, the U.S. Forest Service has contracted with Aerospace Corporation of Los Angeles, California, to put all the simulation packages into a form that will be easy to use; hopefully on a desk-top computer similar to the Hewlett-Packard 9845. This final re-writing and combining of all the programs will make the simulation programs available to a timber sale appraiser who needs not be knowledgeable in the simulation program languages. This final simulation should not be considered an "operating manual" for the Heli-stat. The U.S. Forest Service has planned extensive time studies on each of the six timber sales to check all the assumptions and estimations made in the simulation. This simulation is only a preliminary guide and will undoubtedly be modified and updated.

This landing simulation is intended to cover the following range of conditions: the Heli-stat payload size is to be in range of 18 tons, although projected estimates of the maximum Heli-state payload range as high as 25 tons. The timber will arrive at the landing in loads that are a uniform log type; either bucked logs, tree length logs, or whole tree. Tree length logs are limbed and topped in the woods while whole tree yarding brings limbs and tops to the landing. The payload will arrive at the landing in one of three assembled packages: the conventional helicopter method of chokers on a hook, a tagline and slider system, or a unitized bundle of bucked logs that would be handled on the landing as one large unit. The simulation begins at the drop site and ends at a cold deck. The logs are to be cold decked and sold after all logging operations end. This was necessitated by the experimental nature of the Heli-stat which does not allow the U.S. Forest Service to guarantee arrival of the logs. If the Heli-stat should fail, the Forest Service would have no way of delivering the logs to the landing. The cold decks require a large storage area in/or around the landings. Should the Heli-stat later prove to be successful and dependable, a log loading routine can easily be added to the simulation.

In order to simulate the operation of a landing it was first necessary to determine production rates for chasers, buckers, and loaders and it was here that the first problem was encountered. There have been very few studies done on landing production rates. The available logging engineering research has put a heavy emphasis on productivity in the felling and yarding cycles, but has expended very little effort on the productivity of the landing operations. This is probably because of the wide variations in work demand upon the landing crew and because of the landing crew's total dependence upon the yarding cycle. The tendency of the logging boss is to assign enough men to the landing to handle the worst possible situation (i.e., the shortest turn times) and then take people away from the landing if the crew becomes too underutilized (i.e., when yarding the long corners). At any rate, there is a distinct lack of information on productivity rates in the landing situations that I was interested in.

LITERATURE REVIEW

A simulation program developed by Dykstra (1974) evaluated the trade-offs between earthmoving and log handling in the location and design of a landing. The queuing system used by Dykstra was similar to the one anticipated here, however, Dykstra made several assumptions which do not apply to a Heli-stat landing. Dykstra assumed that the landing would approach a steady state flow condition, which is not true for a Heli-stat or helicopter landing where refueling breaks regularly interrupt the arrival pattern. He also assumed an infinite population of turns, a single channel server system, and placed no restrictions on the queue lengths at the various stations. The service times were based on small timber (u = 14" DBH) and average turn sizes of 2.2 logs. These service times were not applicable to the old-growth study for the Heli-stat.

In 1981 John McIntire at Oregon State University conducted a study of a John Deere 440-C skidder swinging logs from underneath a small Shield Bantam T-350 swing boom yarder. This study was done in 20 to 40 year old Douglas-fir. Although similar in scope to one type of swing operation considered for the Heli-stat the small size of the equipment and timber made the results inapplicable to the Heli-stat. Dennis P. Dykstra's study at Pansey Basin (1975) developed helicopter production rates, but no data was published on the landing production rates. Numerous studies have been made on skidder production rates, but none were easily adaptable to a landing situation where tree length and whole tree logs must be swung from the dropsite to a bucking chute. John Sieffert (1982) did considerable work on skidder production rates on designated skid trails which is similar to a swing situation, however, the study was performed in small timber with small equipment: a Caterpillar 518 Rubber Tired Skidder, a Caterpillar D6D, an International TD-8E, and an FMC 200CA. These machines are too small for the Heli-stat operation. William Yancy (1980) compared studies on several different rubber tired skidders and discussed several different regression equations, however, the problem of adapting these equations to this landing situation could not be overcome. Regression equations based on logging data often have regression coefficients (most notably the B_0 coefficient) that seem unreasonably large for a landing situation. This is probably because the coefficients include many small delays due to weave, small changes in grade, and operator discomfort on rough terrain that would not apply on a flat, open landing.

Similar problems were encountered when evaluating available production rates for the buckers or knot bumpers. Regression equations developed for limbing and bucking in the woods, McDonald (1972) and Kellogg (1980), are not easily adapted to a landing where the terrain is flat, the logs are parallel and evenly spaced, and a front-end loader is available to reposition any particularly difficult logs.

Studies by FERRIC; Lavoie (1980), and Sinclair (1980) gave reference information on general landing operation techniques and space requirements. Simulation work by LeDoux (1975) on helicopter production rates yielded a great deal of information on the helicopter yarding cycle, but no information on the landing operation. A simulation routine developed by Martin (1975) for Appalachian logging was very similar in scope to the overall Heli-stat simulation program. Martin used regression equations to simulate the entire logging operation from pulling to truck haul in a program called THATS, and the flowcharts of his program were very similar to those of the Heli-stat simulation. His regression equations, however, were based on small timber and ground skidding and were not applicable to large timber. Johnson, Gochenour, and Biller (N.D.) developed a similar simulation program for harvesting small timber in the Appalachians.

After reviewing the available production rate equations, it became obvious that data would have to be gathered to develop production rates for a landing. The available regression equations could be used to check any equations developed, but they could not be manipulated with any confidence to fit this particular situation. The obvious choice was to study a helicopter logging operation as the general operation will be similar to that of the Heli-stat.

DESCRIPTION OF STUDY AREA

The operation studied was a Boeing-Vertol 107-II operating in old-growth mixed conifer clearcuts with a Caterpillar 966-B front-end loader on the landing. The average payload of the BV-107II was 9,000 lbs. It would have been preferable to do the study on a Sikorsky 64-E because of its larger payload capacity, but at the time of the study (August, 1981) the logging industry was in a severe recession and there were no 64-E's operating in old-growth timber. The logger was Columbia Helicopters of Portland, logging land belonging to St. Regis Paper Co. near North Bend, Washington, 30 miles east of Seattle, WA. The predominant species being yarded was Douglas-fir with lesser amounts of Western Hemlock and Western Red Cedar. Three sets of chokersetters and hookers were working on slopes ranging from 50-100%. All units were being yarded downhill with yarding distances of 0.75 to 1.5 miles. The landing crew size varied depending upon the yarding distances and corresponding turn times. When turn times were quick (2.5 to 3.5 minutes), the Caterpillar 966-B front-end loader swung the logs from the dropsite to the bucking chute and decked the bucked logs for a heel boom loader. Log trucks were loaded by the heel boom loader. On a second landing where the turn times were 3.5-5.0 minutes, the heel boom loader was not used and the 966-B loaded the trucks in addition to its other tasks. Thus, the 966-B had a high utilization rate during the study. One or two chasers were used depending upon the average turn time. The chasers function was to take the chokers off the logs, coil the chokers, and load bundles of chokers on the hook for delivery to the woods crew. One or two buckers or knot bumpers were used depending upon the turn time. The turns generally consisted of 1 to 6 bucked logs, although some whole tree, tree length logs, and tops (YUM) were also yarded. The weather conditions were hot (60°F - 100°F) and clear. The woods crew and landing crew worked ten hours each day while the loader worked 12 hours per day. The crew had been working together for two months prior to my time study, so I assumed they were fairly low on the learning curve. My subjective opinion of the landing crew is that they were experienced and highly skilled, especially the loader operator.

Figure #1

Landing #1

TIME STUDY PERFORMED ON CHASER AND BUCKER ON THIS LANDING.

SCALE: 1"=60'

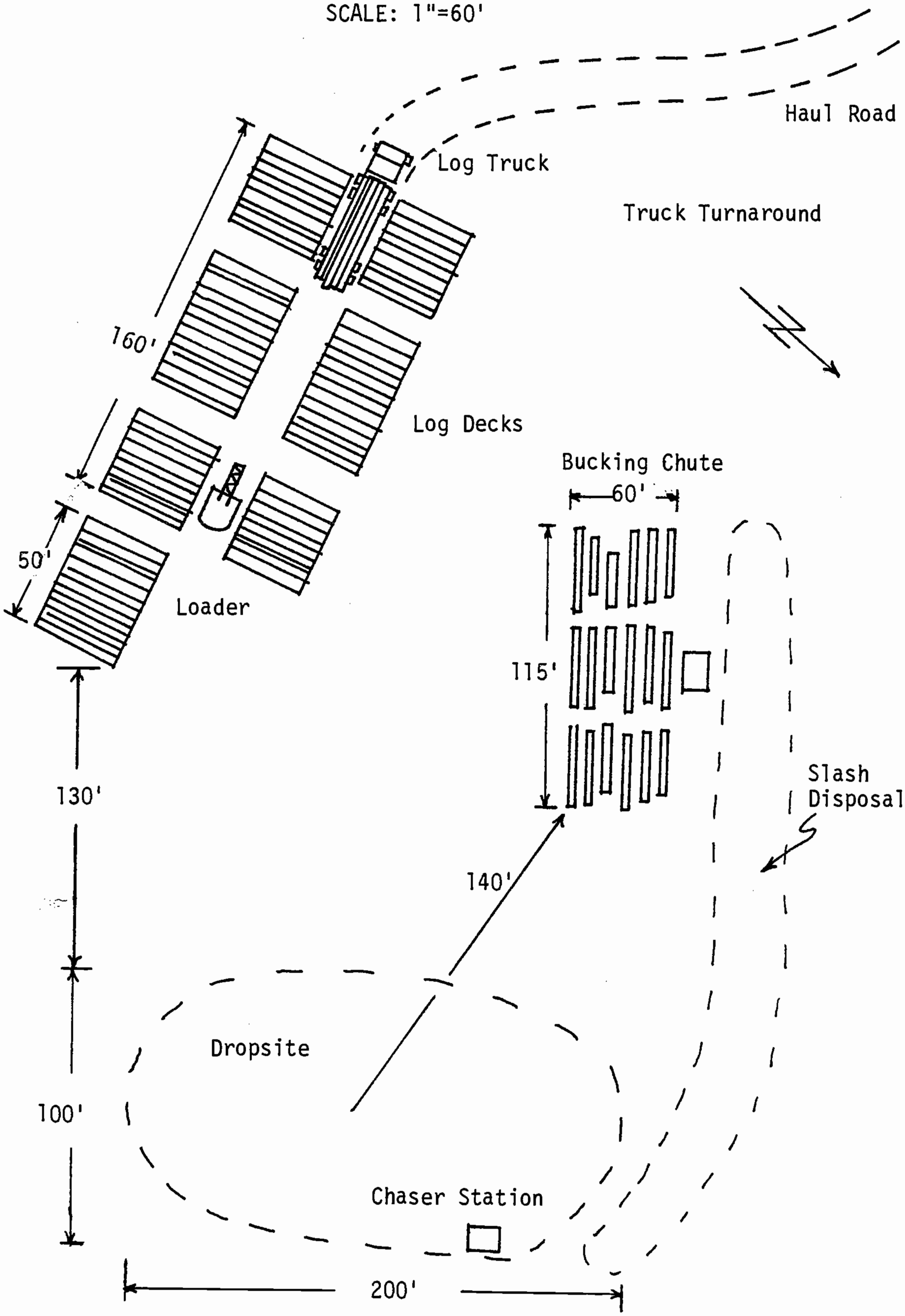
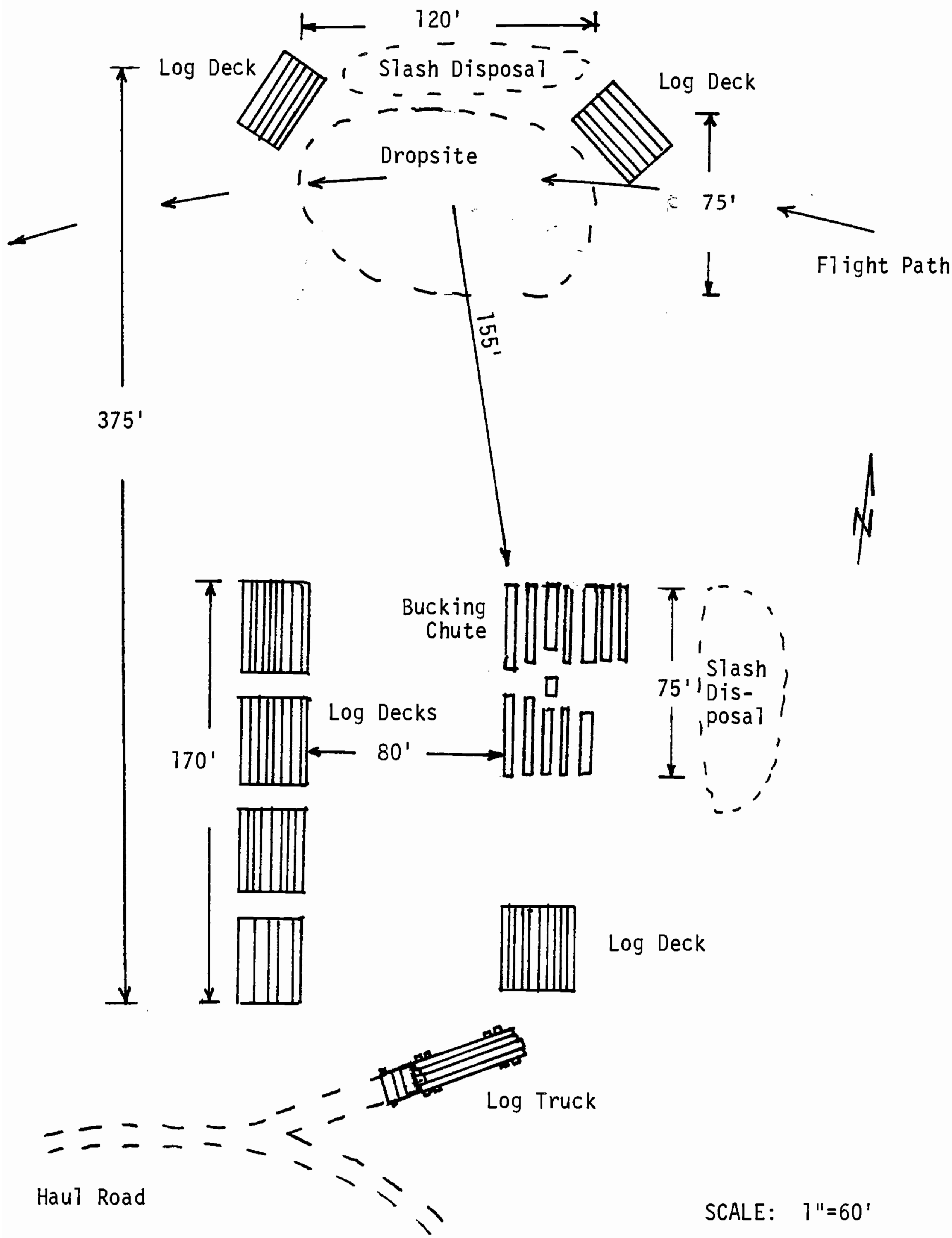


Figure #2
Landing #2

TIME STUDIES ON LOADER, BUCKER, AND CHASER PERFORMED ON THIS LANDING.



TIME STUDY PROCEDURE

Because there was only one data taker on the study, it was necessary to separate the crew into three parts (chaser, loader, and bucker), and study each part separately. A continuous timing method was used for all three functions, but the definition of elements and independent variables were different for each of the three functions. All production times were taken with a stop watch and read to one one-hundredth of a minute. Time elements and independent variables for each of the three functions are described below.

CHASER

The chaser function was studied for a total of 101 turns. When two chasers were working together, which occurred 57% of the time, element times for one chaser were recorded, but it was noted that he was assisted by a second chaser. When two chasers were working together, they generally performed the same elements at the same time; that is, both chasers unhooked the chokers immediately after the drop and after completing that element they both coiled and stacked the chokers. The inability to time each chaser should have no detrimental effect on the results of the study.

Definition of Elements for Chaser

UNHOOK - The time required for the chaser to unhook the choker bells and remove as many of the chokers as possible from the logs. Unhook time started when the eyes of the chokers hit the ground after being released from the hook. Unhook time ended when the chaser began to drag the chokers away from the dropsite towards the coiling area.

COIL - The time required for the chaser to drag the chokers from the dropsite to the coiling area, coil the chokers, stack them in bundles of 10, and prepare them for loading on the helicopter hook. Coil time began when the chaser first began dragging the chokers away from the dropsite and ended with the completion of stacking or bundling of the chokers. The completion of the coil element was usually followed by idle time. Five-eighths inch chokers were used on this show.

LOAD - Twenty-one percent of the turns required the chaser to load a bundle of chokers or a chain saw onto the hook for delivery to the woods crew. This would occur immediately after the drop and thus would delay the beginning of the unhook element. The load element began when the eyes of the chokers hit the ground (same definition as the unhook element) and end when the chaser closed the hook on the eye of the choker that was attached to the load. The unhook element would then begin with the closing of the hook.

STAMP - During a short period of the study, the chaser was also stamping the ends of the logs. This was the lowest priority element in his job routine. He would only do this after completion of the loading and unhooking elements for an individual turn. Stamp time began when the chaser picked up the stamp hammer and ended when he threw the hammer aside.

IDLE - Frequent idle periods resulted from slow helicopter turn times and helicopter refueling breaks. Personal delays for conversation or a drink of water were taken during these idle times so they were recorded as idle time rather than delay time.

DELAY - Only one type of delay was noted for the chaser. This was a mechanical delay which usually resulted from the chasers inability to unhook the choker bell. In most cases he would work somewhere else until the loader came over to assist, but occasionally if the loader was nearby he would wait for the loader to drive over and lift the log. I classified this waiting time as a mechanical delay.

Independent Variables for Chaser

The following information was recorded for each turn: the number of chokers in the turn, the number of logs with the diameter and type (bucked log, whole tree, tree length log, or YUM) for each log, the number of chasers that worked on the turn, a zero-one variable which indicated whether or not the chaser required assistance from the loader to unhook the log, and the number of the chaser being observed. Two different chasers were observed during the study.

LOADER

The Caterpillar 966-B front-end loader performed five separate and distinct functions on the landing. The operator's primary responsibility was to keep the dropsite clear of logs and swing them over to the bucking chute where the buckers could limb and buck the logs.

His secondary responsibility was to move the bucked logs from the bucking chute to the log decks to assure that the bucking chute would not become jammed with logs. His third responsibility was to keep the dropsite and bucking chute clear of slash. The slash was simply pushed over the side of the landing. On the second landing he also had to load approximately 30 log trucks per day. In general, the truck loading element was third priority following the swing and deck elements, although the additional responsibility of loading trucks allowed more logs to build up on the dropsite and in the bucking chute. The main problem encountered in the time study of the loader was defining the exact moment when one element ended and another began. Travel time between elements was included with the element that the loader had been performing since it was difficult to guess what the loader operator was going to do next. A rule of thumb used during the time and motion study on the loader was that one element would not be marked as completed until the loader had definitely begun a new element or encountered a delay. An example of this type of problem is the overlap between the decking element and the loading element. Both elements involve working out of the log decks and it was often difficult to ascertain whether the operator was preparing a load for the log truck or merely shuffling logs among the seven different sorts in the deck element. Therefore, some of the following definitions may seem somewhat ambiguous, but the rule of thumb should have distributed any errors equally among the four elements.

Definition of Elements for the Loader

SWING - The time required to swing the logs away from the dropsite and arrange them neatly in the bucking chute. The logs are placed parallel in the chute with 2 to 3 feet between the logs to allow the bucker to walk between them. Any time spent assisting the buckers or chasers (i.e., rolling logs over to make them easier to work on) is included in the swing element. Swing begins when the loader drops it's forks as it approaches the dropsite in preparation for grapping a log. Swing ends when the loader begins any of the other four elements or encounters a delay.

DECK - The time required to move a log or group of logs from the bucking chute to the log deck. This includes time spent arranging a load at the bucking chute, as well as time spent building neat and orderly log decks. Deck begins when the loader first begins to pick logs up from the bucking chute. Deck ends when the loader begins any of the other four elements.

SLASH - The time required to clear slash from the landing area. Slash begins when the loader approaches a pile of slash with forks lowered to the ground. Slash ends when the loader begins any of the other four functions.

LOAD - The time required to load logs on a log truck. Load begins when the loader touches the log deck to gather a log or group of logs for the log trucks. Load ends when the loader begins any of the other four elements.

UNLOAD - The time required to unload the empty trailer off the log truck and set it on the ground to be hooked onto the tractor. Unload begins as the loader approaches the empty log truck in an attempt to hook the trailer strap. Unhook ends when the loader releases the strap on the tailer.

IDLE - The loader experienced frequent idle periods that can be roughly separated into two classifications. The first class is an idle due to a lack of work. The helicopter could not supply logs fast enough to keep the loader busy, especially during the helicopter's refueling breaks which occurred every 62 minutes. The second type of idle was when the loader would wait for a chaser, bucker, or truck driver to perform some function before the loader could continue working. Usually when this happened the loader would perform some other element in his job cycle, but if there was no other work to be done the loader would sit idle until the chaser, bucker, or truck driver completed his job. Since this idle time was more attributable to a general lack of work on the landing rather than any fault of the chaser, bucker, or truck driver, I classified this as idle time rather than delay.

DELAY - All of the delays the loader encountered were mechanical delays which could be divided into two types. The first type was delays caused by the loader (i.e., refueling the loader, cleaning the windows, removing slash from the steering mechanism). The second type of delay was when the loader was delayed as a result of some negative interaction with one of the other work groups on the landing. This type of delay included waiting for the chaser to unhook a particularly uncooperative choker bell, assisting the bucker when his chain saw bar got stuck in a log, or arguing with the truck drivers.

Independent Variables for the Loader

The following independent variables for the loader were recorded: number of helicopter drops, number of logs per drop, types of logs (bucked logs, tree length logs, whole tree, or YUM), number of trucks loaded, logs per truckload, and number of pieces handled in loading the truck. The volume of logs handled was measured in tons. By timing the loader for a complete day's work and by keeping track of the number of helicopter turns and the average payload from the helicopter's load cell readout a reasonable estimate of the gross production rate in tons/minute for each of the various elements could be made. All the logs delivered by the helicopter would pass through the swing, deck, and slash elements during the course of the day. A production rate for the load element was based on the number of trucks loaded per day. With only one data gatherer it would have been impossible to get an accurate volume through measurement of diameter and lengths of each individual log.

BUCKER - The buckers function was to limb and buck the logs. Since most of the logs arrived limbed and bucked from the woods the buckers job was one of cleaning up the logs: knocking off an occasional limb, bucking off a broken top or a section of cull. There were, however, some loads that arrived with whole trees including limbs and tops, so the bucker had a variety of work. His usual job cycle would consist of walking down the space between two logs bumping the knots on either side as he went with an occasional stop to buck an exceptionally long log or trim off a broken end. His tendency to alternately work on two different logs made it difficult to ascertain exactly how much time was spent on each log, but the goal was to build a regression equation based on diameter and length so a good effort was made to separate the work done on each log. When two buckers were working at the same time they worked completely independent of each other, so only one of the two buckers would be timed.

Definition of the Elements for the Bucker

LIMB - The time required to saw off limbs or staubs from the logs or trees. Limb started when the bucker picked up his saw and ended when he shut the saw off.

BUCK - The time required to buck logs and trim off broken tops or sections of cull. This was usually done between periods of limbing and as a result the bucker's walking time between his saw station and the log or between logs was usually included in the limb time, rather than the buck time. Buck started in one of two ways: if the bucker was bucking a log to length, buck started when the bucker pulled his Spencer tape tight to measure the log. If the bucker was trimming off an end, buck started when he began to cut into the log. Buck ended when the bucker withdrew his saw from the log and resumed limbing.

DELAY - The only delay that the bucker encountered was when he got his bar stuck in a log. This only happened twice during the two days spent studying the bucker.

IDLE - Frequent idle periods were encountered due to a lack of available work. The bucker would maintain his saw during these periods, but this maintenance time was included in the idle time because it was impossible to tell how much was absolutely necessary and how much was being done for lack of anything better to do.

Independent Variables for the Bucker

The following independent variables were recorded for each piece regardless of whether the bucker did any work on the piece: large end diameter of the piece, length of the piece, log type (bucked log, tree length, whole tree, or YUM), the number of bucks made on a single piece, and the condition of the bucking chute when the piece was bucked (i.e., clear of slash, moderately clear, or congested with slash). Diameters and lengths were measured when time permitted and estimated if time did not allow measurement.

RESULTS OF THE TIME STUDY

The goal of the time and motion study was to obtain production rates which could be used in my simulation model. The original plan was to develop regression equations for all the elements in each of the different job functions, but a thorough analysis of the data showed that this was not always practical. Nevertheless, the time study did result in some type of production rate for each of the job functions which could be programmed into the simulation package. The statistical analysis was done using the Statistical Interactive Programming System (SIPS) developed at Oregon State University by Kenneth Rowe and Robert Brenne. The stepwise regression search method was used to determine acceptance or rejection of independent variables based upon: 1) an improvement of the coefficient of multiple determination (R^2) of at least one percent; and 2) a T value with a minimum level of significance of 95%. Many different transformations on the independent variables were considered, but the results of a transformation were always evaluated critically to make sure that the transformation removed enough of the random variation (i.e., raised the R^2 value of the resulting regression equation) to justify the transformation.

Figure 3. Log Diameters and Lengths.

LGTYPE	MEAN DIA.	ST. DEV.	MEAN LENGTH	ST. DEV.	N
All	19.96	6.60	30.28	11.31	215
1) Bucked Logs	20.33	6.61	29.29	9.75	193
2) Tree Length	20.40	6.84	40.80	5.76	5
3) Whole Tree	17.60	4.88	51.60	17.36	10
4) YUM-Tops	12.86	3.80	19.43	4.69	7

Results of the Time Study on Chasers

UNHOOK TIME - Statistical analysis using an "F" test showed no difference at the 50% significance level between the two different chasers observed. It also showed no difference at the 90% significance level between the unhook times for loads composed entirely of bucked logs and loads which contained tree length or whole tree pieces. This was probably a result of the small number of pieces per turn and the fact that the chokers are attached to the butt ends of the logs where the limbs on the whole tree pieces would create very little interference with unhooking the chokers. All independent variables with the exception of the number of chokers were found to be insignificant. The resulting regression equations were:

for 1 chaser:

unhook time (in minutes) = 0.271 + 0.290 (# chokers/turn)

$R^2 = 0.525$

$n = 44$

for 2 chasers:

unhook time (in minutes) = 0.218 + 0.195 (# chokers/turn)

$R^2 = 0.517$

n = 52

An F test was performed to see if these two regression lines were significantly different from each other and it was found that they were different at the 99.5% significance level. The graph on the following page shows the two lines with a surrounding 95% Confidence Interval. The regression's coefficients for (# chokers) was found to be significantly different from zero at the 99.5% level.

Because the Heli-stat may require three or four chasers, it was necessary to extrapolate these two equations. This was accomplished by assuming that the percent reduction in the two coefficients (B_0 and B_1) due to interference between the chasers would remain the same as more chasers were added. This resulted in a 20% reduction in the value of B_0 and a 33% reduction in the value of B_1 with each additional chaser. The resulting equations were:

1 chaser: Unhook time (in min.) = 0.271 + 0.290 (# chokers)

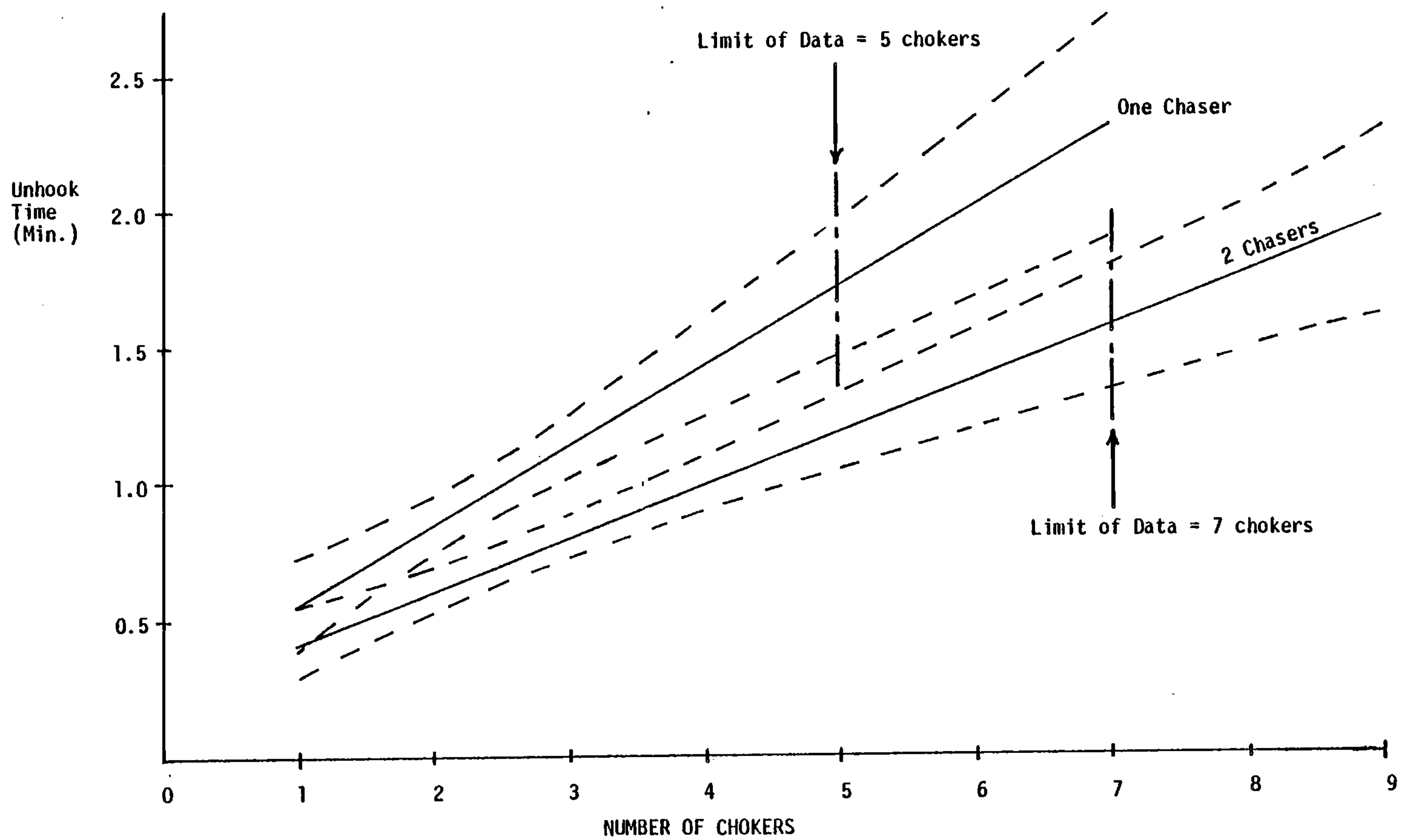
2 chasers: Unhook time (in min.) = 0.218 + 0.195 (# chokers)

3 chasers: Unhook time (in min.) = 0.174 + 0.131 (# chokers)

4 chasers: Unhook time (in min.) = 0.139 + 0.087 (# chokers)

This method would not be very reliable for more than 4 chasers, but fortunately the simulation runs called for no more than 3 chasers, so the results of the simulation can be assumed to be reasonably accurate.

Figure 4. 95% Confidence Interval for Unhook Time.



It was surprising to find a linear relationship between number of chokers and unhook time. The unhook time might have been expected to rise exponentially with the number of chokers because of tangled chokers and buried choker bells. The data, however, did not show any appreciable exponential effect over the range studied (1 to 7 chokers per load).

COIL TIME - The regression equation for coil time was very straightforward and could logically involve only one variable: the number of chokers coiled.

Coil Time (in minutes) = 0.156 + 0.470 (# chokers)

n = 92

R^2 = 0.651

Level of significance of regression coefficient for # chokers = 99.5%

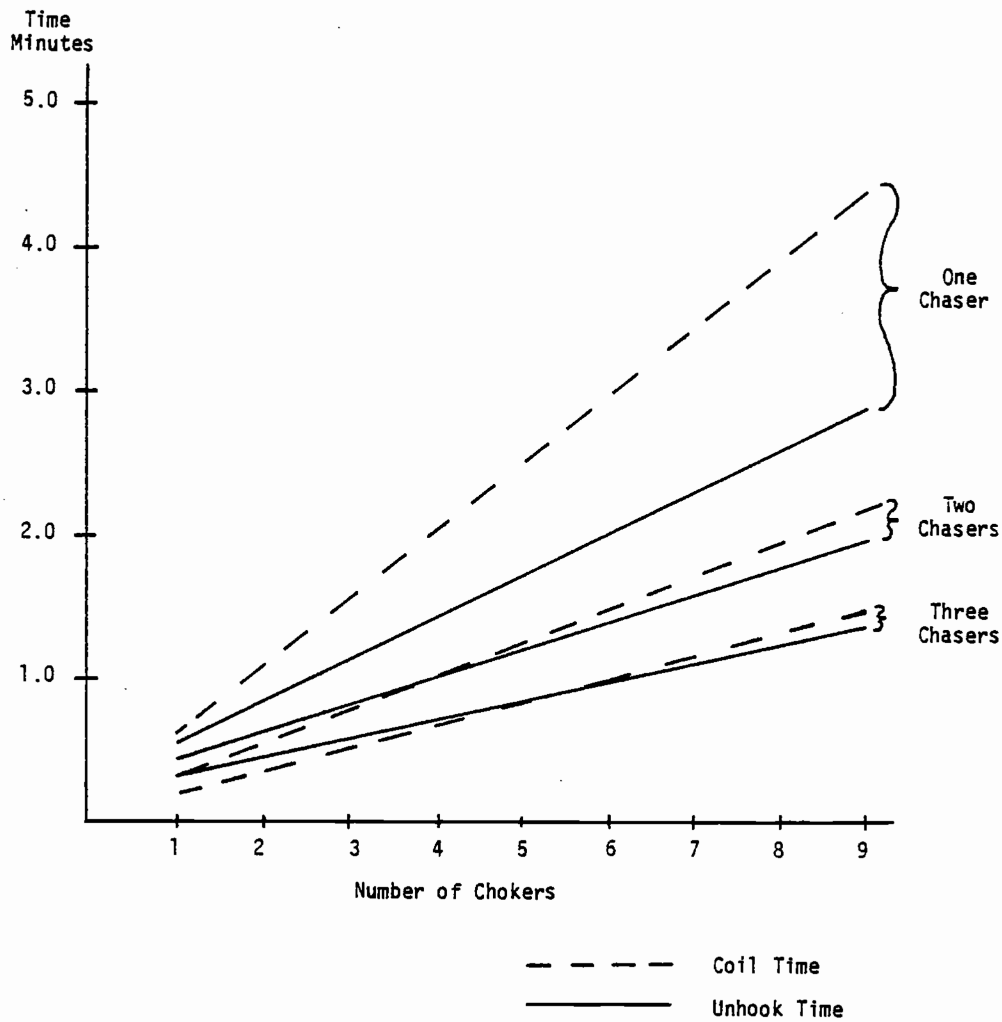
Because there is almost no interference between chasers during the coil element, it was assumed that two chasers could coil a given number of chokers twice as fast as one chaser. A breakdown of the element times for the chasers yielded the following information:

Job Element	% of Total Time
Unhook	20.92%
Coil	24.32%
Stamp	0.006%
Load	0.012%
Idle	54.74%
Delay	0.009%
	100.007%

From this data it is easy to see that the majority of the chaser's time is idle time and the first suggestion that comes to mind is that he should be better utilized. There is, however, a danger in this thought. The chaser or chasers must get the chokers off the logs as quickly as possible in order for the loader to swing the logs away from the dropsite and clear it for the next load. If the unhook time is lengthened the loads may pile up at the dropsite and the productivity of the helicopter may drop off while the helicopter waits for the chaser. With helicopter hourly costs being over 100 times the hourly cost of the chaser, it is easy to see why the logging boss is willing to pay for the chaser's idle time.

The following graph compares unhooking time and coil time requirements for the chasers. The time requirements are nearly equal for 2 and 3 chasers, but the coil time is 1-1/2 to 2 times the unhook time for one chaser. This will have to be kept in mind when analyzing the results of the simulation, but with chaser utilization rates of 50% or lower it is obvious that the critical element is going to be unhook rather than coil.

Figure 5. Comparison of Unhook Time and Coil Time.



Results of Time Study for Loader

The time study on the Caterpillar 966-C loader only permitted calculation of the average production rates in tons per minute for the three different work functions that were to be used in my simulation model: swing, deck and slash disposal. This average production rate was calculated by dividing the total weight processed each day by the total processing time for each function. The results for each work function are given below.

RESULTS FOR SWING PRODUCTION - The swing production rates were calculated for two different work conditions. The first condition was the typical method of operation where the loader would swing each helicopter load from the dropsite to the bucking chute with no build-up of logs on the dropsite. The second condition occurred when the loader was busy decking logs or loading a log truck and he would allow 3 to 7 helicopter loads to accumulate on the dropsite. This second condition was of particular interest for two reasons. First, the increased time pressure factor might cause him to work nearer to his true maximum production rate and second, the accumulation of log loads more closely approximates a Heli-stat load. (One Heli-stat load is approximately equal to four Boing Vertol 107II loads.) The results were that the average single load swing progressed at 3.68 tons/minute (221 tons/hour) while the average accumulated log swing progressed at 4.01 tons/minute (241 tons/hour). Because the two rates differed by only 8.3%, it seems reasonable to use the accumulated load rate for the production rate under Heli-stat work conditions.

RESULTS FOR THE DECK PRODUCTION RATE - The mean deck production rate was 3.02 tons/minute (181 tons/hour). It was felt this production rate, although accurate for the landing condition studied, would not be accurate for the Heli-stat simulation. The landing that was studied required seven different sorts and it was not uncommon for the loader to deck one small log at a time. The Heli-stat landing, on the other hand, will probably not have any sorts and most certainly will not have seven sorts. Furthermore, the largest logs will be larger than those delivered by the Boing Vertol 107II. The loader on the Heli-stat landing should be decking larger loads than it was under the conditions studied. Therefore, the deck production rate was adjusted based on expected travel distances and payload capacity as shown in the table below.

	Helicopter Landing	Heli-Stat Landing
Average Travel Distance	120 feet	305 feet
Average Load	2.0 tons	6.0 tons
Average Loaded Speed	6.0 MPH	7.0 MPH
Average Unloaded Speed	7.0 MPH	10.0 MPH
Load and Unload Time	0.25 Minutes	0.35 Minutes
Travel Time Loaded	0.227 Minutes	0.495 Minutes
Travel Time Unloaded	0.195 Minutes	0.345 Minutes
Total Turn Time	0.6721 Minutes	1.192 Minutes
Production Rate	2.97 tons/minute	5.03 tons/minute

RESULTS FOR SLASH DISPOSAL PRODUCTION RATE - Slash was disposed of by pushing it over the side of the landing with the 966-B loader. The slash disposal production rate was calculated in a somewhat indirect manner. There was no method for estimating the tons of slash that was brought to the landing, but there was fairly accurate data on the total weight of logs brought to the landing. The slash disposal production rate was based on the log weight rather than the slash weight or volume. The units for the slash disposal production are therefore "the slash from a number of tons of logs/minute." For the remainder of the paper I will use the abbreviation tons/minute, but the reader should bear in mind that it refers to tons of logs per minute, not tons of slash per minute. The mean production rate for the slash disposal rate was 18.7 tons/minute or 1,124 tons/hour.

GENERAL RESULTS OF LOADER STUDY - The loader time study yielded the following general results:

Job Function	% of Time
Swing	22.6%
Deck	25.5%
Load	27.4%
Slash Disposal	4.6%
Idle	15.4%
Delay	4.5%
TOTAL	100%

Period of Study - 20 working hours on Loader

Helicopter Refueling Break Frequency - 66.2 minutes

Mean Duration of Helicopter Refueling Breaks - 11.0 minutes

Mean turn time - 3.85 minutes

Std. Dev. Turn Time - 1.05 minutes

Mean Logs/Turn - 2.7 logs

Std. Dev. Logs/Turn - 1.5 logs

Range of Logs/Turn - 1 to 7 logs/turn

Mean Helicopter Payload Weight - 9,000 lbs.

Results of Time Study for Bucker

The data allowed for the development of separate regression equations and histograms for each of the three different types of logs (bunched logs, tree length logs, whole tree) that the bucker encountered. It also allowed the development of separate regression equations for limbing time and bucking time. The original intention was to develop a regression equation based on length, diameter, and number of bucks in each log. Many different transformations on these independent variables were considered, but the results of these transformations were often unreasonable or did not result in a sufficiently high R^2 value to justify their use.

LIMB TIME ON BUCKED LOGS - The variability in the independent variables proved to be too large of an obstacle to overcome in the development of a regression equation for limbing time. Forty-six percent of the bucked logs sampled required no additional limbing on the landing. That is, they were sufficiently limbed by the felling crew in the woods. The data also shows that a much larger percentage of the smaller logs require limbing. If the data is divided into log diameter greater than 24" and diameters less than 24". Sixty-two percent of the logs less than 24" in diameter required additional limbing while only 29% of the logs greater than 24" required additional limbing. This agrees with the natural pruning process that occurs as trees grow larger, but it rules out any consideration of linear regression equation that covers the entire range of data. The other problem with building a regression equation for bucked logs is the enormous amount of variability that cannot be accounted for by any data taken on the landing. Bucked logs are supposed to be limbed by the woods crew. The bucker on the landing only cleans up the few limbs that were left by the woods crew. The variability in the dependent variable is thus extremely large and the corresponding coefficient of determination (R^2) is very low. These problems were resolved by using the probability distribution shown in Figure 6, which plots time to limb a single log as the number of occurrences in 0.20 minute-wide intervals.

BUCKING TIME ON BUCKED LOGS - The same problems discussed in the previous section on limbing time apply to bucking time. High unexplained variability and low R^2 values lead to the use of the probability distribution shown in Figure 7.

The simulation required the generation of the total time to process a turn of bucked logs through the bucking chute. Ideally, this should be accomplished by generating a random number for limb time, another random number for buck time, and two more random numbers to adjust limb time and buck time by the percentage of logs actually requiring processing. Unfortunately, the simulation program

Figure 6. Limbtime Probability Distribution For Bucked Logs.
(58.5% of Bucked Logs Required Limbing.)

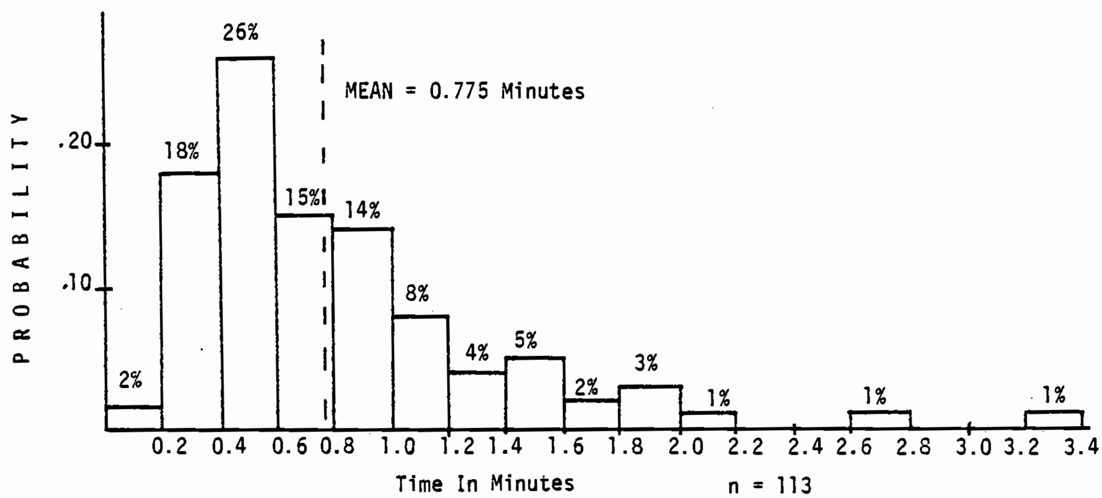
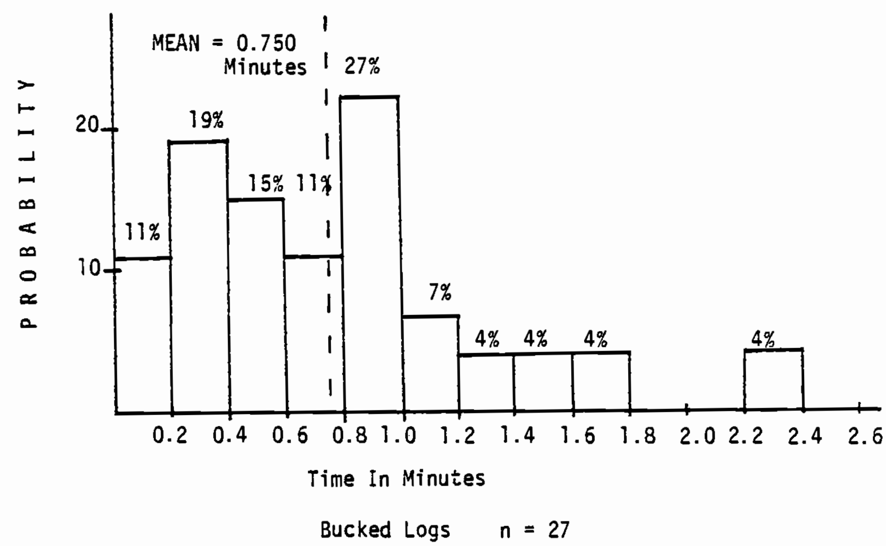
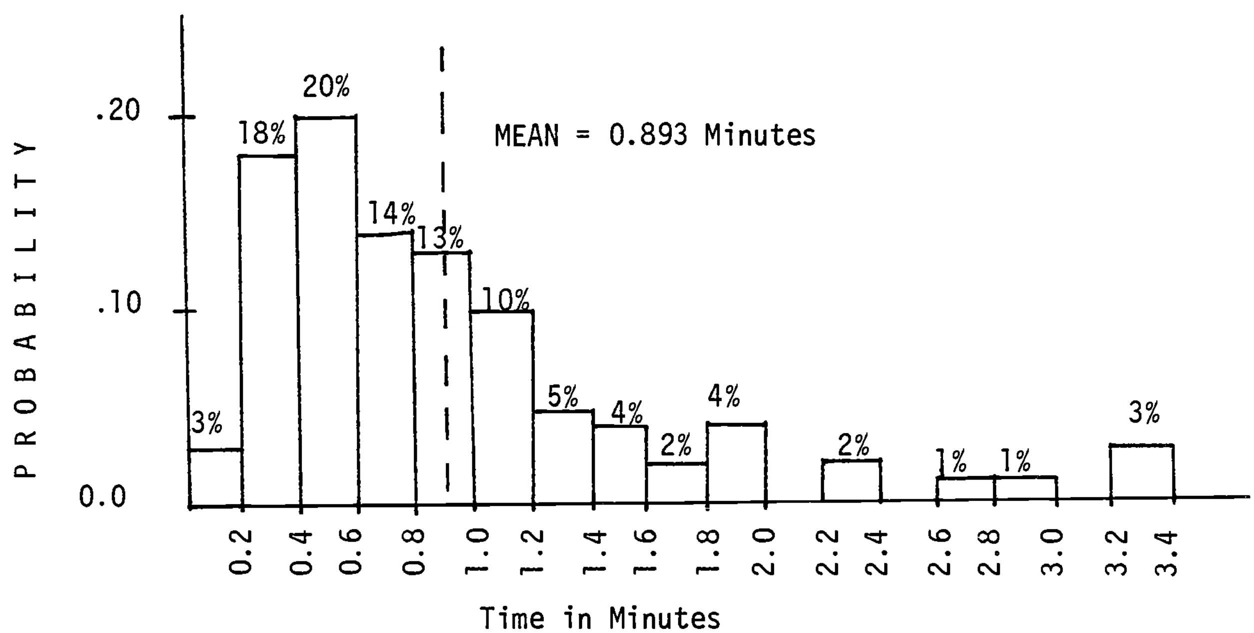


Figure 7. Bucktime Probability Distribution For Bucked Logs.
(14.0% of Bucked Logs Required Additional Bucking.)



used in the second portion of this paper only allowed the generation of nine random number strings. Using the method above would have required more than the available number of random number strings when random number strings for all the other functions were included. To conserve the number of random number strings used by the program, the limb time and buck time distributions were combined into a single probability distribution by adding the two times together for each log. This resulted in the probability distribution for total processing time shown in Figure 8. The use of this combined probability distribution will increase the variation of the processing time over that which would have resulted from the use of two separate distributions, but unfortunately, it could not be avoided.

Figure 8. Derived Production Function for Bucked Logs.
(58.5% of Bucked Logs Required Additional Processing.)



Buck Time + Limb Time Probability Distribution
Bucked Logs

The time to process a turn through the bucking chute was then calculated as follows: a random number was generated which gave a time to process a single log. That time was then multiplied by the number of logs in the turn. Finally, a second random number was generated which reflected the fact that not all the logs required additional processing in the bucking chute. This second random number was generated from an approximation of a normal curve with a mean of 0.58 and a standard deviation of 0.13 based on the fact that only 58% of the bucked logs in the helicopter study required additional processing.

$$\text{Processing Time} = (\text{time/log})(\text{no. logs/turn})\left(\frac{\%\text{ logs processed}}{100}\right)$$

Note that the method discussed above introduces an unnecessarily large variation into the processing time for the load. Another procedure would have been to treat each log individually, generating one random number to determine if additional processing is required and, if necessary, a second random number to determine the processing time for the log. The sum of the processing times would then be the processing time for the entire load. The mean time for processing all the days loads would be the same for either method, but the increased variation resulting from the first method will have an adverse effect on the results, particularly when only one or two buckers are being used. In future runs and in the Aerospace Corporation simulation, the second method will be used. Because this error will only affect the number of buckers on the landing, and will only result in a possible decrease of one bucker, it was decided not to run all the simulations over. A change in the number of buckers would have no effect on the critical elements of the simulation.

PROCESSING TIME FOR TREE LENGTH AND WHOLE TREE LOGS - The sample size for tree length and whole tree processing in the bucking chute were very small (n = 5 for tree length and n = 10 for whole tree). Because of the small sample size some gross assumptions were needed to build the processing time probability distributions which were made as follows: it was assumed that the mean and the range would change while the general shape of the probability distribution would remain the same. A mean (tree length = 2.238 minutes, whole tree = 3.183 minutes) and a range were calculated for both types of logs, and the probability distribution was shifted about the new mean and within the new range. Thus, the standard deviation and the mean have both increased dramatically in the new distributions, but the general shape of the curve has remained the same. In calculating the processing time for a turn of logs it was assumed that all pieces would require some additional processing so the formula for processing time was simplified to:

Processing time/turn = (time/log)(no. of logs/turn)

The left side of the probability distribution was truncated under the assumption that tree length logs could not be bucked and limbed in less than 0.5 minutes and whole trees would require at least 1.0 minute.

Figure 9. Bucking Production Distribution Function For Tree Length Logs.

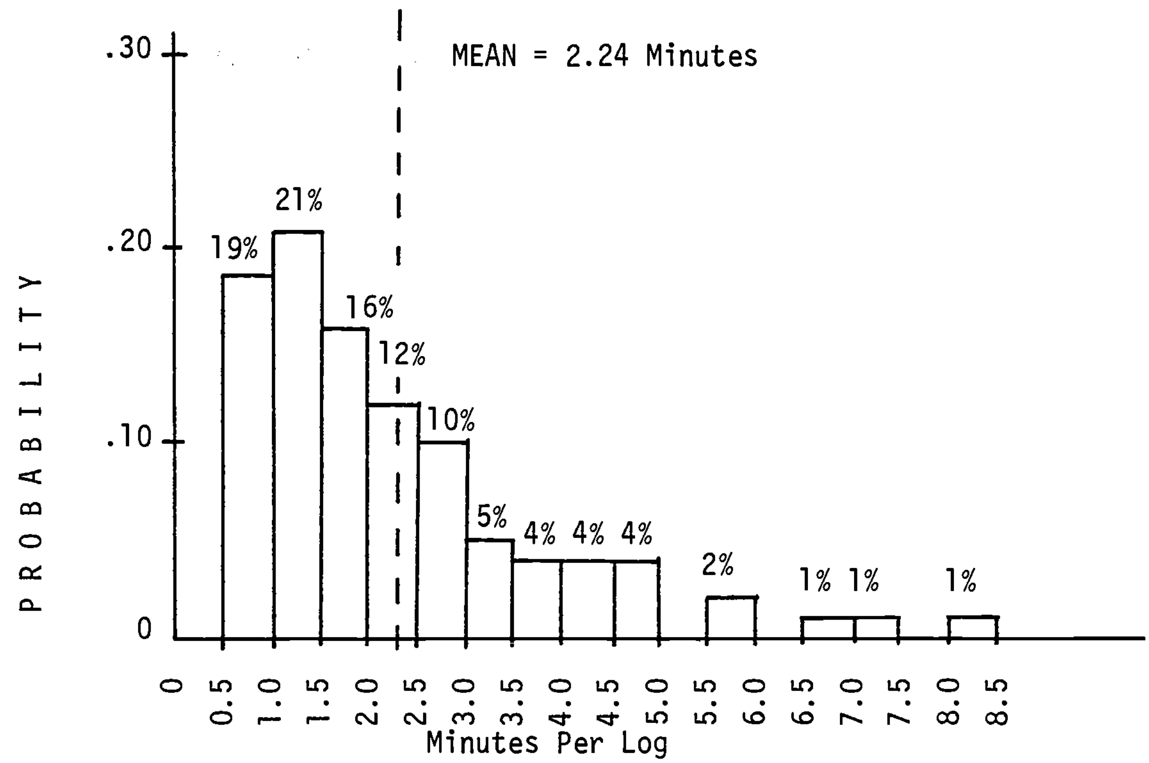
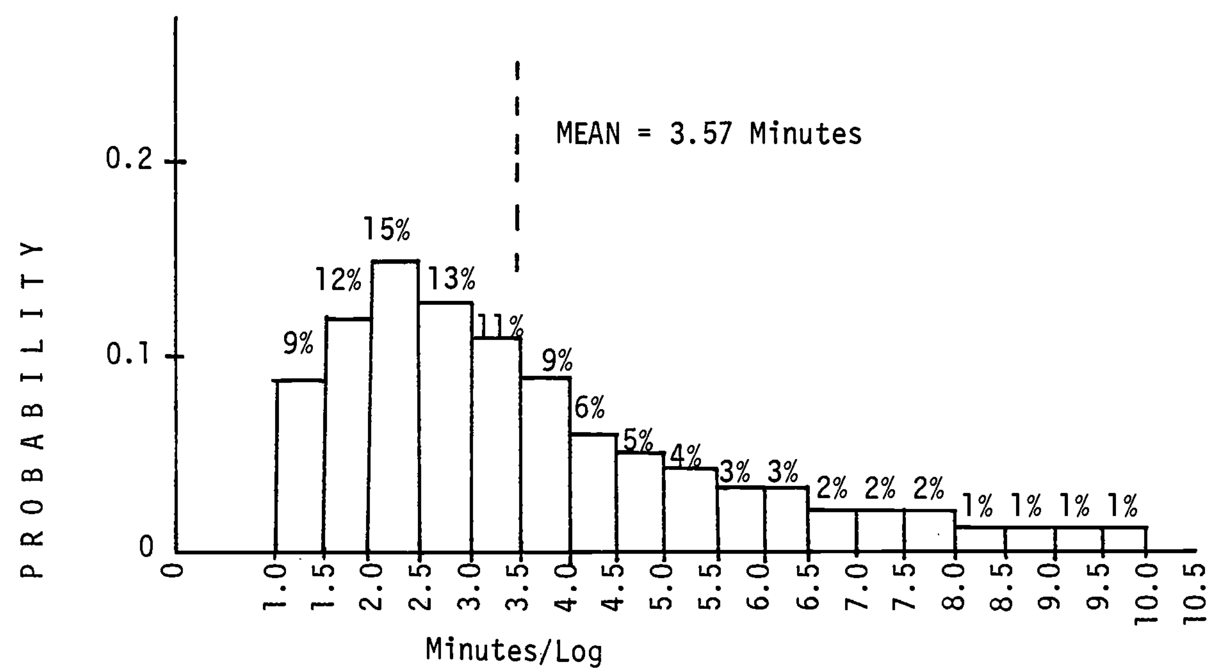


Figure 10. Bucking Production Distribution Function for Whole Tree Logs.



SIMULATION PROCEDURE

The purpose of the preceding time study was two-fold. The primary purpose was to provide landing production data for the Aerospace Corportion of Los Angeles, California so that they could build a user-oriented simulation program that would simulate all logging operations from the stump to the cold deck. The purpose of their simulation is to determine the most economical overall logging system for the Heli-stat. The secondary purpose for the time study was to provide data for an independent simulation of the landing operation. This simulation was performed to verify the production rates and to act as a back-up program to the main Aerospace program. The results of this simulation program give a tool with which to check the results of the Aerospace simulation. At the time of this writing, the Aerospace simulation is not complete.

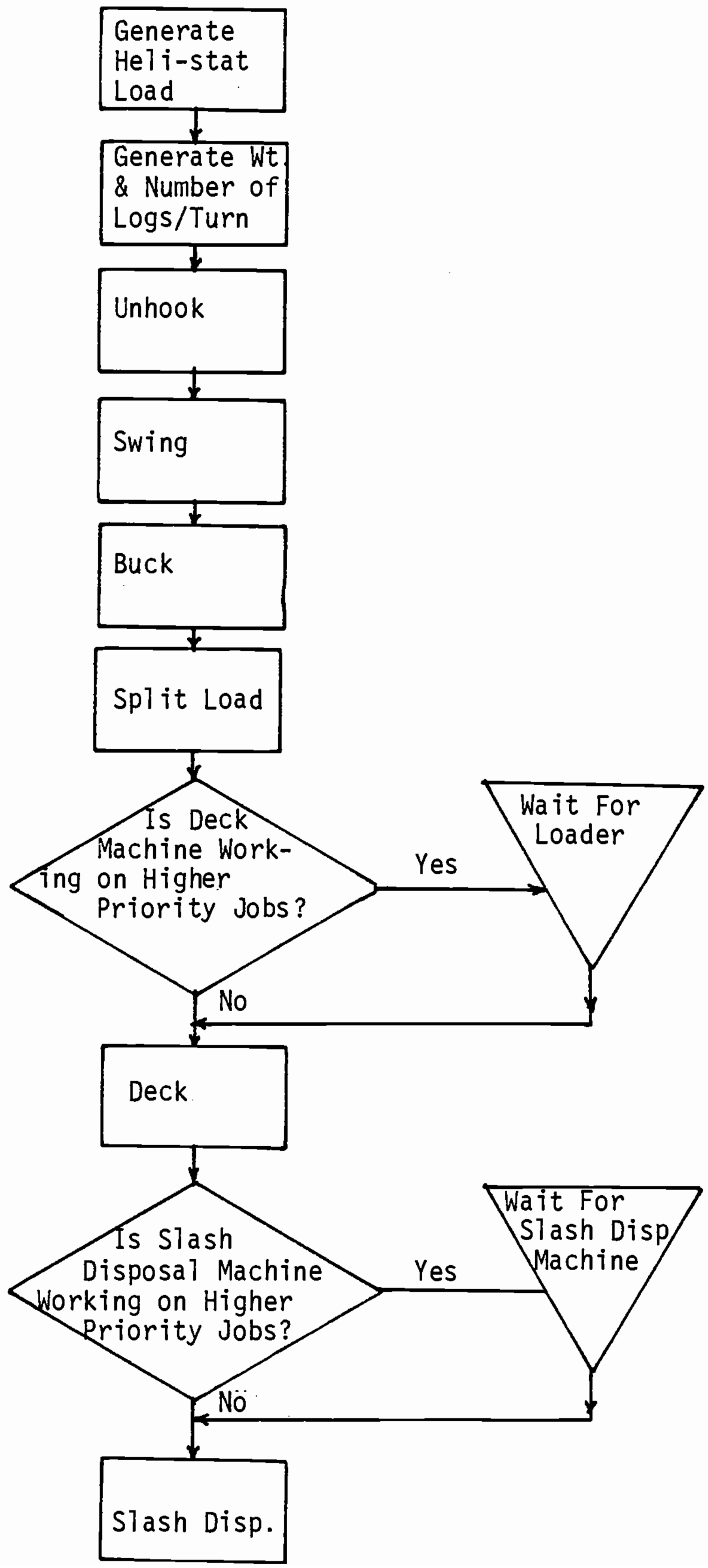
The computer programs for the landing simulations analyze the operation of the Heli-stat landing for the three types of logs (log length, tree length, and whole tree) and the three different arrival configurations (convention hook and chokers, tagline and sliders, and unitized bundles). The programs are capable of evaluating a number of different landing configurations and equipment types.

The production rates for landings with two dropsites were compared against landings with a single dropsite. The simulation also compared landing configurations where the loader handled three job functions (swing, deck, and slash disposal) against a configuration with a separate machine for each job function.

The programs were written in the General Purpose Simulation System (GPSS V) language developed by IBM Corporation in 1971. The programs were run on the Cyber 70/73 computer at Oregon State University. GPSS V is an excellent language for simulating queuing problems and the Heli-stat landing is essentially a queuing problem. Each Heli-stat load was treated as an entity which had to be processed through five separate facilities: unhook, swing, buck, deck, and slash disposal. Accumulations of logs can develop at each of the five facilities. The objective of the simulation was to determine the fastest average turn time which a given landing configuration could process without building up unacceptable queues at any of the facilities. A long queue indicated that the landing had become jammed with logs which would cause the Heli-stat to be idled. The basic assumption behind the simulation was that the landing must always operate efficiently so that the Heli-stat would never be idled due to a jammed landing. The basic flowchart for the simulation program is shown in Figure 11.

A trial and error procedure was used for determining the critical turn time for a given landing configuration. Random turn times were generated from a uniform distribution that was equal to the desired turn time ±1 minute. An initial decision was made on the number of dropsites and the number and type of heavy equipment for a single simulation run. The number of chasers and buckers were varied as different turn times were investigated until a turn time was found which would keep the loaders and skidders 80 to 90% utilized while keeping queue lengths down to acceptable limits. Keeping small queue lengths meant that the chasers and buckers were usually underutilized (50% utilization or less), but there are two very good reasons for this underutilization. The first

Figure 11. Flowchart of Simulation Program.



reason is related to the Poisson distribution of their service curves. Keeping the queue lengths small meant that the buckers and chasers had to be able to process the "worst case" loads efficiently enough to prevent a large queue from developing. This meant that the average loads were processed very quickly creating the underutilized condition. The second reason for the low utilization is related to the logistics of the landing operation. The queue for the chasers and the queue for the swing machine both form on the dropsite. Similarly, the queue for the buckers and the queue for the deck machine both form in the bucking chute. These queues have a direct effect upon each other. Keeping a high utilization rate on the skidders and loaders means that some small queues may develop behind the swing and deck functions. These queues reduce the allowable queues for the chasers and buckers, thus decreasing their utilization rate.

Critical queue lengths at each station varied with the type of log being yarded and the landing configuration, but generally followed these guidelines:

Dropsite: Unhook queue + Swing queue ± 1 Heli-stat load

Ninety-five percent of the queue lengths had to be zero because of the critical nature of the dropsite. Any queue build-up at this point would idle the Heli-stat. Ideally, 100% of the queue lengths should be zero, but this is impractical both in a real logging situation and in the simulation. Ninety-five percent was used as a practical compromise.

Bucking Chute: Buck queue + Deck queue ± 3 Heli-stat loads

Queues could be more easily handled at this station. Logs waiting in the bucking queue must be laid out individually, but logs waiting in the deck queue can be pushed to the back of the bucking chute by the loader and stored in a pile.

Slash Disposal Queue:

More slash is generated by a whole tree load than by a tree length or log length load. The slash is defined in turns of the Heli-stat load, not in terms of the actual tons of slash generated.

Whole tree queue $\leq$ 4 Heli-stat loads

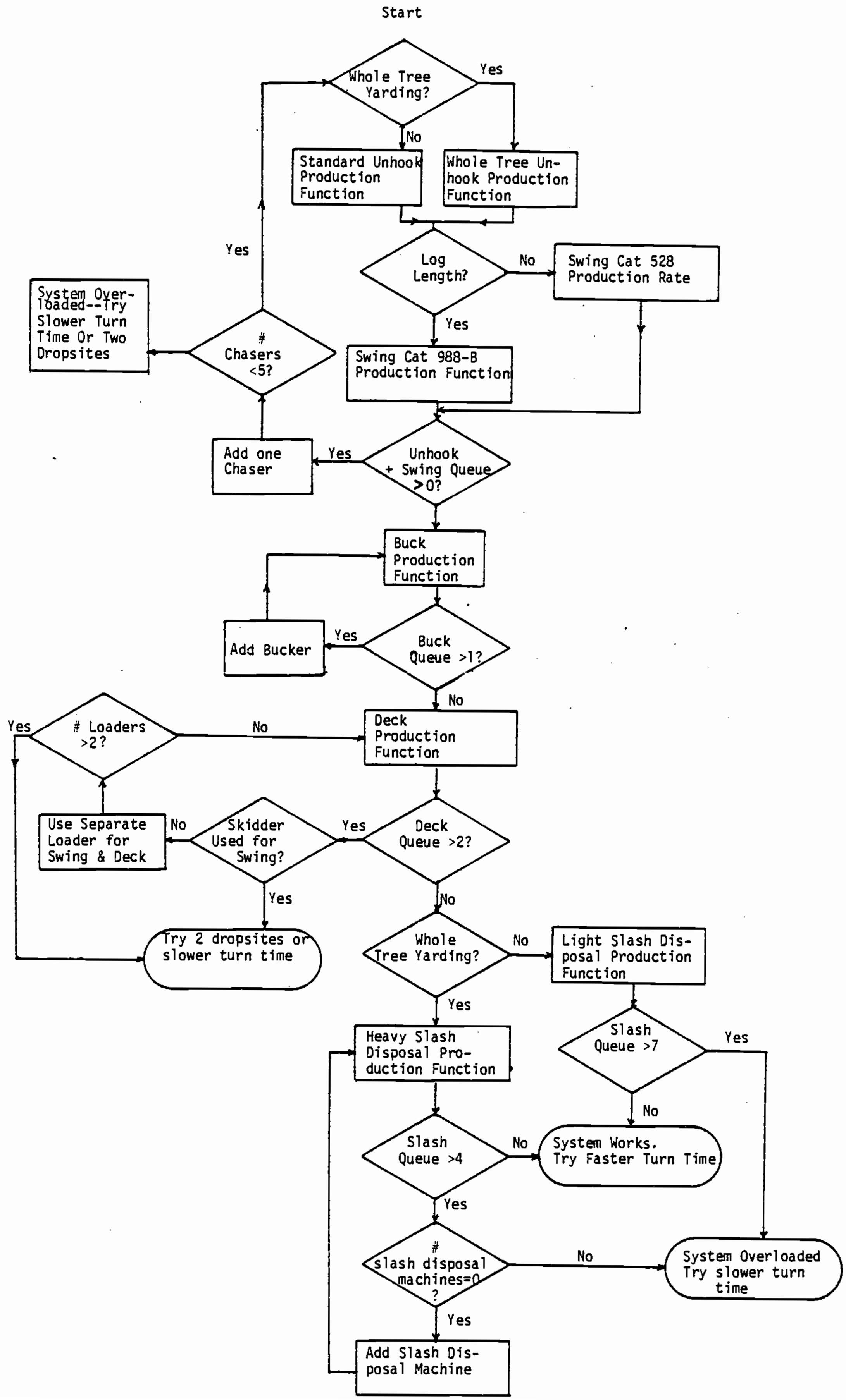
Tree length or log length queue $\leq$ 7 Heli-stat loads.

A general flowchart of the decision-making processes for finding the minimum turn time and optimum crew size is shown on the following page.

An example of the GPSS program is included in the Appendix of this paper. The highlights of the program are as follows:

1. Each Heli-stat load is assigned a weight in tons and a random number of logs in the load. The weight was drawn from a uniform distribution with a range of two tons. The number of logs was drawn from a uniform distribution of 3 to 9 logs for bucked logs and a right skewed distribution of 1 to 6 logs for tree length logs and whole trees.
2. All load parameters and production functions are generated by random number generators to simulate the variability in logging operations.
3. The Heli-stat load moves through each processing function (unhook, swing, buck, deck, slash disposal) in a sequential order.
4. When one loader is used for several functions, a priority is assigned to jobs waiting in the different queues. The swing queue has the highest priority, deck queue has the next highest priority, and the slash queue has the lowest priority. This prevents queues from building up at the points where they would do the most harm. It also simulates the decision-making process of the loader operator.

Figure 12. Flowchart of Trial and Error Process for Simulation.



5. The simulation runs are made for a 10-hour day with a 15-minute refueling break every 2 hours. Two hours is the upper range of the estimated operating period and is used in this simulation to allow the landing to approach a steady state condition.
6. The program allows the loader to process a partial load in the deck and slash disposal functions. This allows the loader to stop working on a job when a higher priority job becomes available. This is necessary to make the priority system work effectively. It also simulates a real landing situation where the loads are mixed together in the bucking chute and processed in pieces thereafter.
7. The most important outputs of the simulation are:
   a. utilization rates for buckers, chasers, loaders, and skidders
   b. mean processing time per transaction through each station
   c. mean waiting time in each queue
   d. maximum queue lengths
   e. percent of transactions that had a zero waiting time in each of the queues
   f. a table that gives a frequency distribution of the queue lengths throughout the ten hour day. Queues for swing, deck, and slash are measured each minute throughout the day
   g. a table that gives the frequency distribution of waiting time in the queues for each transaction at each heavy equipment facility

The output must be evaluated both objectively and subjectively to verify that the system is working efficiently. When a minimum turn time and optimal crew size is determined, five simulation runs are made to verify the results. An analysis for the statistical significance of the results of these five runs is difficult because each of the five queues is radically different from the others. The histograms for queue lengths are badly skewed with a mean very close to zero. Using this mean for statistical analysis would be possible, but the results would not be a reflection of the evaluation criteria, i.e., maximum queue length. A more realistic approach is to use maximum queue length since this was the criteria for accepting or rejecting a given crewing system. The problem with doing any type of statistical analysis on the maximum queue length is that by definition none of the five runs will exceed the critical queue length. The data base therefore is extremely biased. Also, there is no reasonable method for testing significance of the extreme numbers on skewed distributions. Therefore, the results of this simulation are best evaluated in a subjective manner rather than trying to perform statistical analysis on data that does not lend itself to statistical analysis.

The production functions used in the simulation are the same ones that are described in the previous section entitled, "Results of Time Study." It was necessary to add two additional pieces of equipment whose production rates were determined by mechanical analysis techniques. The first piece of equipment was a Caterpillar 988-B class front-end loader. The time study was done on a Caterpillar 966-B front-end loader which has a payload capacity of less than half of the 988-B. After a few simulation runs with the 966-B, it became obvious that a 966-B was too small for the large loads yarded by the Heli-stat. A mechanical analysis using payload, travel speeds, and maneuverability determined that the production capacity of a 988-B was roughly double that of the smaller 966-B. The 988-B was used in most of the simulation runs. The second piece of equipment was a large skidder for swinging whole tree and tree length logs from the dropsite to the bucking chute. Using a front-end loader to swing these tree length pieces would be inefficient in terms of production rates and maneuvering room. A large skidder could hook onto the chokers that are still attached to the load or use a set of grapples. The mechanical analysis procedure outlined in the Caterpillar Handbook (10th Edition, 1979) was used to determine the production rate for a Caterpillar 528 skidder on the landing. The result was compared to studies done on skidding in the woods (Ohmsteade, 1977), (Seiffert, 1982), and (BLM Schedule 20, 1977), to verify the calculated production rate. The production rate was slightly higher than those predicted by the above three articles, but that is to be expected when comparing an open landing to skidding in the woods.

Probability distributions for the Cat 528 skidder, the 966-B loader, and the 988-B loader were developed based on average production rates. Reasoning that a front-end loader would have an upper load limit above which it becomes unstable, the following triangular probability distributions were used.

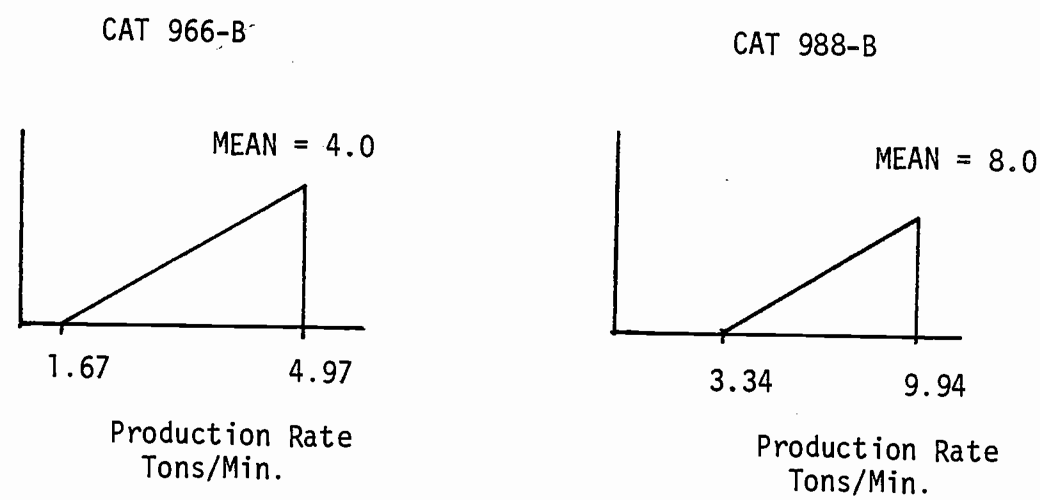


Figure 13. Probability Distribution Functions for Swing Production Rates of Front-End Loaders for Swing.

The 528 skidder does not have a stability limitation, so a normal distribution was approximated with the following triangular distribution.

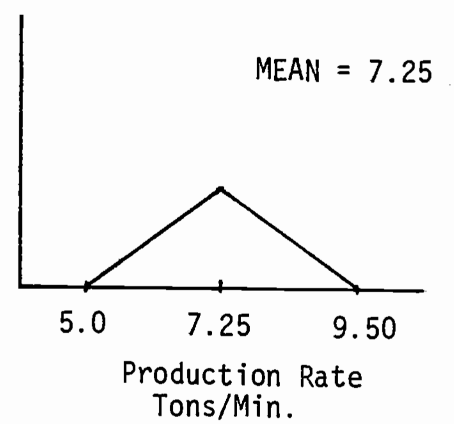


Figure 14. Probability Distribution Functions for Swing Production Rates of Large Skidder.

The probability distributions for decking and slash disposal production rates also had to be estimated from the means determined in the time studies.

Figure 15. Probability Distribution Function for Decking Production Rate.

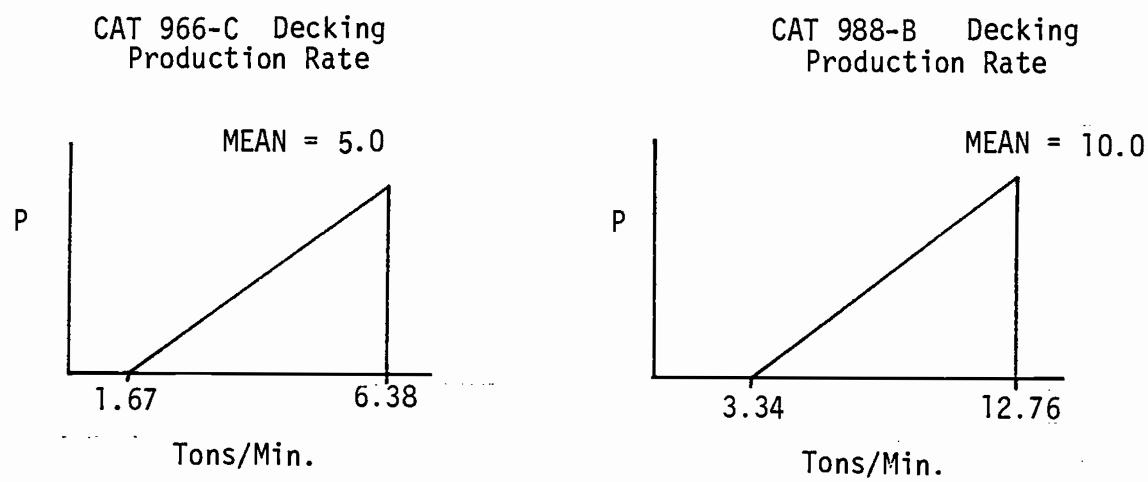
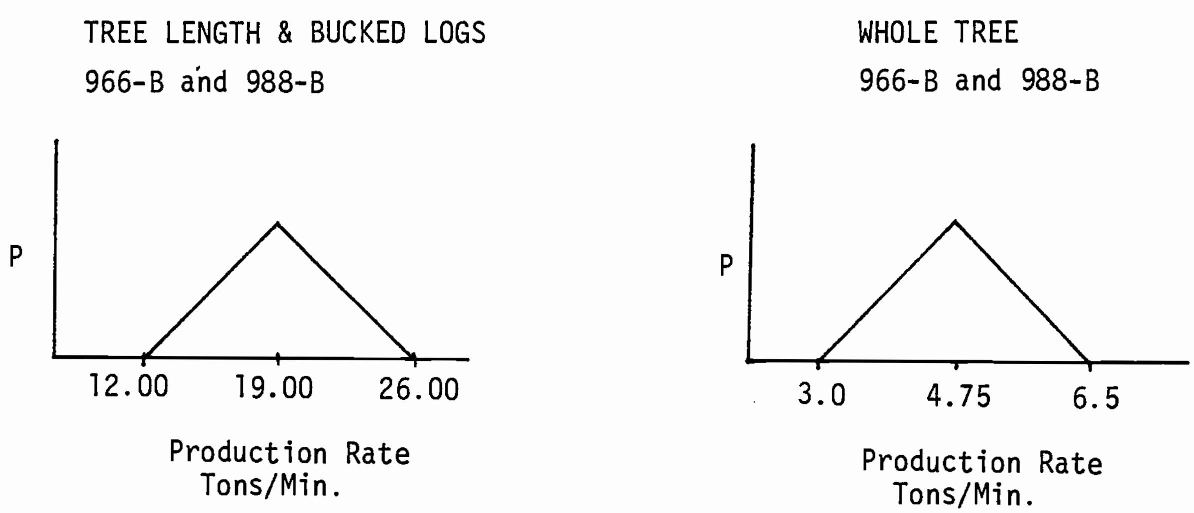


Figure 16. Probability Distribution Functions for Slash Disposal Production Rates of Front-End Loaders.



The units for the slash disposal production rates are in tons of Heli-stat load/minute, or in other words, in terms of the slash generated by a ton of logs. Thus, the left hand graph shows that the mean production rate of the loaders is the disposal of the slash from 19 tons of Heli-stat load in 1 minute. It was felt that there would be a negligible difference between the 966-B and the 988-B in pushing slash around the landing.

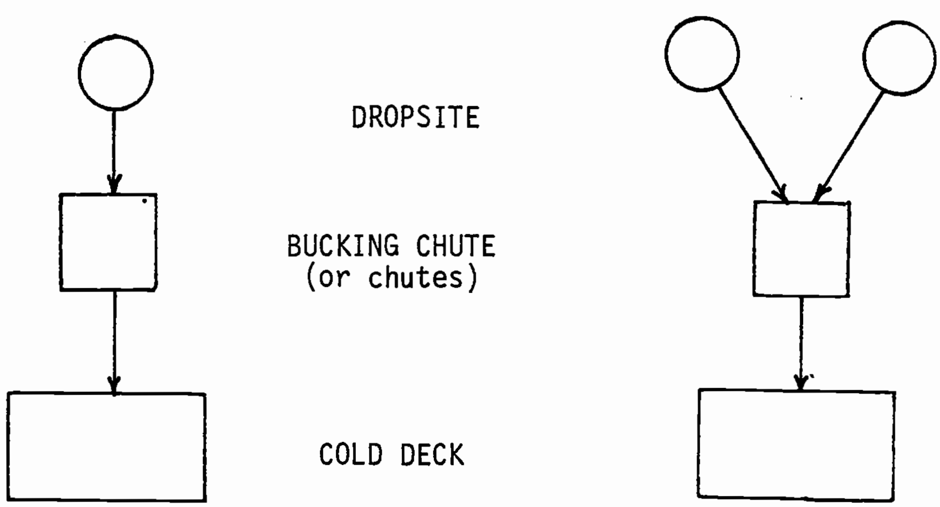
RESULTS OF SIMULATION

Optimizing and verifying the GPSS simulation runs is both time consuming and expensive. The trial and error procedure used in determining the optimal landing crew size for the fastest turn time requires many unusable runs, each of which costs $0.50 to $1.00 on the Cyber 70/73.

The expense of investigating and optimizing every possible condition was prohibitive for this particular type of simulation program. For this reason, only those conditions which were most representative or most probable were simulated.

The main objective was to determine the fastest allowable turn time for a landing with one dropsite and compare these turn times to the turn times for a landing with two dropsites.

Figure 17. Diagrams of Simulated Landings.



The minimum turn time was determined for loads consisting entirely of either bucked logs, tree length logs, or whole trees. Yarding of one type of load was simulated for the entire 10 hour day. Loads consisting of mixed log types were not considered, nor was the possibility of alternating loads of different types.

The processing of loads that were assembled with conventional hook and chokers was nearly identical to those assembled with a tagline and sliders. The only difference was that the chaser must spend more time handling the tagline in the latter option. Processing unitized bundles was, of course, radically different.

Most of the simulations were run with a Heli-stat payload weight drawn from a uniform distribution of 17 to 19 tons. A few runs were made with a uniform payload weight distribution of 23 to 25 tons. These weights were based on estimates from the U.S. Forest Service Operational Plan, Heli-stat Evaluation Trials (Beavers et. al., 1980). The number of logs in the turn varied with the type of log being yarded. Loads consisting of bucked logs were drawn from a uniform distribution of 3 to 9 logs. Loads of tree length or whole tree logs were drawn from a right skewed distribution of 1 to 6 logs with the mean load of 2.7 logs. These distributions were the same for all runs except those with 24 ton Heli-stat payloads where the number of logs per turn was increased by approximately 33%. The payload weights and number of logs per turn could easily be varied on future runs, but they were kept constant in this study in order to compare landing configuration solely on the basis of turn time and crew size with the corresponding production rates and cost figures.

The landing production rate in tons/hour was calculated from the mean number of turns for each simulated 10 hour day. The cost per ton was based on equipment and labor costs using February, 1982 cost data. The cost per ton was based on an 8 hour day, that is, no overtime was included in the wages. Hourly costs for the skidders and loaders were calculated using an average annual investment procedure as outlined by Ron Miffin (1980). The following equations and variables were used in the equipment costs.

I. Ownership Costs:

Residual value = 15% of new equipment cost

Depreciable value = new equipment cost - residual value = I-R

$$\text{Equipment depreciation} = \frac{\text{depreciable value}}{\text{depreciation period}} = \frac{I-R}{N}$$

$$\text{Average Annual Investment} = AAI = \frac{(I-R)(N+1)}{2N} + R$$

Interest Expense = .20 (AAI)

Taxes, license, insurance = .09 (AAI)

$$\text{Ownership Costs} = \frac{\text{annual ownership cost}}{\text{total annual hours}} =$$

$$\frac{\text{equipment depreciation + interest expense + (T,L, and I)}}{\text{total annual hours}}$$

II. Operating Costs in $/Hr.

Repairs and maintenance = $\frac{\text{(repair rate in percent)(equipment depreciation)}}{\text{total annual hours}}$

Fuel cost = fuel consumption rate x $1.10/gal.

Oil and lubricant = 7% of fuel costs

Tire cost = Depreciated Tire Cost, Plus 15% Maintenance

Labor cost = 140% of wage rate

Travel time = $.70/hr.

Supervision and overhead = 20% (direct labor + travel time costs) +

Total Operating Costs = Sum of Above Costs

III. Total Hourly Costs = Ownership Costs + Operating Costs

The following figures were used in the cost calculations:

	CAT 518 Skidder	CAT 528 Skidder	CAT 966-B Loader	CAT 988-B Loader	Chainsaw
Initial Cost (minus tires)	$ 74,149	$106,839	$166,692	$214,541	$ 600
Depreciation Period	4 years	4 years	4 years	4 years	2 years
Annual Use (HRS)	1400 hrs.	1400 hrs.	1600 hrs.	1600	1400 hrs.
% for Repairs & Maintenance	50%	50%	50%	50%	50%
Fuel Consumption (Gals/Hr.)	4.5	6.3	5.5	6.5	0.25
Tires ($/Hr.) (see Appendix A)	$1.96	$3.54	$3.72	$9.17	0
Operator's Wage ($/Hr.)	$12.10	$12.10	$12.10	$12.10	0
Total Cost/Hour	$55.78	$71.52	$85.15	$107.22	$0.92

Other wage costs include 40% social costs:

Chaser: $13.16/hr.

Bucker: wage = $13.94/hr.

saw = $ .92/hr.

$14.86/hr.

The Cat 518 skidder was costed out for use as a slash disposal skidder for those landing configurations which required a separate slash disposal machine. The Cat 518 was used because it could also serve as a skidder for swinging smaller logs if needed.

Figures 18 and 19 show the minimum turn times and required crew sizes for the two different landing configurations. The number of required chasers and buckers will decrease as the turn time increases from the minimum. The size of the bucking chute will have to be large enough to accommodate the required number of buckers. Two or three buckers can work safely in an area 120' x 50', but a work area for eight buckers would require a much larger area plus maneuvering room for the equipment. The number of required pieces of heavy equipment normally cannot be varied within the turn time limits. The production rates vary widely for the different landing arrangements, but the cost per ton for bucked or tree length logs are roughly clustered around $1.20/ton. The last column explains which job function or work area will fail if the turn times become faster than the recommended minimum.

Some good conclusions can be inferred from the production cost data, but one should refrain from jumping to hasty conclusions. The production rates and cost figures should be used only for comparison of different alternatives and not relied upon as absolute costs. The production rates do not include time for breakdown and delays. The time study of the helicopter landing showed breakdown time to be non-existent and delay time to be nearly negligible (less than 5%). Rather than including these suspiciously low times in the simulation, it was decided to make the simulations delay free. By comparison, Gilles (1977) found delays and breakdowns in a sort yard to be 30.7% of the total time. Omitting delays will mean that the absolute values of the production rates resulting from this simulation will be larger than can reasonably be expected, while the absolute costs will be less than expected. The relative costs and production rates should remain approximately the same. The production costs include only those costs which will vary between alternatives. Landing construction, surfacing, maintenance, and supervision will be equal for all alternatives and will, therefore, add only a large constant to each figure. Since these costs will have a wide variance between sites, they were left out of the calculations. Also, in an operation of this scale, a logging boss would be foolish not to have additional equipment on hand for use in an emergency. A major breakdown on a loader or skidder would quickly shut down the Heli-stat until repairs are made. An additional skidder or loader would be an inexpensive insurance policy against such a breakdown. The equipment would probably be old and fully depreciated, so the fixed cost of allowing it to sit idle should be relatively small. Finally, the total cost of slash disposal was not included in the analyses. A cost was computed for pushing the slash away from the dropsite and bucking chute, but no cost was included for activities such as burning, burying, chipping, or hauling the slash. It was felt that this cost would be site specific and could not be determined for a general case that would apply to all landings. This slash disposal cost will contribute a large additional cost to the whole tree logging alternatives and should definitely be included in any total cost evaluations. It was left out of this analyses because slash disposal in the woods could not be included for comparison.

The costs and production rates given in figures 18 and 19 should be considered as part of the larger, overall logging operation. For example, the most economical load type for the landing operation is obviously a unitized bundle of logs. It can be picked up in one bundle by a large loader and placed directly on the cold deck. However, the additional cost of assembling a unitized bundle in the woods will probably offset the savings at the landing or may not even be possible in steep terrain. Similarly, the most expensive alternative for the landing is whole tree logging, however, the savings gained by avoiding limbing and bucking in the woods may make whole tree logging the most economical choice, particularly

Figure 18. Simulation Results for Landing with One Dropsite.

LANDING CONFIGURATION: 1 DROPSITE

Load Type	Minimum Turn Time (Minutes)	# Chasers	# Buckers	#528 Skidders	#988 Loaders	#966 Loaders	# Slash Skidders	Cost/Hr.	Tons/Hr.	$/Ton	Limiting Factor
18 TON LOADS											
Bucked Logs	10.0	2	2			1		$141.19	98	$1.44	Loader Overworked
	6.0	3	3		1			191.28	163	1.17	Loader Overworked
	4.5	3	3		2			298.50	216	1.38	Dropsite Becomes Jammed
Tree Length	4.0	2	5	1	1			279.36	245	1.14	Queue Lengths on Dropsite
Whole Tree	4.0	3	6	1	1		1	363.16	241	1.51	Queue Lengths In Bucking Chute
	6.0	2	5	1	1			279.36	163	1.71	Slash Disposal
Unitized Bundle	3.5	1			1			120.38	279	0.43	Loader Overworked
24 TON LOADS											
Bucked Logs	13.0	1	2			1		128.03	99	1.29	Loader Overworked
	7.0	3	2		1			176.42	184	0.96	Dropsite Becomes Jammed
Tree Length	5.0	2	6	1	1			294.22	258	1.14	Slash Disposal
Whole Tree	6.0	2	6	1	1		1	350.00	217	1.61	Bucking Chute Clogged With Logs and Slash

Figure 19. Simulation Results for Landing With Two Dropsites.

LANDING CONFIGURATION: 2 Dropsites

18 TON LOADS

Load Type	Minimum Turn Time (Minutes)	# Chasers	# Buckers	# Skidders	# Loaders	# Slash	Cost/Hr.	Tons/Hr.	$/Ton	Limiting Factor
Bucked Logs	3.00	6	5		2		$367.70	325	$1.13	Deck Queues Become Too Long in Bucking Chute
	2.50	6	6		3		489.78	390	1.25	Dropsites Become Jammed
Tree Length	3.50	2	5	1	1		279.36	275	1.02	Loader is Limiting
	2.00	4	8	2	2		600.40	475	1.26	Bucking Chute & Dropsite Both Become Jammed
Whole Tree	4.00	2	6	1	1	1	350.00	243	1.44	Bucking Chute Becomes Clogged With Slash
	3.00	4	8	1	2	1	513.26	319	1.61	Slash Disposal & Queues on Dropsites

in steep terrain. When this simulation data is combined with the data on load assembly and yarding the most economical overall alternative should emerge. This is the purpose of the Aerospace Corporation's simulation.

Another misleading item in the results is the basic assumption that regularly spaced 18 ton loads will be yarded to the landing under any of the four load types. It is relatively easy to assemble an optimal 18 ton payload of bucked logs, but estimating weights and assembling loads for tree length and whole tree turns will be more difficult and will probably result in more aborts and more loads that are appreciably less than optimal weights. This may result in lower production rates than those indicated in Figures 18 and 19 for tree length and whole tree yarding.

One reliable conclusion which does emerge from the results is found in the comparison of production costs for bucked logs vs. tree length logs. The production costs for the tree length logs compare favorably to the production costs for bucked logs. This is probably due to the economy gained in swinging the logs from the dropsite to the bucking chute with a skidder as opposed to a front-end loader. At the dropsite the skidder can quickly assemble a load either by using the chokers that are still attached to the log or by using a set of grapples. In old-growth timber, each butt log will still be attached to one or more additional logs, thus the loads are already assembled for the skidder. The front-end loader with bucked logs, on the other hand, must take more time to arrange the jack straw logs into a manageable load. At the bucking chute the skidder can quickly lay out his tree length logs for bucking, while the front-end loader must exercise more care in rolling out his load of logs to avoid creating a small jack straw situation in the bucking chute. When this faster production is combined with the lower hourly cost, the savings are enough to offset the cost of employing additional buckers on the landing.

Also, tree length logging requires fewer chokers for an equal volume of wood, thereby requiring fewer chasers. With the landing costs for the two alternatives being roughly equivalent, one wonders what the savings in the entire logging cycle will be when one avoids the need for bucking logs in the steep country that the Heli-stat is designed to access. The completed simulation by Aerospace Corporation should answer this question.

A second interesting result of the simulation is the relatively low Heli-stat turn times which can be handled by conventional equipment on large scale landings. Although the exact production capabilities of the Heli-stat will not be known until after completion of the qualification tests in Lakehurst, New Jersey, it is unlikely that the Heli-stat will have the maneuverability necessary to be faster than the 2-4 minute minimum turn times shown in Figures 18 and 19. Based upon the results of the simulation a decision tree has been developed in Figure 20 to be used for selecting the landing configuration and crew size for 18 ton loads.

Finally, some type of analyses of the significance of the results of the simulation must be made. As mentioned previously, the criteria used to evaluate the simulation runs (i.e., equipment utilization rates and maximum daily queue lengths) do not lend themselves to statistical evaluation, however, the cost per ton for each of the alternatives can be compared. These costs can be evaluated relative to each other to verify the fact that the costs for the different landing configurations and load types are significantly different from each other. Graphs of the stocastic convergence of the production costs are shown in Figures 21 and 22. They compare costs of equal or nearly equal turn times for 18 ton Heli-stat loads.

Figure 20. Decision Tree for 18 Ton Loads.

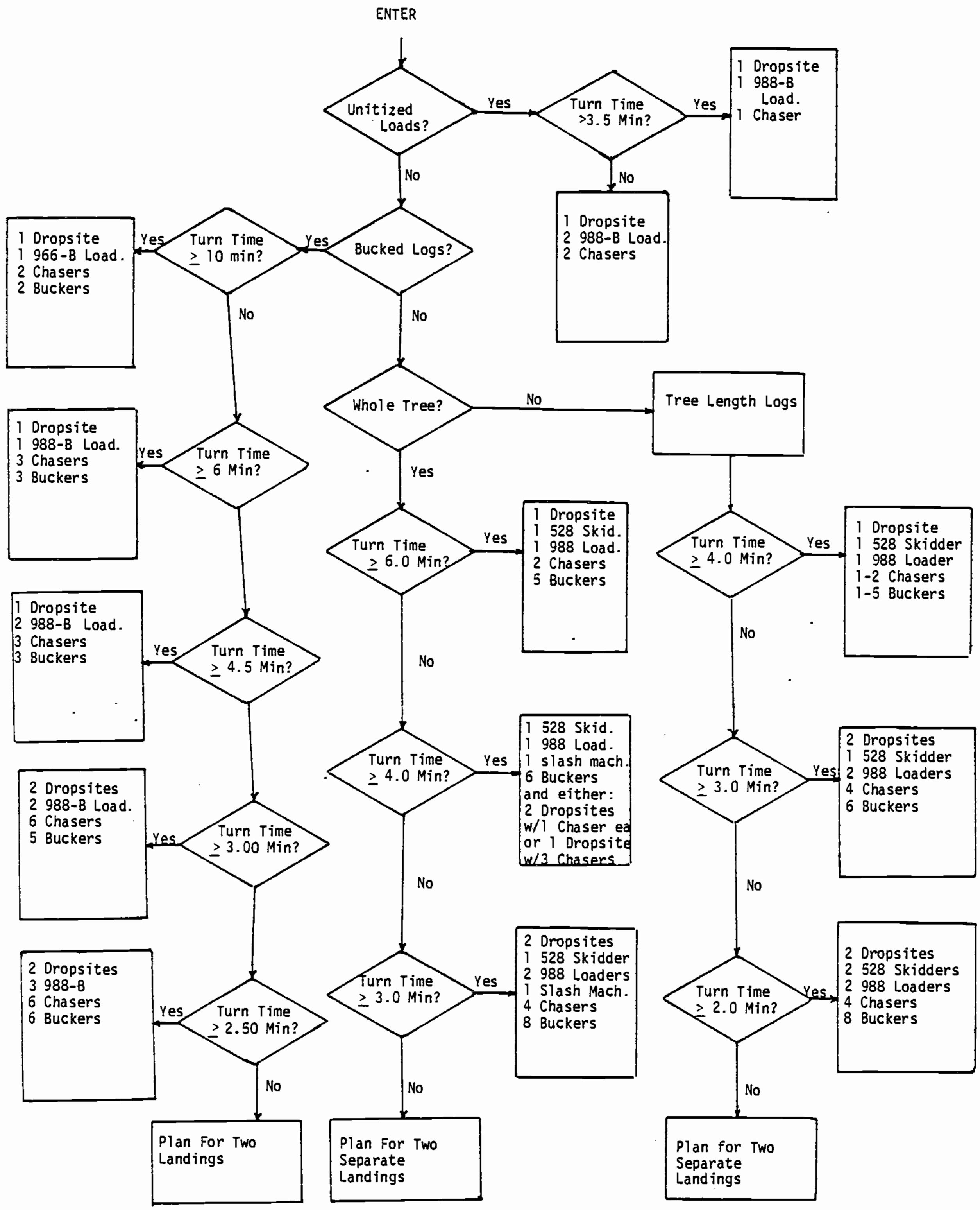


Figure 21 is for a landing with one dropsite. Figure 22 is for a landing with two dropsites. These two charts show that within the limits of the simulation model the production costs rapidly converge on a cost that is significantly different for each log type. Thus, the production costs can be relied upon to be a valid indication of the relative costs of the various alternatives.

Finally, some mention should be made of the sensitivity of the landing production rate to the piece size distribution. A decrease in the average stand Dbh will result in an increase in the number of pieces required to make an 18 ton load. Because the production rates for the buckers and chasers are based on a time per piece, an increase or decrease in the distribution of pieces per load will have a direct effect on the number of buckers and chasers required. Production rates for the skidders and loaders are based on tons per load so a change in the piece size distribution will have no effect on the production rates of the heavy equipment.

Figure 21. Stocastic Convergence Cost/Ton.

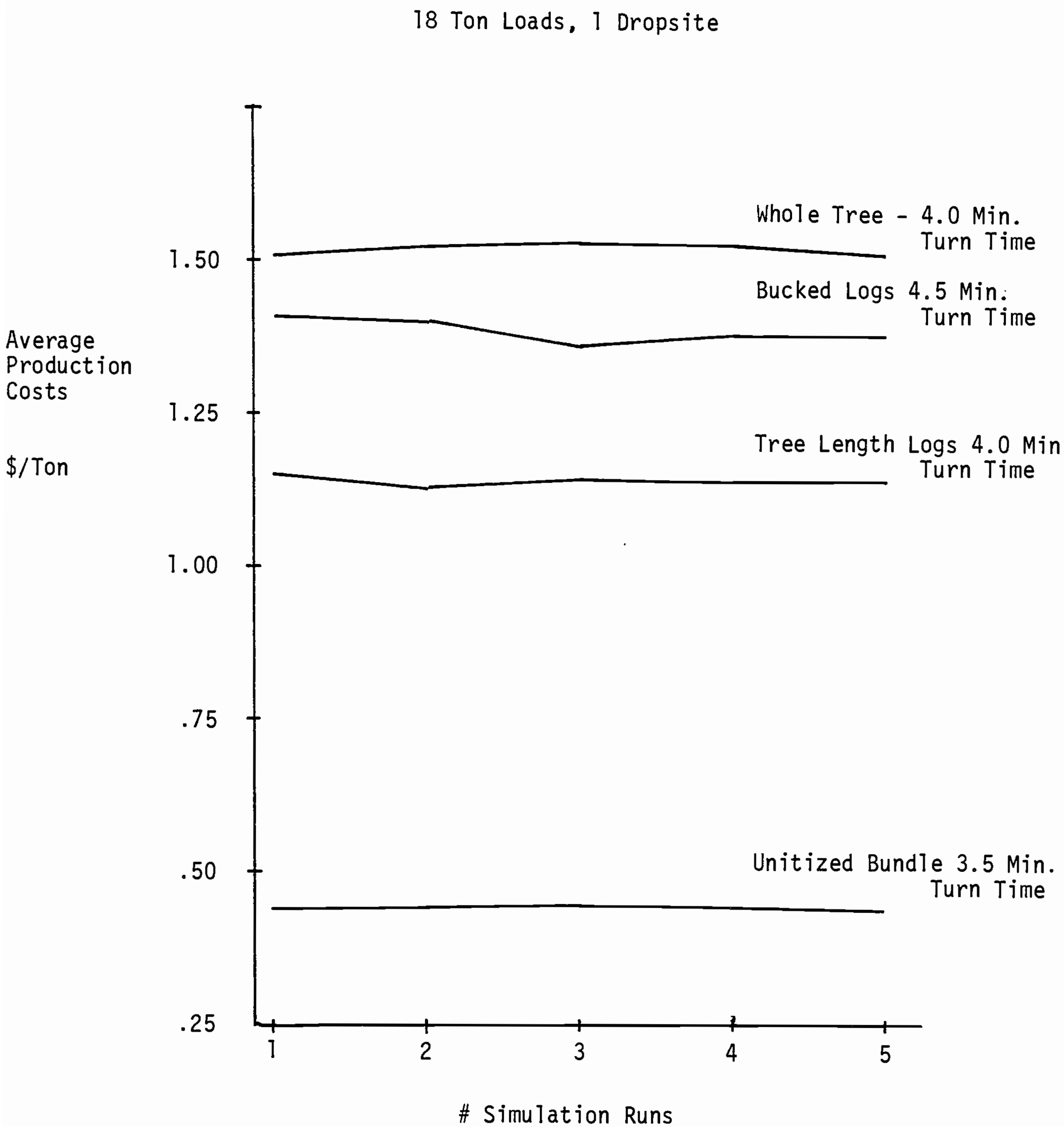
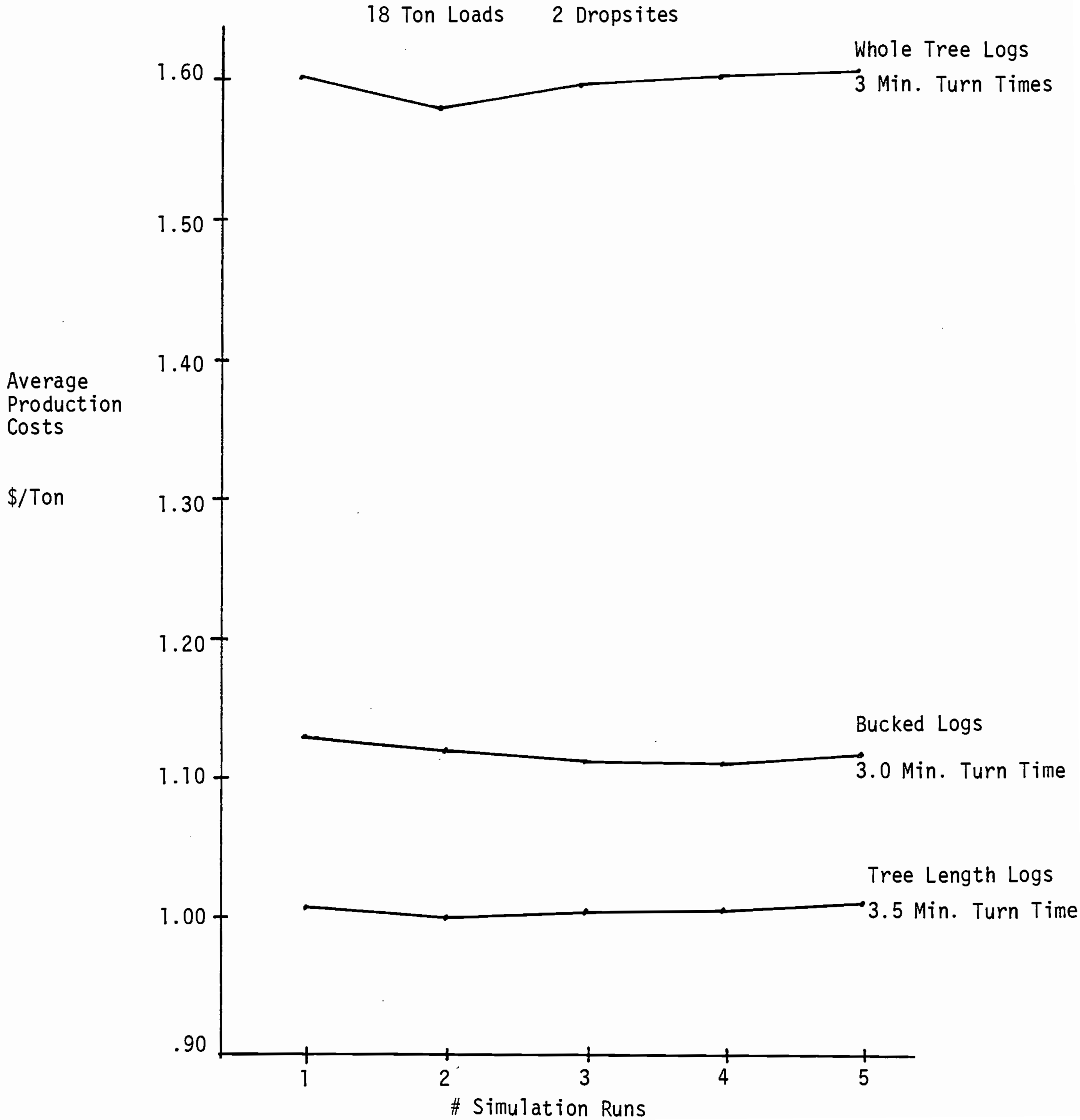


Figure 22. Stocastic Convergence of Production Cost.



SUMMARY AND CONCLUSIONS

This report is intended to be a preliminary investigation for a much larger project. The landing production rates for the chasers, buckers, loaders, and skidders presented in the first part of this paper will be used by the Aerospace Corporation of Los Angeles, California in the simulation of the complete logging cycle of the Heli-stat. The GPSS simulation program presented in the second part of the report was performed as a preliminary simulation.

The production functions for the various work processes on the landing can be divided into two types: regression equations and probability distributions. Reliable regression equations were developed for both portions of the chaser's work cycle: unhook and coil times. Probability distributions were used for the bucker's production rate and for all aspects of the loader's production rates. A probability distribution was also developed for a large rubber tired skidder.

The production functions were then used in a GPSS simulation program which generated random number strings for each Heli-stat load. Random numbers were generated from independent random number strings for time between arrivals, load weight, number of logs per load, percent of bucked logs which actually required further processing, and production rates in tons per minute for swing, buck, deck, and slash disposal.

The simulation resulted in a minimum turn time for a number of different landing configurations. Processing cost per ton and hourly production rates were determined for each landing configuration. These costs and production rates were then judged relative to each other to make a preliminary decision on which landing configuration and load types were preferable to others.

The results show that large front-end loaders (Caterpillar 988-B class) and large rubber tired skidders (Caterpillar 528 class) can be used effectively on a standard type of helicopter landing to accommodate most of the turn sizes and turn times that can reasonably be expected from the Heli-stat. The results also indicate that yarding tree length pieces may have some definite advantages over yarding logs that are bucked and limbed in the woods. The cost of processing tree length logs is roughly equal to the cost of processing bucked logs. It is anticipated that the savings accrued from not having to buck the logs in the woods will make tree length logging a preferred alternative. Also, tree length logging will offer the logger a better opportunity to buck for scale on the landing where the quality of the logs can be more carefully considered.

The physical dimensions of the Heli-stat landings will be larger than the dimensions of a standard helicopter landing. The experimental nature of the first six timber sales on National Forest land requires that whole tree yarding be studied and evaluated. This will require large dropsites and bucking chutes. In addition, the logs must be cold decked for the duration of the operation which requires large acreages. Provisions for disposing of the large quantities of slash generated by whole tree yarding will also have to be made.

This landing simulation project should be regarded as a preliminary investigation into the operation of a Heli-stat landing. It is possible to validate the production equations used in this simulation by using a Sikorsky 64 E helicopter (payload $\cong$ 9 tons) to accumulate Heli-stat sized loads on a dropsite of an existing U.S. Forest Service helicopter timber sale. Large skidders and loaders could then be employed to process the loads as if they had been delivered by the Heli-stat. A few days of study could yield valuable validation data. If this is not available, validation will have to be postponed until the arrival of the Heli-stat. The six U.S. Forest Service timber sales were planned as experimental situations which will be thoroughly studied and analyzed. The results of these studies will be used in validating and modifying the simulation program.

LITERATURE CITED

Beavers et. al. 1980. Operational Plan for Heli-stat Evaluation Trials. U.S.D.A. Forest Service, Washington, D.C.

Bureau of Land Management. 1977. Manual Supplement Schedule 20, Timber Production Costs, BLM Oregon State Office, Portland, Oregon, June 20.

Caterpillar Corporation Equipment Specifications for 528 Skidder, 518 Skidder, 966-B Log Loader and 988-B Log Loader. Caterpillar Tractor Co., Peoria, Illinois.

Caterpillar Performance Handbook, 1979. Edition 10, Caterpillar Tractor Co., Peoria, Illinois, October.

Dykstra, Dennis P. 1976. Production Rates and Costs for Yarding by Cable, Balloon, and Helicopter Compared for Clearcuttings and Partial Cuttings. Research Bulletin 22, Forest Research Laboratory, School of Forestry, Oregon State Univ., Corvallis, Oregon.

Dykstra, Dennis P. 1975. Computer Simulation Analysis of Timber Harvest Landings. Paper submitted to Systems Analysis and Forest Resource Management Workshop at University of Georgia, Society of American Foresters, August 11-13.

Gilles, G.C. 1977. Sort Yard Analysis. A paper presented to the Log Sort Yard Conference, School of Forestry, Oregon State Univ., Corvallis, Oregon.

Johnson, Leonard R., Gochenour, Donald L., and Biller, Cleveland J. Simulation Analysis of Timber Harvesting Systems, Northeastern Forest Experiment Station, U.S.D.A. Forest Service, Morgantown, West Virginia.

Kellogg, Loren D. 1980. Thinning Young Timber Stands in Mountainous Terrain. Forest Research Lab, School of Forestry, Oregon State Univ., Corvallis, Oregon, September.

Kosdick, D and Craig, R.J. 1977. Some Alternative Methods of Log Sorting. A paper presented to the Log Sort Yard Conference, School of Forestry, Oregon State Univ., Corvallis, Oregon.

Lavoie, Jean Marc. 1980. The Transport of Full Trees from the Stump Area to the Millyard. FERRIC Technical Report No. TR-44.

LeDoux, Chris B. 1975. Simulation of A Helicopter Yarding System in Old-growth Forest Stands. M.S. Paper, Oregon State University, Corvallis, Oregon.

Martin, A. Jeff. 1975. T-H-A-T-S Timber Harvesting and Transport Simulator. U.S.D.A. Forest Service Research Paper NE-316.

McDonald, Phillip M. 1972. Logging Production Rates in Young Growth Mixed Conifer Stands in North Central California. U.S.D.A. Forest Service Research Paper PSW-86.

McIntire, John Charles. 1981. The Effect of Swinging and Sorting with a Skidder on Yarding and Loading Efficiency in Small Diameter Douglas-fir. M.F. Paper, Forest Engineering Dept., Oregon State University, Corvallis, Oregon.

Mifflin, Ronald W. 1980. Computer Assisted Yarding Cost Analysis. U.S.D.A. Forest Service General Technical Report PNW-108.

Ohmsteade, Robert H. 1977. Production Rates and Skidding Cost of the FMC 210 CA High Speed Skidder. M.F. Paper, Department of Forest Engineering, Oregon State University, Corvallis, Oregon.

Seiffert, Jon Carl William. 1982. Production Rates and Residual Stand Impact for Four Skidding Machines During Overstory Removal. M.S. Paper, Dept. of Forest Engineering, Oregon State Univ., Corvallis, Oregon.

Sinclair, A.W.J. 1980. Evaluation and Economic Analyses of Twenty-Six Log Sorting Operations on the Coast of British Columbia. FERRIC, Technical Note No. TN-39.

Yancey, William F. 1980. Comparison of Rubber Tired Skidder and Skyline Cable System for Appalachian Timber Harvesting. Master's Paper, School of Forestry & Environmental Studies, Duke University.

SIMULATION PROGRAM FOR:

6 1 Min. Turn Time

18 1 Ton Loads

3-9 Logs/Turn

1 988-B Front-end Loader

3 Chasers

3 Buckers

```
*
       SIMULATE
*
 PCBK1 FUNCTION   RN6,C11
0.00,0/0.18,0/0.28,0.031/0.38,0.125/0.48,0.28/0.58,0.5/
0.68,0.72/0.78,0.87/0.88,0.97/0.98,1.00/1.00,1.00
*
 BUCKL FUNCTION   RN3,C15
0.0,0/0.026,0.2/0.203,0.4/0.407,0.6/0.549,0.8/
0.673,1.0/0.779,1.2/0.832,1.4/0.876,1.6/
0.894,1.8/0.938,2.0/0.956,2.4/0.965,2.8/0.972,3.0/1.00,3.4
*
 BUCKW FUNCTION   RN3,C12
0.0,0/0.071,0.5/0.143,1.00/0.286,1.25/0.357,1.50/
0.429,1.75/0.5,2.00/0.571,2.5/0.714,3.5/
0.786,4.25/0.929,5.25/1.00,5.75
*
 BUCKT FUNCTION   RN3,C12
0.0,0/0.071,0.33/0.143,0.67/0.286,0.837/0.357,1.00/
0.429,1.17/0.5,1.33/0.571,1.67/0.714,2.35/
0.786,2.85/0.929,3.52/1.00,3.85
*
 GASUP FUNCTION   RN6,D3
0.0,15/0.5,15/1.0,15
*
 CHOKE FUNCTION   RN1,D8
0.0,3/0.14,3/0.28,4/0.42,5/0.58,6/0.72,7/0.86,8/1.00,9
*
 SWING FUNCTION   RN2,C21
0.00,1.67/0.05,2.41/0.10,2.71/0.15,2.95/0.20,3.14
0.25,3.32/0.30,3.47/0.35,3.62/0.40,3.75/0.45,3.88/0.50,4.00/0.55,4.11
0.60,4.22/0.65,4.33/0.70,4.43/0.75,4.53/0.80,4.62/0.85,4.71/0.90,4.80
0.95,4.88/1.00,4.97
*
*
 DECK  FUNCTION   RN4,C25
0.00,1.67/0.01,2.14/0.025,2.41/0.05,2.72/0.10,3.16/0.15,3.49
0.20,3.78/0.25,4.02/0.30,4.25/0.35,4.46/0.40,4.65/0.45,4.83
0.50,5.00/0.55,5.16/0.60,5.32/0.65,5.47/0.70,5.61/0.75,5.75
0.80,5.88/0.85,6.01/0.90,6.14/0.95,6.26/0.975,6.15/0.99,6.36
1.00,6.38
*
 PILE  FUNCTION   RN5,C27
0.00,12.00/0.01,12.99/0.02,13.40/0.03,13.71/0.05,14.21/0.10,15.13
0.15,15.83/0.20,16.43/0.25,16.95/0.30,17.42/0.35,17.86/0.40,18.26
0.45,18.64/0.50,19.00/0.55,19.36/0.60,19.74/0.65,20.14/0.70,20.57
0.75,21.05/0.80,21.57/0.85,22.16/0.90,22.87/0.95,23.79/0.97,24.28
0.98,24.60/0.99,25.01/1.00,26.00
*
 BUKR  STORAGE    3

       GENERATE   600,100
       GATE LR    REFUL,ABND
       GATE LR    OVER,ABND
 INTO  ASSIGN     1,22
       ASSIGN     2,FN$CHOKE
       SAVEVALUE  4,P2
       TABULATE   LOGS
       QUEUE      HKLN
       SEIZE      CHASE
       DEPART     HKLN
       ADVANCE    V8
       RELEASE    CHASE
       PRIORITY   3
       MARK       5
 LLL   SAVEVALUE  PR+,1
       BUFFER
       QUEUE      MAINL
       SEIZE      LOADR
       SAVEVALUE  PR-,1
       DEPART     MAINL
       TEST E     PR,3,DCK
       ADVANCE    V1
       RELEASE    LOADR
       TABULATE   SWG
       PRIORITY   2
       QUEUE      BKLN
       ENTER      BUKR
       DEPART     BKLN
       ADVANCE    V10
```

```
        LEAVE       BUKR
        SPLIT       8,DKLD
 DKLD   ASSIGN      1,2
        MARK        6
        TRANSFER    ,LLL


 DCK    TEST E      PR,2,SLPL
        ADVANCE     V3
        RELEASE     LOADR
        PRIORITY    1
        TABULATE    DKTM
        MARK        7
        TRANSFER    ,LLL
 SLPL   TEST E      PR,1,CHK
        ADVANCE     V4
        RELEASE     LOADR
        TABULATE    SLTM
 OUT    TERMINATE
 ABND   TERMINATE
 CHK    TERMINATE
*
 SWG    TABLE       MP5,100,100,20
 DKTM   TABLE       MP6,500,500,10
 SLTM   TABLE       MP7,500,500,16
 LOGS   TABLE       X4,1,1,20
 SWQ    TABLE       X3,0,1,10
 DKQ    TABLE       X2,0,5,10
 SLQ    TABLE       X1,0,5,20
*
 1      FVARIABLE   P1/FN$SWING*50
 2      FVARIABLE   P1/FN$BUCK*100
 3      FVARIABLE   P1/FN$DECK*50
 4      FVARIABLE   P1/FN$PILE*100
 5      FVARIABLE   N$OUT/9
*        UNHOOK FUNCTIONS
*
 6      FVARIABLE   27.1+29.0(P2)
 7      FVARIABLE   21.8+19.5(P2)
 8      FVARIABLE   17.4+13.1(P2)
 9      FVARIABLE   13.9+8.7(P2)
 10     FVARIABLE   FN$PCBK1*FN$BUCKL*P2*100*1.38
 11     FVARIABLE   FN$BUCKW*P2*100
 12     FVARIABLE   FN$BUCKT*P2*100
*       MODEL SEGMENT 3
        GENERATE    12000
        LOGIC S     REFUL
        ADVANCE     1500
        LOGIC R     REFUL
        TERMINATE
        GENERATE    100
        TABULATE    SWQ
        TABULATE    DKQ
        TABULATE    SLQ
        TERMINATE
*
*        MODEL SEGMENT 4
        GENERATE    60000
        LOGIC S     OVER
        TEST E      N$INTO,V5
        TERMINATE   1
*
        START       1
        CLEAR
        START       1
        CLEAR
        START       1
        CLEAR
        START       1
        CLEAR
        START       1
        END
END OF FILE
??
```