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DIGITAL SIMULATION OF A PRODUCTION LINE

BY

JORGE F. MERINO

A THESIS

Submitted to the Faculty of Graduate Studies through
the Department of Mechanical Engineering
in Partial Fulfillment of the
Requirements for the
Degree of

MASTER OF APPLIED SCIENCE
at the
UNIVERSITY OF WINDSOR

Windsor, Ontario

1970

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(Invited External Examiner)

331338

(Chairman)

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I wish to dedicate this
work to my parents, who,
with their moral and fi-
nancial support, made my
undergraduate and gradu-
ate studies possible.

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ABSTRACT

A computer model and program are developed for the simulation of a production line in a wheel-manufacturing concern using the General Purpose Simulation System (GPSS) on the 360/50 IBM computer.

The model is tested and correlated with the actual system before changes, representing improvements in the mechanical design of the machines in the line, are introduced in the model. The simulation results are analyzed and later evaluated and compared on the basis of their profitability. Recommendations are formulated with regards to the best investment prospects.

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CHAPTER I

INTRODUCTION

The automation of manufacturing processes has resulted in the installation of large automatic facilities or transfer lines; lines in which many machines are coupled together so that parts can be automatically transferred from one machine to another. This type of system saves time and cost in transporting the parts between successive machines and reduces the manpower requirements per unit of output.

The most serious drawback of such a system is that when one machine breaks down, the entire production system must stop. Consequently, the utilization of the facilities is reduced considerably.

One of the local companies has such a production system in operation. The management of this company was interested in improving the productivity of this system and felt that minimizing the "transfer times" (time needed by a part to be transported from one machine to the next one) was the desired way of handling this problem. It was suggested to the management that, in addition to the minimization of transfer times it would be a step in the right direction if the following investigations were carried out:

1/ Utilization of each station (this depends upon the breakdowns of the machines and their position in the system.)

2/ Output of the production system taking into account the downtime of each station.

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3/ Segregate the bottlenecks in the system and study the desirability of replacing or modifying these stations.

The management of the company agreed to the suggestions and the present study is a result of these investigations.

For the purpose of analyzing the problems under consideration, digital simulation of the production system was felt to be an adequate method, since analyzing the problems mathematically is too time-consuming and entremely difficult. Furthermore, the assumptions regarding the randomness and independence of data, which are required to be made for finding a mathematical solution, are open to question.

The criteria used in selecting a specific language was based on the availability of equipment, ablility to communicate the problem to the machine without doing so in machine language, and the ease of understanding such language. The General Purpose Simulation System (GPSS) best fulfilled these requirements and was chosen for the study.

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1.1 PRESENTATION PLAN.

The proposed study is to be presented under the following topics:

First, the history and rationale of computer simulation as well as a brief description of the most important simulation languages are to be presented in Chapter II. Next, the present production system is to be described in Chapter III. This includes sections on Time Standards and Production and Downtime Records kept by the company. In Chapter IV, the model development for several stations of the production system is described along with the model of the entire system. It also includes the computer program and samples of the requested output for the system. The simulation of the present system is carried out and discussed in Chapter V, and the results are correlated with the actual system. In Chapter VI, several proposed mechanical design changes along with their cost and expected system output improvement are described. Results of the simulation run for each of the suggested changes are also presented. Chapter VII includes a machine replacement study. The applicability of the model as developed for other similar production systems is discussed in Chapter VIII. The conclusions and suggested areas for conducting further investigations are listed in Chapter IX.

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CHAPTER II

COMPUTER SIMULATION

2.1 DEFINITION AND HISTORY.

A computer simulation model is a logical-mathematical representation of a concept, system, or operation programmed for solution on a high-speed electronic computer.[1]

In the early development of electronic digital computers it became apparent that mathematical and analog models could be programmed for solution on high-speed computers. At first the applications were restricted to small, simple models because of the limitations of early computer technology, but as computers increased in flexibility of operation, speed, and memory capacity it became feasible to apply them more frequently to models of larger scope.

Applications of computer simulation in the two decades after World War II were heavily oriented toward military problems such as war gaming, military systems analysis, and military operations research. As a result, several large-scale war games have been computerized to study and experiment with military tactics and strategy. However, an increasing number of applications are being made nowadays in commercial, scientific, and other nonmilitary problems as well. The greatest impact of computer simulation has been in the physical sciences, mathematics, engineering,

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1 Martin, Francis F. Computer Modeling and Simulation, John Wiley & Sons, Inc., New York, N.Y. 1968. pg 5.

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operations research, operations analysis, systems analysis, probability and statistics, military sciences, and business administration. Computer modeling can be applied to virtually every discipline in which phenomena can be quantified and represented by mathematical models. This means that disciplines such as medicine, law, library sciences, social sciences, and life sciences can find some application of the technique for problem solution.

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2.2. COMPUTER SIMULATION IN INDUSTRY.

The function of management has always been to control the operations of the business in its various areas and to plan future operations. Control functions carry out the operating policies of a firm and are mainly concerned with the daily decisions necessary to maintain operation on a continuing basis. Such decisions could be how to handle special jobs, whether overtime will solve a temporary bottleneck, etc., and are usually based on experience and carry little risk for the firm.

Planning functions, however, are concerned with major changes intended to improve the efficiency of current methods or operations, or other changes caused by expansion or by ever changing business conditions. As such, little, if any, experience is available to aid in making the correct decisions. Questions such as: What would be the effect of replacing one or more machines in the line? Of increasing the maintenance force? Of automating one or more manual operations?, are difficult to answer without actually adopting a plan, implementing it, and evaluating it in operation. Then adjustments can be made and the new plan tested and evaluated as often as needed to achieve the desired result. This, of course, can be very difficult and expensive, aside from being time-consuming.

These shortcomings, however, can be minimized by developing a representation, or model, of the present system; then, by testing the proposed changes on this model, enough information can be obtained to evaluate the efficiency and value of such

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changes. This can be done with the use of a computer. Once the choice is made from among the various alternatives, it can be implemented in the actual situation with considerable savings in time, effort, and money.

However, not until recently was the use of the many types of simulation economical or practical, thanks to two important factors: experience and easier methods of model making. Nowadays, new methods by which the model may be described (general purpose languages) allow the user to describe the model in terms that both the computer and other people can easily understand.

Simulation is used by a wide variety of industries to assist management in decision making. Its applications range from helping determine the number of cashiers in a Supermarket to assisting in laying out a completely automated assembly line in a large automotive plant.

The simulation model is a representation of an actual system. Once the system has been described, the model is installed in the computer and it is tested for accuracy in representing the situation. The accuracy of the model will determine the accuracy of the results being evaluated, so the more accurate the model, the more accurate the results to be evaluated. This makes modelling an all-important part of simulation, and considerable care must be exercised in constructing the model.

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2.3. RATIONALE FOR COMPUTER SIMULATION.

Some of the reasons why computer simulation is used today and which relate directly to this paper are:

1) It is very costly to study certain processes in the real world.
2) The observed system may be too complex to describe in terms of a set of mathematical equations which would yield analytic solutions to be used for predictive purposes.
3) Using simulation, it is possible to study the effects of certain informational, organizational, and environmental changes on the system's operation through alterations in the model of the system.
4) Simulation can be used to expetiment with new situations about which we have little or no information.
5) Simulation enables us to study dynamic systems in compressed time (or equal or expanded time for that matter.)
6) When changes are introduced into a system, simulation will help foresee bottlenecks and other problems that may arise in the operation of the system.
7) Simulation of complex systems can give valuable information about which variables are more important that others in the system and how they interact.

Some of the above-mentioned points have already been either mentioned or discussed in previous sections or will be in future ones, and do not, in any way, exhaust the long list of advantages and benefits of computer simulation.

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2.4. SIMULATION LANGUAGES.

Recent years have witnessed the development of a number of simulation languages aimed at simplifying the task of writing simulation programs for a variety of different types of models and systems. Some of these languages include: GPSS, SIMSCRIPT, GASP, and SIMPAC, and will be discussed briefly in this section.

1. GPSS.[2]

In GPSS, the structure of the system being simulated is described in the form of a block diagram drawn with a fixed set of predefined block types. Each block type represents a specific action that is characteristic of some basic operation that can occur in a system. Connections between the blocks of the diagram indicate the sequence of actions that occur in the system. Where there is a choice of actions, more than one connection is made from a block to indicate the choice. Moving through the system being simulated are certain basic units that depend upon the nature of the system. These units are identified with entities called transactions. The sequence of actions occurring in the system in real time is reflected in the movement of transactions from block to block in simulated clock time.

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2 Efron, R, and Gordon, G."A General Purpose Digital Simulation and Examples of its Applications." IBM Systems Journal, vol.3:1. 1964.

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2.- SIMSCRIPT.- [3]

The SIMSCRIPT language is based upon a description of systems involving concepts denoted by entity, attribute, set, state, and event. In this language, these terms have been assigned the following meanings. Briefly, an entity is a class of objects described by a fixed collection of parameters called attributes. Individual members of an entity class have specific numerical values assigned to their parameters. Sets are collections of individual entities having certain common properties. The state of the model at any given instant is completely described by the current list of individual entities, their attributes and set memberships. The dynamics of the system are represented by changes of state; that is, addition or deletion of individuals, change of attribute values, set memberships, or some combination of these. These changes take place instantaneously at discrete points in simulated time and are called events. The time at which an event is to occur is most frequently prescribed by SIMSCRIPT programming as current time plus some increment.

3.- GASP.- [4]

GASP is a FORTRAN-compiled set of 23 subroutine programs and function subprograms linked and organized by a main program known as the GASP EXECUTIVE. The principal advan-

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3 Dimsdale, B., and Markowitz, H.M. "A Description of the SIMSCRIPT Language." IBM Systems Journal, vol.III:1. 1964. 57-67.

4 Kiviat, P.H., and Colker, A. "GASP--A General Activity Simulation Program." The RAND Corporation, P-2864, Feb.1964.

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tages offered by GASP are its machine-independence and its modular characteristics, which make it quite easy to expand and alter simulation programs to suit the needs of any given system.

Once the components, variables, parameters, and functional relationships for the system under study have been specified, then a small set of special symbols and GASP-oriented flow-charting conventions can be used to write flow charts describing the behaviour of the system. Flow charts written with these GASP conventions are easily transcribed into machine-translatable FORTRAN statements. Four different concepts are embodied in GASP flow charts: operations, decisions, transfers, and control.

4.- SIMPAC.- [5]

Models formulated in SIMPAC consist of four basic components: activities, transactions, queues, and operational resources. SIMPAC is a fixed time increment language written for the IBM 7090 and uses standard flow chart symbols. Although SIMPAC is characterized by a fairly flexible range of output reports, it is a somewhat more difficult language to learn than GPSS and GASP. In terms of applications, SIMPAC was developed to handle waiting line and scheduling problems of a similar nature to those problems which are treated by GPSS, SIMSCRIPT, and GASP.

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5 Balintfy, J.L., Burdick, D.S., Chu, Kong, and Naylor, T.H. Computer Simulation Techniques. John Wiley & Sons, Inc., New York, N.Y. 1967. p. 305.

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CHAPTER III

THE PRESENT SYSTEM

3.1 . DESCRIPTION OF THE SYSTEM.

The system to be simulated is a semi-automated rim line consisting of eight stations, each of them performing one or more operations on the future rim, starting from the strips of cut steel. Figure 1 shows the layout of the line.

The first station is the Shear and Coil. A mechanism of suction cups picks up the metal strip and places it on the machine which first cuts it to size and then coils it in the shape of the rim-to-be. The rim is then kicked onto one of the two chutes leading to the welding stations, the rim going to the open chute, depending on which has fewer rims as indicated by switches triggered by the rolling rims.

In the Welding Station, an operator loads the welder manually and welds the rim. An automatic arm places the rim on the deburring machine and the weld is given a smooth finish. Another magnetic arm loads the rim on the edge trimmer and the rim is later dropped on the chute leading to the next station.

The third station is the Elevator Washer consisting of a "dip tank" and a system of chains and hooks which picks up the rim after being soaked in oil (to cool the weld and lubricate the metal for the rolling operations) and lifts it about five feet before releasing it into the McKay Roll chute.

The McKay Roll performs the first rolling operation on the rim, and it is loaded by way of a feeder arm which places

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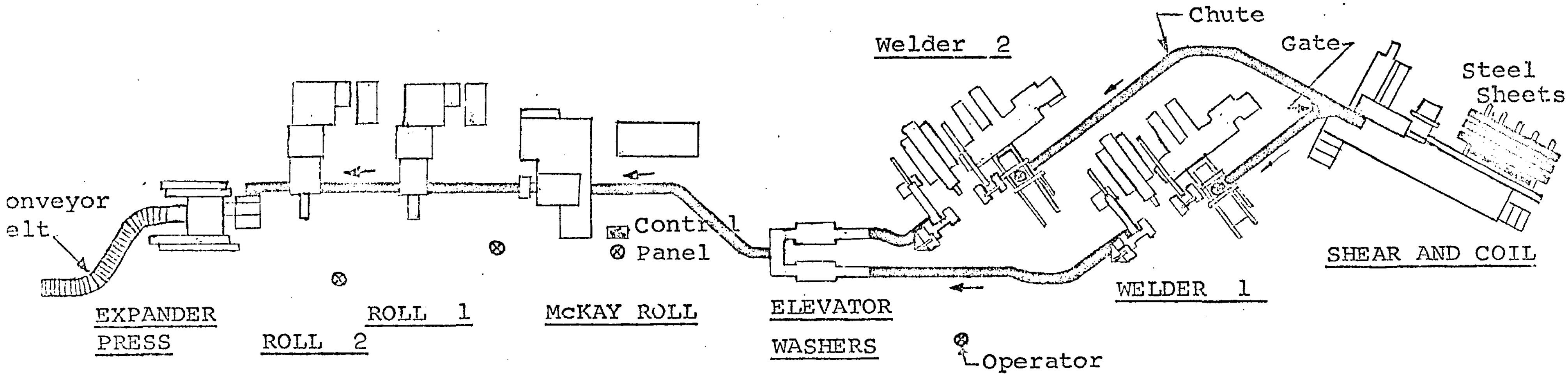
FIGURE 1 -RIM LINE



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the rim between the rolls. Once the rolling is completed, the rim queues for the Finish Rolls (#1 and #2) where further rolling operations are performed on the rim. These two rolls actually refine the work of the McKay Roll and shape the rim a little more. Finally, the rim moves to the Expander Press, the function of which is to correct any deviations from the specified diameter and width of the rim by way of a heavy press previously set to the exact specifications required.

From the Expander Press the rim is dropped on a conveyor which takes it to the Wheel Department where the corresponding spider is welded on the rim to make a finished wheel.

Six men attend each line: one on each welding station, one on the control panel of the McKay Roll, one attending all three rolling operations , a line leader and set up man in charge of setting the machines, and a sixth man to visually inspect the rims and assist during breakdowns. The approximate position of each man is shown in Figure 1.

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3.2. TIME STANDARDS.

The Standards Section in the Engineering Department of the company is in charge of setting the time stardards for all machines in the line. This is done in the form of a Production Routing like the one shown in Figure 2. The times indicated in the column "minutes each" are the times each man is supposed to spend on one rim. These times added to the time needed to adjust the line for a gross production of 840 rims per hour (0.0254 min), make a total time of 0.4284 minutes per rim. It can be noted that the welders and the man inspecting the rims do not have to work at 100% efficiency since the other men have longer cycle times for their respective jobs.

Allowances for the men of 7 % delay and 8 % personal (which includes the two 10-minute coffee breaks as well) reduce the production figure to an expected net of 714 rims per hour. Finally, an allowance of 20 % is made for breakdowns and routine maintenance which brings the total time cost per rim to 0.630 minutes. Thus the expected production after allowances and breakdowns is 4571 rims per 8-hour shift or an average production of approximately 571 rims per hour.

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PRODUCTION ROUTING

PART NAME 14 x 5½ JK RIM CUSTOMER AMERICAN MOTORS PART NO. 79083

DATE December 4, 1969 ISSUE NO. 3 NO. OF SHEETS 1 SHEET NO. 1 PLANT WINDSOR

EQUIP. NO.	EQUIP.	TOOL NO.	OPERATION	100% PROD'N	REGISTER NUMBER	OP. NO.	DEPT.	NO. MEN	MINUTES EACH	PRODUCTION PER HOUR
			SHOTBLAST: SEE MASTER FOR 5/6-10							
			SHEAR: SEE MASTER FOR 5/6-10							
			Shear and coil (automatic)	1000	W1759	1	2	-	-	
			Weld (load manual auto eject)	494	W1760	3	2	1	.0607	
			Weld (load manual auto eject)	494	W1762	5	2	1	.0607	
			Flash trim (automatic)	461	W1761	7	2	-	-	
			Flash trim (automatic)	461	W1761	9	2	-	-	
			Edge trim (automatic)	461	W1761	11	2	-	-	
			Edge trim (automatic)	461	W1761	13	2	-	-	
			McKay roll (panel man)	840	W1763	15	2	1	.0714	
			2nd Roll (automatic)	840	W1764	17	2	-	-	
			3rd Roll (automatic)	840	W1765	19	2	-	-	
			Expand (automatic)	1000	W1766	21	2	-	-	
			Operations 15 to 21 one attendant			23	2	1	.0714	
			Line leader and set up and assist where necessary			25	2	1	.0714	
			Wash (automatic)	1200	W1767	27	2	-	-	
			Visually inspect	890	W1768	29	2	1	.0674	
			Adjust line to 840 rims per hour gross						.0254	
									.4284	
			7% delay and 8% personal						.0756	
			Net production 6 men will produce 5712 OK rims in 8 hours						.504	
			Repairs %			31	2	2	.126	
			McKAY PANEL OPERATOR "TEMPORARY" ONLY							OLD COST
			TRANSFERRED TO PLANT #2 FROM PLANT #1							1.050
						TOTAL			MINUTES .630	
MATERIAL SIZE			40 ¼ x .115 x 84½ 5/6-10							

Figure 2.- Production Routing Sheet

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3.3. PRODUCTION AND DOWNTIME RECORDS.

A Production Record sheet is prepared by the Production Control Department on a daily basis. A sample is shown on Figure 3 . These sheets contain the production in the Wheel Department (Dept. 223), Rim Departments (222 and 224), and Spider Department (227). The wheels, rims, and spiders are listed by number and make and the three columns of figures show the total number of pieces produced, the number of scrap, and the total number of good pieces produced, in that order.

From the Production Schedules, the particular line on which a specific type of wheel, rim or spider was made can be easily traced to keep a record on the production of any one line.

The Line Leader in the Rim Department keeps a record of all downtime in the line and the cause of each breakdown. This information is later tabulated in the Engineering Department for each machine in the line and according to four categories: electrical, hydraulical, tooling, and air, set-up, and other breakdowns. See Figure 4 . In this way, the major sources of downtime can be traced and corrective measure taken as soon as possible. Aside from the Downtime Records, periodical Delay-Time Studies are conducted by the Engineering Department throughout the year. The Downtime Records are tabulated on a weekly basis and they also include one of the machines from the Wheel Dept. which is not part of the Rim lines.

Another method of keeping the record of all downtime now used by the company is by tabulating the information of the

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...heels: May 7, 1970

...117	G.M.	2923	22	2901	85121	85120
...237	A.M.	9665	27	9638	79083	79085
...910	Gd.	1301	0	1301	83372	83374
...642	I.H.C.	2448	5	2443	83372	86191
...148	Gd	4967	14	4953	75155	77961
...351	Chry.	6800	19	6781	80103	82347
...326	Gd	7143	11	7132	82329	82729
...993	Gd	9030	14	9016	82282	82729
...8631	Gd. Mutt	477	1	476	58633	58634

Total Prod 44,641
Dept 223: 30,783

...UMBER	RIM TYPE	TOTAL PIECES	SCRAP	GOOD PIECES
...mo):				
...121	G.M.	3267	151	3116
...083	A.M.	10243	265	9978
...443	G.M.	1917	131	1786
...155	Gd	6016	95	5921
...103	Chry.	6033	337	5696
...329	Gd.	7270	87	7183
...282	Gd	8054	353	7701
...5324	Boat Trailer	1254	113	1141

Dept 222 + 224:
42,52[illegible]

...ders)				
...9085	A.M.	10400	199	10201
...3347	Chry.	6675	9	6666
...729	Gd.	16092	97	15995
...634	Gd Mutt Assy	1125	37	1088

Dept 227:
32,862

58635 58636

...rson

1. 1760
2. 1400
3. 6635

Figure 3.- Production Record Sheet

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(NEW BUILDING) DATE March 2, 1970 to March 6, 1970

			HYDRAULICAL						TOOLING						AIR, SET-UP, OTHER					
D	E	TOTAL	A	B	C	D	E	TOTAL	A	B	C	D	E	TOTAL	A	B	C	D	E	TOTAL
.25		6.30								1.15			1.35	2.50	1.05	2.00	1.00	1.55	1.30	7.30
.05	.20	.45								.10	2.15	.25	.10	3.00	.45	1.10		3.20		5.15
1.10	.20	3.05									.55		.30	1.25	.30	.15	2.20	1.15		4.20
		.30													2.20			.05		2.25
.10		.10							.30				.15	.45				.10		.10
		.20													.30	1.15		.50		2.35
.45	.15	4.05							.10	1.45	1.20	.30	.05	3.50		1.15	7.20	1.10	1.45	11.30
.50	.20	1.35							1.15	.10		1.15		2.40	.35	1.20	.30	.55	.40	4.00
.30		.50							.30		1.05	.35		2.10	2.05	1.15	1.15	1.00	.40	6.15
1.25		1.25							.15			.50		1.05	.10	.10	.05	.45	.10	1.20
	1.15	6.00	1.55				.25	2.20	3.45	3.45		3.35	6.10	16.15	.35	3.40		1.45	.55	6.55
															9.15	6.10	18.40	11.40	2.55	48.40
5.20	2.30	25.15	1.55				.25	2.20	5.25	7.05	5.35	7.10	8.45	34.00	17.50	18.30	31.10	24.50	3.35	00.55

. GOLLWITZER B. JOHNSTON C. GRAHAM C. KABISCH A. McKINNON L. VIDA J. FRIESEN

COMBINED TOTAL FOR ALL MACHINES:
162 HOURS 30 MINUTES

Figure 4.- Downtime Record Sheet

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(NEW BUILDING)

DATE March 2, 19

MACHINE	ELECTRICAL A	B	C	D	E	TOTAL	HYDRAULICAL A	B	C	D	E	TOTAL	TOOLING A	B	C	D	E	TOTAL	AI A
SHEAR &COIL	4.15		1.50	.25		6.30								1.15			1.35	2.50	1.05
WELDER	.20			.05	.20	.45								.10	2.15	.25	.10	3.00	.45
WELDER	1.10	.10	.15	1.10	.20	3.05									.55		.30	1.25	.30
FLASH TRIM.	.30					.30													2.20
FLASH TRIM.				.10		.10							.30				.15	.45	
EDGE TRIM.																			
EDGE TRIM.																			
ELEV.WASHER	.20					.20													.30
McKAY ROLL	.35	.35	1.55	.45	.15	4.05							.10	1.45	1.20	.30	.05	3.50	
ROLL #1	.20	.05		.50	.20	1.35							1.15	.10		1.15		2.40	.35
ROLL #2	.10	.10		.30		.50							.30		1.05	.35		2.10	2.05
EXPANDER				1.25		1.25							.15			.50		1.05	.10
SCIAKY		4.45			1.15	6.00	1.55				.25	2.20	3.45	3.45		3.35	6.10	16.15	.35
																			9.15
TOTAL	7.40	5.45	4.00	5.20	2.30	25.15	1.55				.25	2.20	5.25	7.05	5.35	7.10	8.45	34.00	17.50

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COMBI

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Figure 4.- Downtime Record Sheet

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so-called 181 cards. The 181 card is the requisition for maintenance personnel signed by the foreman whenever a breakdown is reported to him by the line leader or one of the workers. This card contains information regarding the nature of the breakdown as well as the times of requisition and of completion of the repair work. Even though the 181 cards have been used for some time in the plant, it was only recently that all this information was tabulated by the Engineering Department with the idea of having records on the frequency and duration of breakdowns as well as the specific cause of such breakdowns.

Since the work on this paper was already started when this new method was adopted, it has been used only in later chapters while the previous Downtime Records have been used in Chapter Three.

A sample copy of the latter method is reproduced in Figure 5. It shows the Downtime for Roll #2 in Line A for the period between April 22 and June 5, 1970. The T/Time column gives the total repair time for each group of breakdowns, with the number to the left of the decimal point representing hours, and the one to the right representing minutes.

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DOWNTIME PER 181 FORMS

"A" LINE #2 ROLL - W 6667 FROM APR. 22 TO JUNE 5/70

DESCRIPTION	NO. OF OCCURRENCES	T/TIME
Broken wire	7	2.59 hrs.
Repair carriage	7	8.49 hrs.
Repair oil leak (tension roll cyl.	4 (1 card no time)	5.23 hrs.
Repair switch	3	1.22 hrs.
Adjust speed	2	1.10 hrs.
Repair chute	1	2.31 hrs.
Guide roll not going up	1	1.30 hrs.
Reset	1	.10 min.
Lube light staying "on"	1	.39 min.
Change piston	1	.20 min.
Loader	1	.22 min.
No water	1	.21 min.
Water pump	1	.13 min.
		25.49 hrs.

Note: 9 cards - no description - 8.06 hrs.

TOTAL REPAIR TIME . . . . . 33.55 HRS.

Figure 5.- New Downtime Record

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CHAPTER IV

MODEL DEVELOPMENT

4.1 DEFINITION OF BLOCKS.

In this section, all of the blocks used in this paper are described briefly along with the definitions of some important pertinent terms used in GPSS.

The basic assembly program input format consists of three distinct major fields: the location field(columns 2-6), the operational field (columns 8-18), and the variable field (starting at column 19). The meaning of each field depends on the type of card being entered. The location and operation fields are single-entry fields and are straightforward. Their meaning and use are discussed individually in the following subsections. The variable field consists of seven subfields, which are labeled A, B, C,..., G. Succeeding subfields are denoted by separating commas which are entered directly on the input card. The significance of each subfield is also a function of the particular card in which it appears. Subfields need not be specified if not required; however, if a subfield is omitted between two defined subfields, the separating commas must be entered to indicate that a subfield is being omitted. The end of the variable field is denoted by the first blank character encountered after column 19. Any subfields which are not defined by the user when the end of the variable field is encountered are assumed by the program to be blank.

Any information found after a blank in the variable

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field is treated as a comment.

1.- Equipment-Oriented Block Types.-

a) SEIZE Block.-

The SEIZE block records the use of a facility by the entering transaction so that it remains in use until the seizing transaction enters a corresponding RELEASE block. If a transaction is currently using the facility specified in field A of the SEIZE block, no other transaction is allowed entry to the SEIZE block.

b) RELEASE Block.-

The RELEASE block releases, or frees, a facility seized by the entering transaction. A transaction may never be refused entry to the RELEASE block, but the facility referred to by this block must have been seized by the entering transaction. No other transaction except the one that originally seized a facility is able to release it. Additional transactions which arrive at the SEIZE block before the preceding transaction enters the RELEASE block, must wait at the SEIZE block until the facility becomes free. If two or more transactions are waiting at the SEIZE block, they are serviced on a first-come,first-served basis.

c) ENTER Block.-

The ENTER block records the usage of a storage by a transaction. Field A indicates a specific storage number. A STORAGE definition card is used to define the capacity of the storage. When a transaction enters an ENTER block, the record of the total number of units occupying the storage specified

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in field A is incremented, for our purposes, by one. If there is not enough space available for a particular transaction, it will be refused entry to the storage.

d) LEAVE Block.-

The LEAVE block serves the function of removing a number of units from the contents of a storage (one in our case). Field A indicates the storage from which a unit is to be removed.

2.- Transaction-Oriented Block Types.-

a) ADVANCE Block.-

The ADVANCE block is the means by which transactions are delayed in the course of their progress through the simulator block diagram, and it is used to represent such things as cycle times of machines, breakdown times, etc.

b) GENERATE Block.-

The function of this block is to create transactions for entry into the system where Field A represents the average or mean time between originations. This mean may be modified by specifying either a spread or a function as a modifier in field B.

c) TERMINATE Block.-

The TERMINATE Block removes transactions from the system. Field A specifies whether or not this block contributes to the total termination count and, if so, how many units it will contribute.

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3.- Flow Modification.-

a) TRANSFER Block.-

The TRANSFER block is generally used to direct the entering transaction to a nonsequential next block . This may be done in a variety of ways: logically, statistically, conditionally, or unconditionally. Only the second and fourth of these will be discussed here as they are the only ones used in this paper. For the unconditional transfer, field A remains blank, and every transaction entering the block will be sent to the field B next block, (i.e., the block whose number is in field B. In the statistical transfer, the probability of selecting the next block in field C is given by the fraction of field A. The rest of the time the transaction will be directed to the block specified in field B.

4.- Program Features.-

a) TEST Block.-

The TEST block specifies a condition to be met by the transaction entering the block, such as less than, less than or equal to, equal to, not equal, greater than, and greater than or equal to. If the desired relation is satisfied, the transaction goes to the next block in the program. If it is not, it goes to the block specified in field C. The arguments are specified in fields A and B.

5.- Statistical Block Types.-

a) TABULATE Block.-

When a transaction enters a TABULATE block, it signifies to the program that certain statistics are to be gathered. Field

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A specifies the number of the TABLE in which the statistics are to be tabulated. The type of information to be tabulated is defined on a separate TABLE definition card. The table mode used in this paper is the Arrival Rate Mode which operates as follows: when a transaction enters a TABULATE block which refers to a TABLE that is operating in this mode, an entry is not made in the frequency distribution. Instead, the number of units specified at the TABULATE block is added to the arrival count for the TABLE. The TABLE card contains a time interval in field E, so that the arrival count will be entered into the frequency distribution every t clock units, where t is the time interval.

6.- Control Cards.-

a) START card.-

This card indicates to the simulator that all input data has been received and that the run may now proceed. Field A specifies the number of terminations to be executed before printing the final summary statistics. Field B may be used to suppress the final printout of statistics at the end of the run.

b) RESET card.-

This card causes all accumulated statistics to be set to 0.

c) END card.-

This card specifies the end of the input deck.

d) COMMENT card.-

An asterisk in column 1 will cause a entire card to be treated as a COMMENTS card. Also, any card with a blank operation field will be treated as a COMMENTS card.

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7.- Definition of terms.-

a) Real-time clock.-

In order to provide the correct time sequence the program maintains a clock that records the instant of real time that has been reached in the modeled system, and this is referred to as the "clock time". All clock times in the simulator are presented as integral numbers.

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4.2. MODEL DEVELOPMENT FOR SHEAR AND COIL STATION.

1.- Model 1.-

The first model for the Shear and Coil Station consisted of five blocks arranged in the manner shown in Figure 6. The ENTER 3 block referred to a storage whose capacity was 1. This would mean that no other transactions would be allowed to proceed until the previous one had passed through the LEAVE 3 block. The purpose of this was to ensure that when a breakdown occurred, new transactions would wait before proceeding any further. The TRANSFER block would provide for a time delay to take place at certain intervals, representing the breakdowns in the machine. The rest of the time, transactions would move right through to the LEAVE 3 block without causing any delay. Finally, transactions would enter the ADVANCE block representing the cycle time for the machine.

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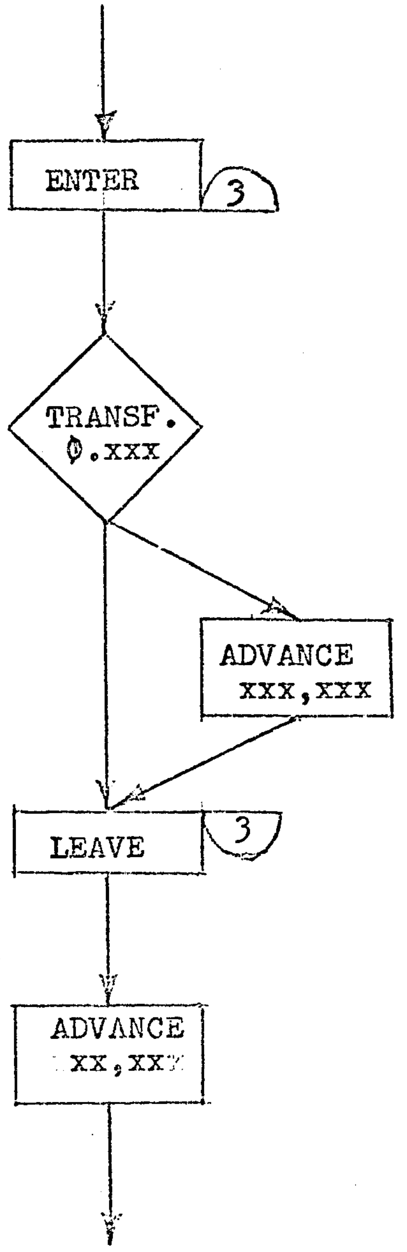

Figure 6.- Model 1, Shear and Coil Station.

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2.- Model 2.-

The final model substituted the Storage blocks of model 1 with the Facility blocks shown in Figure 7. This was done because it made the model simpler and it represented the real situation more accurately. When a transaction entered the SEIZE 10 block, facility 10, representing the shear and coil machine, would be seized without allowing any oncoming transactions to move until the first transaction reached the RELEASE 10 block.

Another change consisted of including the ADVANCE block representing the machine cycle time within the SEIZE-RELEASE sequence, so that no more than one transaction utilized the machine at any time. In the real situation, the machine can only take care of one piece of raw material at a time. In model one, several transactions could have been going through the ADVANCE block at the same time, something impossible in the real situation.

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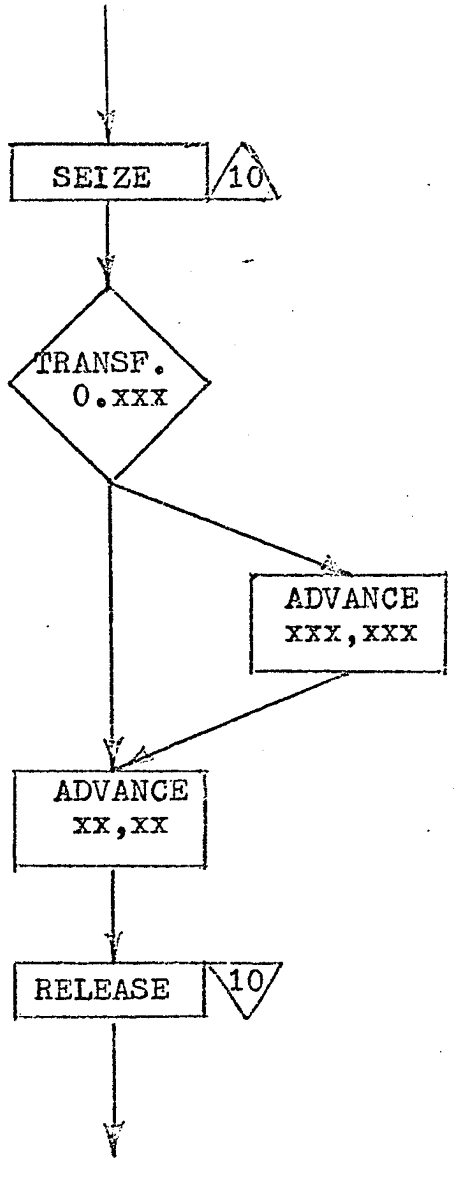

Figure 7.- Model 2, Shear and Coil Station.

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4.3 MODEL DEVELOPMENT FOR WELDING STATION.

1.- Model 1.-

The first model consisted of twelve blocks, the first five corresponding to the welding operation, and they were arranged in a similar way as for the shear and coil. The last seven, however, included a SEIZE block preceeding the elevator washer operation, and a RELEASE block following it. The storages corresponding to the ENTER 5 and ENTER 6 blocks had capacities of 1, as before. See Figure 8 .

2.- Model 2.-

As in the Shear and Coil Station, the ENTER-LEAVE combinations were replaced by SEIZE-RELEASE ones. However, the ENTER block now represented the capacities of the chutes in front of the welder and elevator washer, fact that was ignored in Model 1. The storages referred to by the ENTER 1 and ENTER 21 blocks would have a capacity indicated by the maximum number of rims that can be placed in the chutes, e.g. 7 for the welder and 22 rims for the elevator washer. This would cause the Shear and Coil machine to halt whenever the chutes were full of rims.

As before, the ADVANCE blocks were placed within the SEIZE-RELEASE sequence to keep transactions going through the machine one at a time and occupying the facility until released by the outgoing transaction. See Figure 9 .

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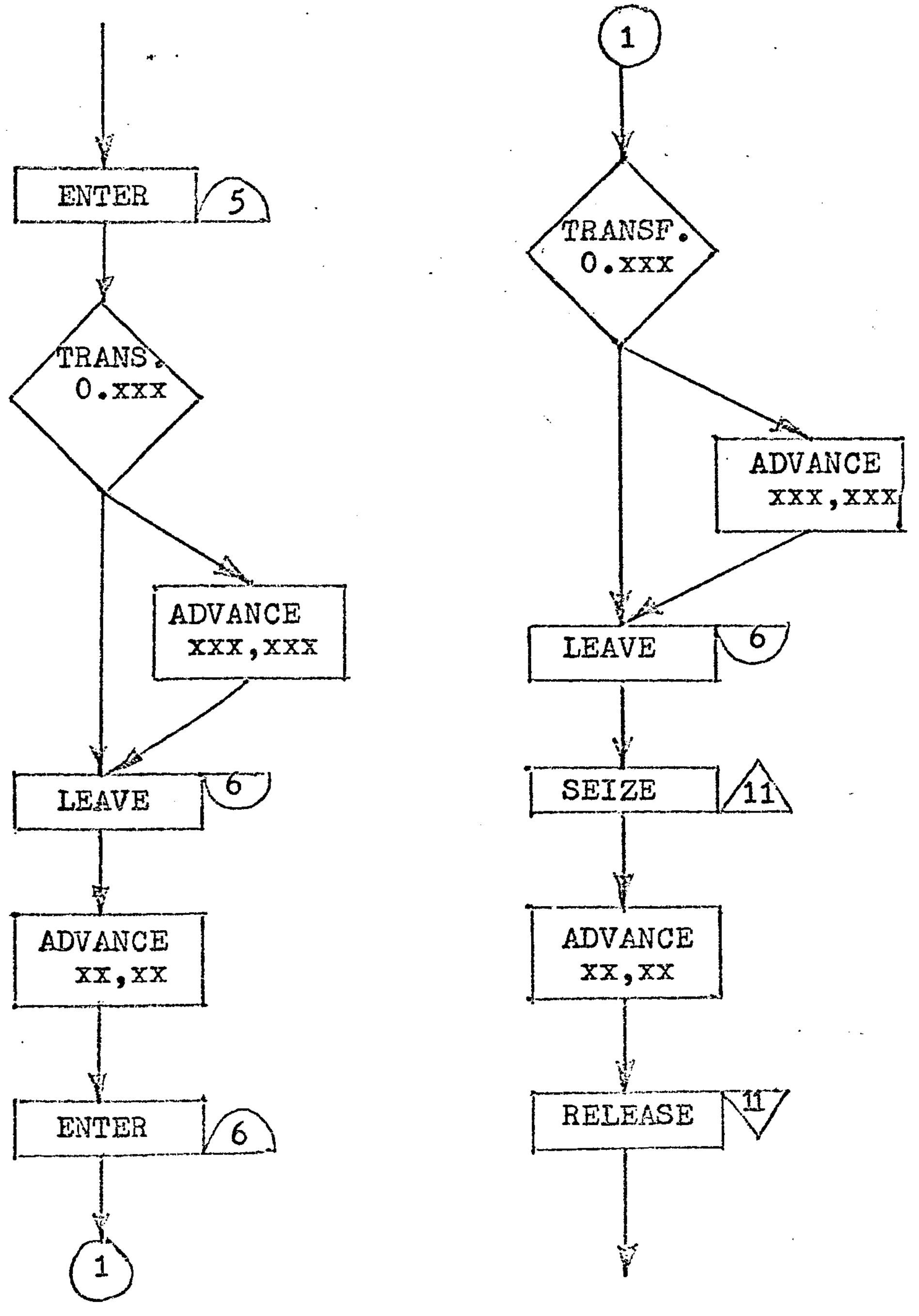

Figure 8.- Model 1, Welding Station.

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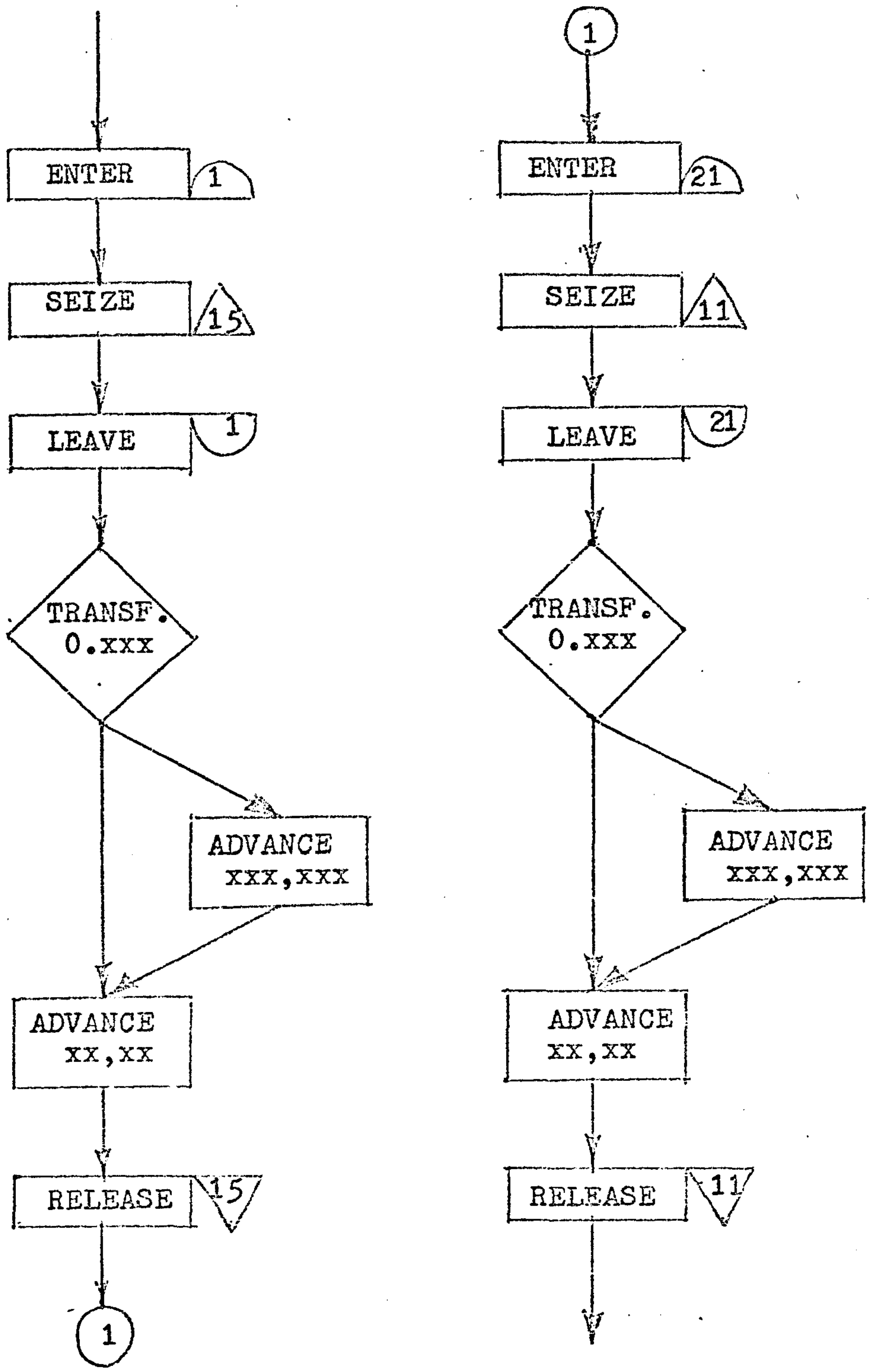

Figure 9.- Model 2, Welding Station.

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4.4 MODEL DEVELOPMENT FOR MCKAY ROLL STATION.

1.- Model 1.-

The first model was made up of seven blocks, as shown in Figure 10. The ENTER 8 block indicated a one-rim storage capacity to keep transactions from going through during a machine breakdown. The TRANSFER block indicated the percentage of transactions to go through the ADVANCE block, which represents the average duration of breakdowns. The LEAVE 8 block would allow another transaction to move into the ENTER 8 block. Then, the transaction would SEIZE facility 20 corresponding to the McKay Roll, it would be delayed by a time equal to the cycle of the machine and would finally be RELEASEd from the machine.

2.- Model 2.-

This new model included an ENTER 23 block with the storage representing the chute capacity for the McKay Roll, equal to 10 rims. The purpose of this again was to stop the Elevator Washers when the chute was full. The storage was considered available again once the machine was seized by means of the SEIZE 20 block. The facility was RELEASEd once the transaction passed through the ADVANCE block(s). The reason for moving the ADVANCE block for the cycle time within the SEIZE-RELEASE sequence was explained before. See Figure 11.

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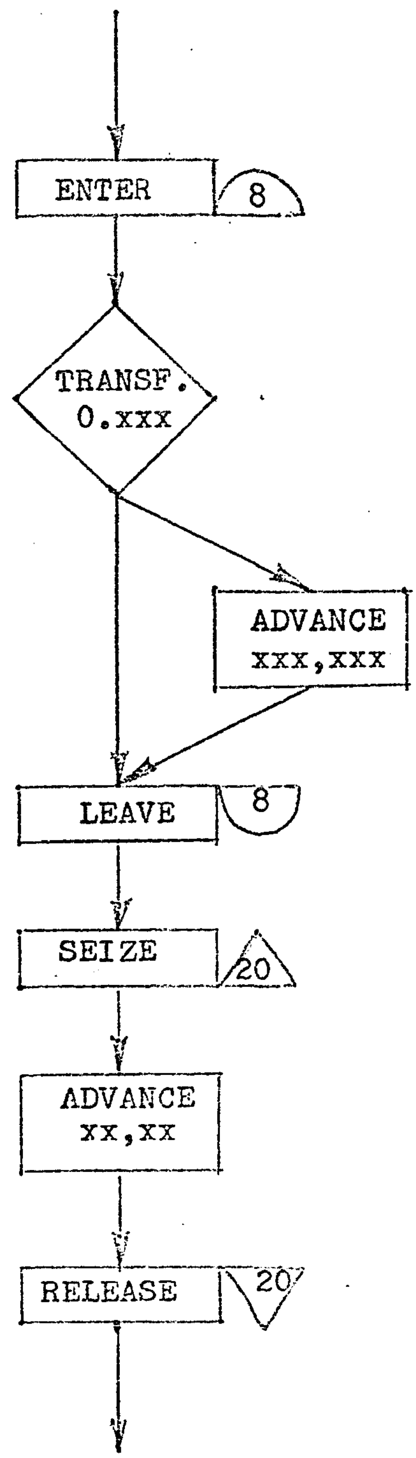

Figure 10.- Model 1, McKay Roll Station.

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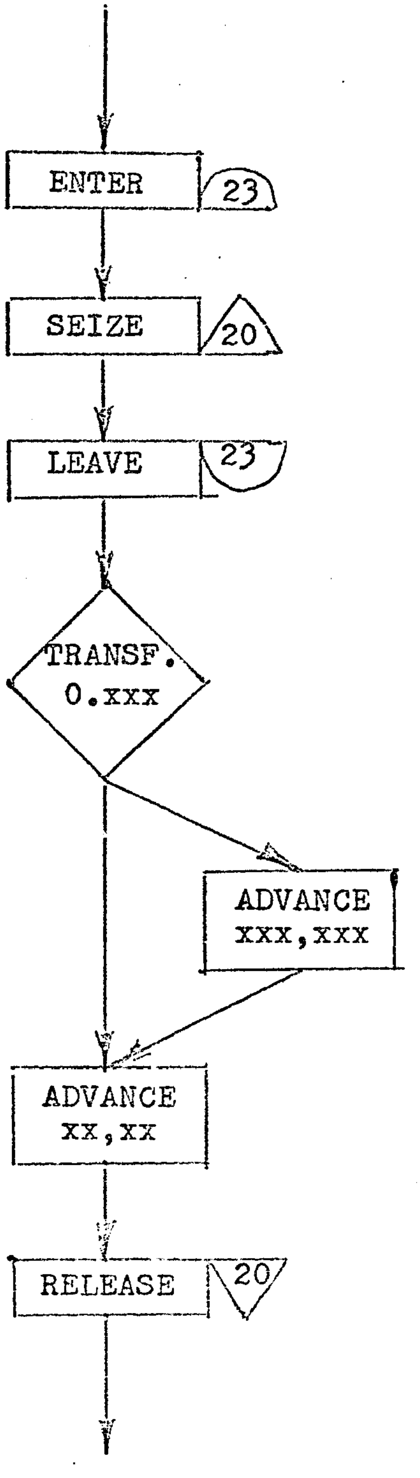

Figure 11.- Model 2, McKay Roll Station.

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4.5 BLOCK DIAGRAM OF THE MODEL.

The block diagram for the model of the entire system is pictured in Figure 12 (pages 42 through 48.) The criterion used in developing such model is discussed in this section.

1.- Chain Stoppage of Machines.-

One of the biggest problems encountered in developing the model was that of having a machine stopped whenever a breakdown delayed the following station or when the chute leading to that station was filled to capacity with rims. In the first few models developed, transactions would pile up in blocks such as the TEST, RELEASE, TRANSFER, LEAVE, and other blocks. To solve this problem, it was necessary to overlap the blocks from one station with those of the next without departing from the real situation but also ensuring that transactions would not pile up in blocks representing nonexistent points in the system.

This was achieved by having the ENTER card identifying the chute capacity for a station placed before the RELEASE card for the previous station, and by inserting the LEAVE card after the RELEASE card for the station.

For example, in the Elevator Washer Stations, shown in section 3-5 of Figure 12 (page 44), the machine has been seized by block #20a; then, after going through the breakdown and cycle blocks (21a, 22a, and 23a), the transaction will enter storage #5, which is the storage representing the chute capacity for the McKay Roll Station. Next it will enter the RELEASE block freeing the machine for the next transaction, and finally it will leave storage #3, which represents the chute capacity

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for the Elevator Washer, which the transaction has now left.

In this way, whenever the chute for the McKay Roll is full, transactions will not be allowed past the ENTER 5 block, and thus the Elevator Washer will not be made available for any more transactions until the machine is released. This, of course, will not happen unless chute space is made available in front of the McKay Roll.

2.- Distribution of Breakdown and Cycle Times.-

The breakdown as well as the cycle times for the various stations are more or less normally distributed. However, in the model the distributions have been assumed rectangular. This is not considered to have a marked effect in the results, since the average times do not change, and the total times also add up to the same, regardless of the distribution.

3.- Frequency of Breakdowns.-

The frequency with which breakdowns occur are represented in the model by the TRANSFER blocks. The decimal figure specified in field A represents the frequency in terms of the number of transactions going through the station in between breakdowns. In other words, if the figure is, say, 0.001, it means that a breakdown will take place every 1000 transactions, approximately. The problem,however, was to represent smaller frequencies, such as 0.00033 and 0.00008. This was achieved by having two TRANSFER blocks as in the following example:

```
      TRANSFER    .001,OKY2,TRA3
TRA3  TRANSFER    .330,OKY2,BDW2
BDW2  ADVANCE     24750,15000
OKY2  ADVANCE     137,13
```

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The first block will cause 1 out of 1000 transactions to enter the next block TRA3, the remaining 999 going on to block OKY2 which represents the cycle time of the machine. The second block allows one third of the entering transactions to enter the breakdown block (BDW2). In other words, one out of 3000 transactions will eventually reach block BDW2, all other 2997 skipping over to block OKY2.

4.- Transaction Generation.-

The GENERATE block was arbitrarily set at 0.055 minutes, that is, a few milliminutes less than most of the cycle times to ensure that transactions were available at all times, to correspond with the real situation in which the raw material is piled up next to the Shear and Coil.

5.- Chute Rolling Times.-

A very important time delay had been neglected in the early models, representing the time taken by the rim to roll down the various chutes joining the eight stations. This has been incorporated in the final model, and is represented by blocks number 10a, 10b, 19a, 19b, 28, 36, 44, and 52 in the model of Figure 12. It can be seen that there is no seizing of facilities involved. This enables more than one transaction to be delayed at the ADVANCE blocks for overlapping periods of time, since in the real situation, more than one rim might be rolling down a chute.

6.- Program Running Time.-

The running time of the program is controlled by blocks 61 and 62. The transactions that were generated in block 1, are

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destroyed (in the real situation, the rims leave the line) by the TERMINATE block # 60. Block 61 generates transactions at the rate of one per clock unit (milliminutes in the real situation), and these transactions are immediately destroyed by block 62. So that, if we, for example, have 1000 transactions generated in block 61, and the same terminated in block 62, the entire program will run for 1000 x 1000 milliminutes, or 1000 minutes. In this manner, the program could be run for a period representing one shift, one hour, or ten days, etc.

7.- Gate Simulation at Shear and Coil.-

The gate which directs the rims coming out of the Shear and Coil machine into the chutes leading to Welder #1 and Welder #2 is represented in the model by the TEST G S2,S1,WEL2 block, which operates in the following manner: whenever a transaction enters the TEST block, the contents of storages 1 and 2 (representing the chute capacities of the welders) are compared. If storage 2 has fewer or the same number of transactions stored, the transaction in the TEST block is transferred to Welder #2, otherwise it goes to Welder #1. The reason for the bias introduced by transferring transactions to Welder #2 when both storages have the same number of transactions stored, is that the chute leading to Welder #2 has a much larger rim-capacity that the one leading to Welder #1.

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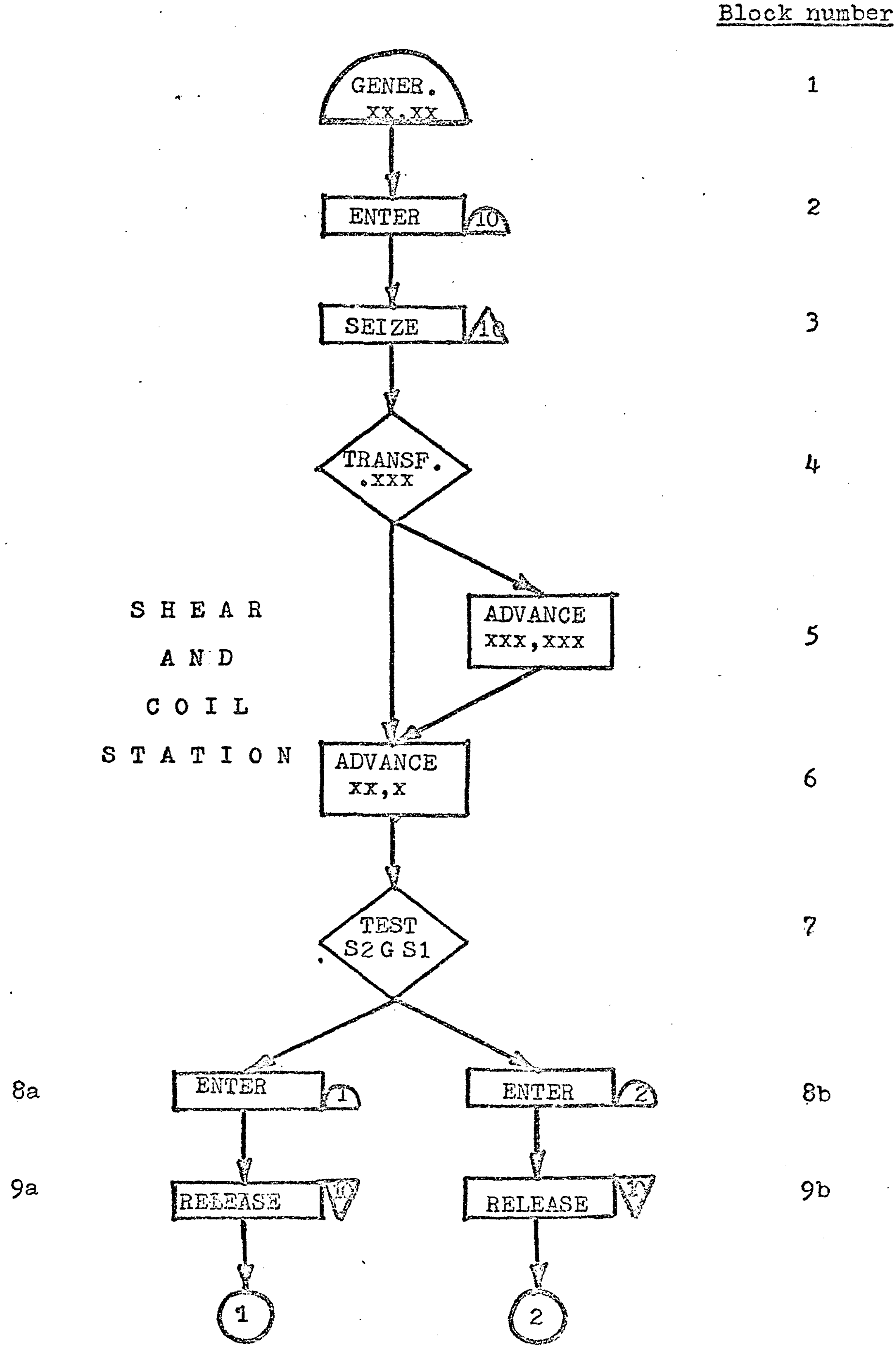
Figure 12.- Block Diagram of the Model.



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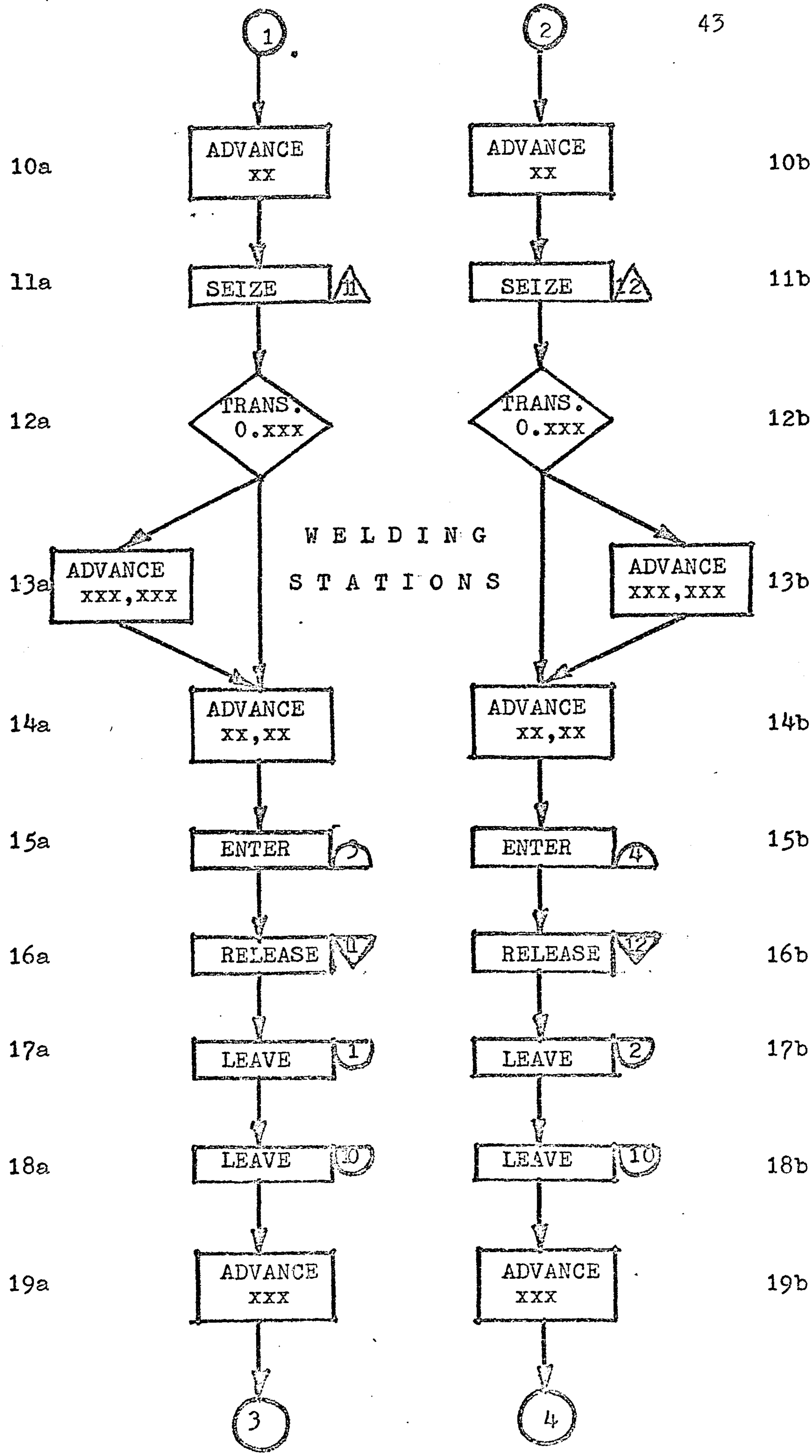

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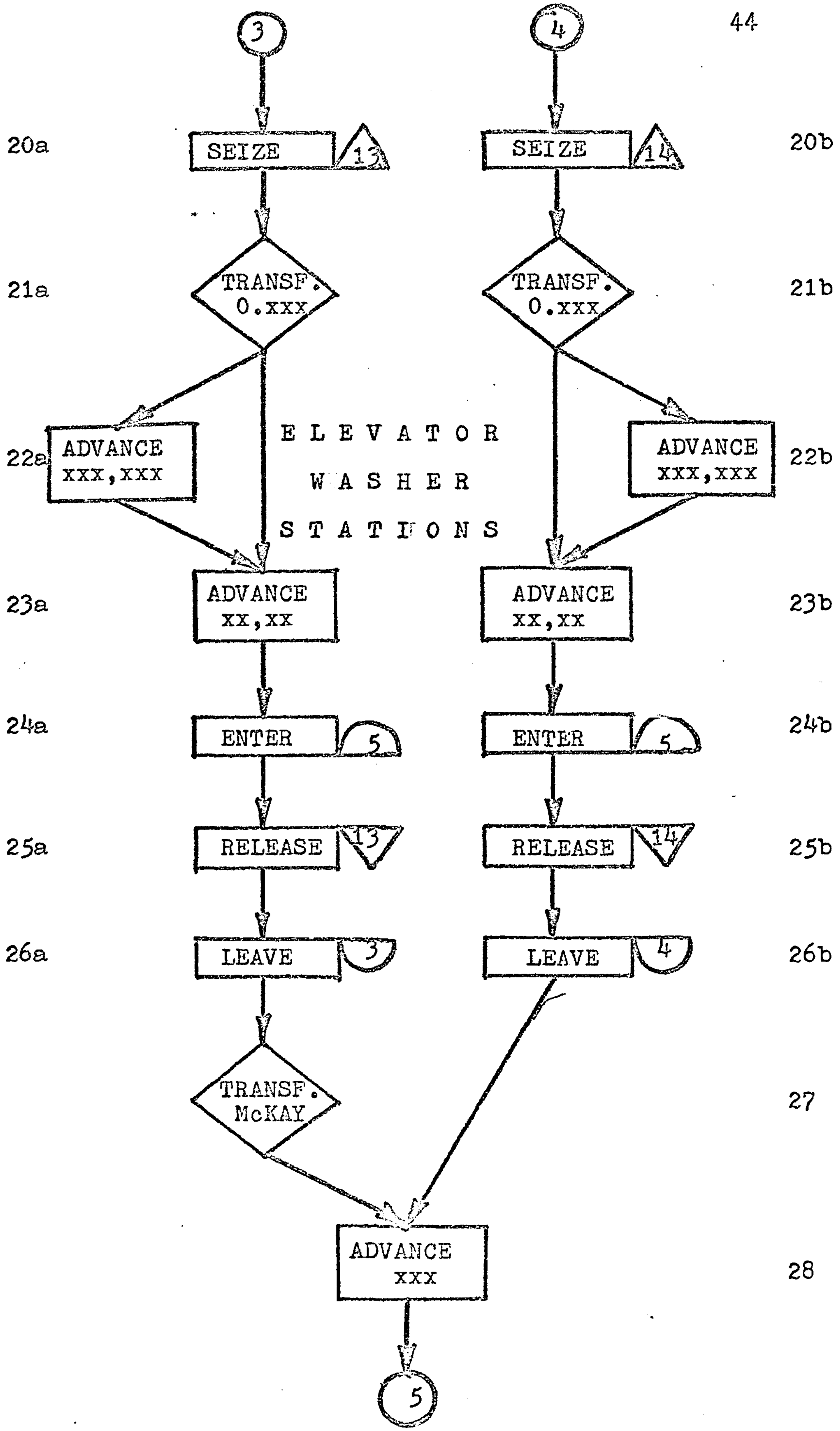

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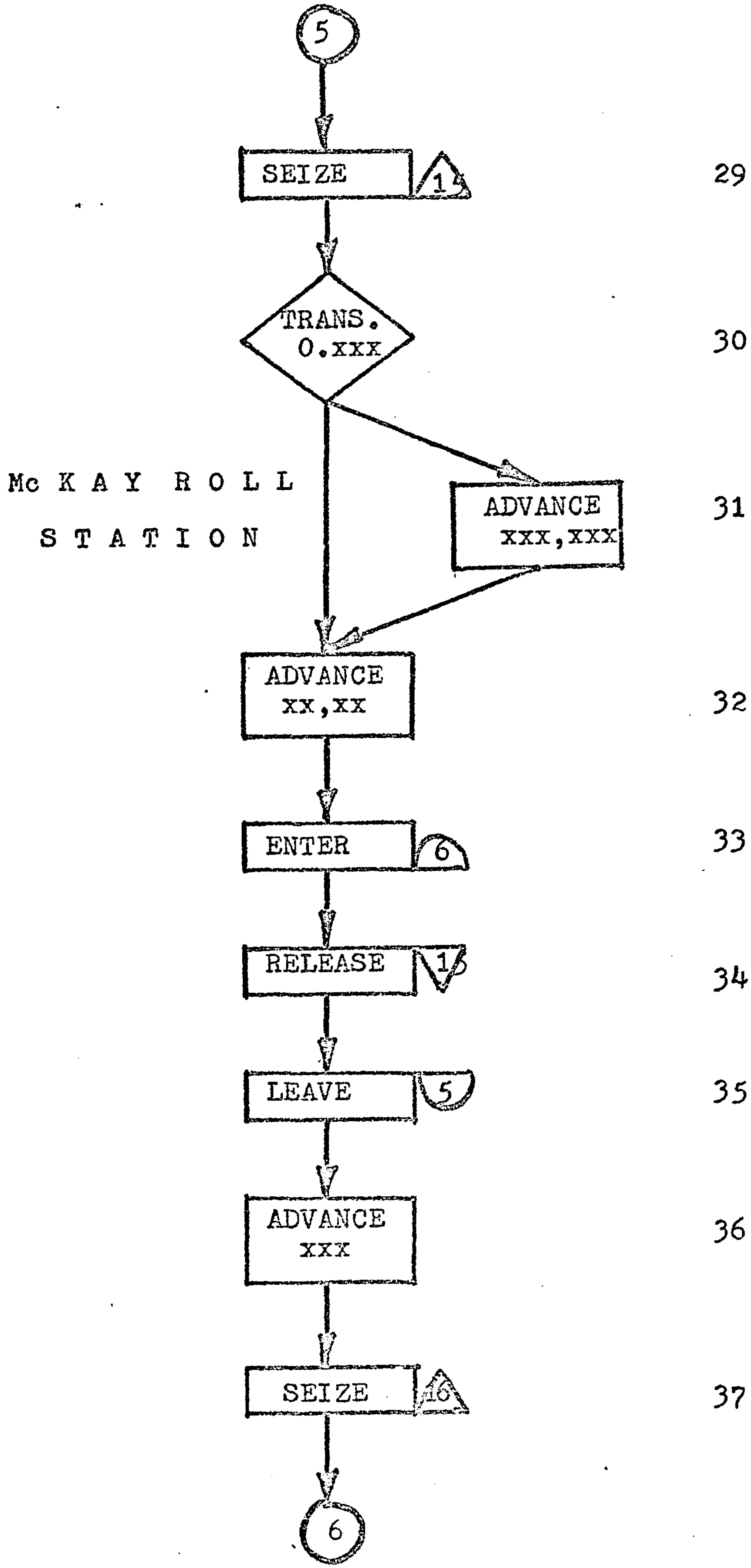

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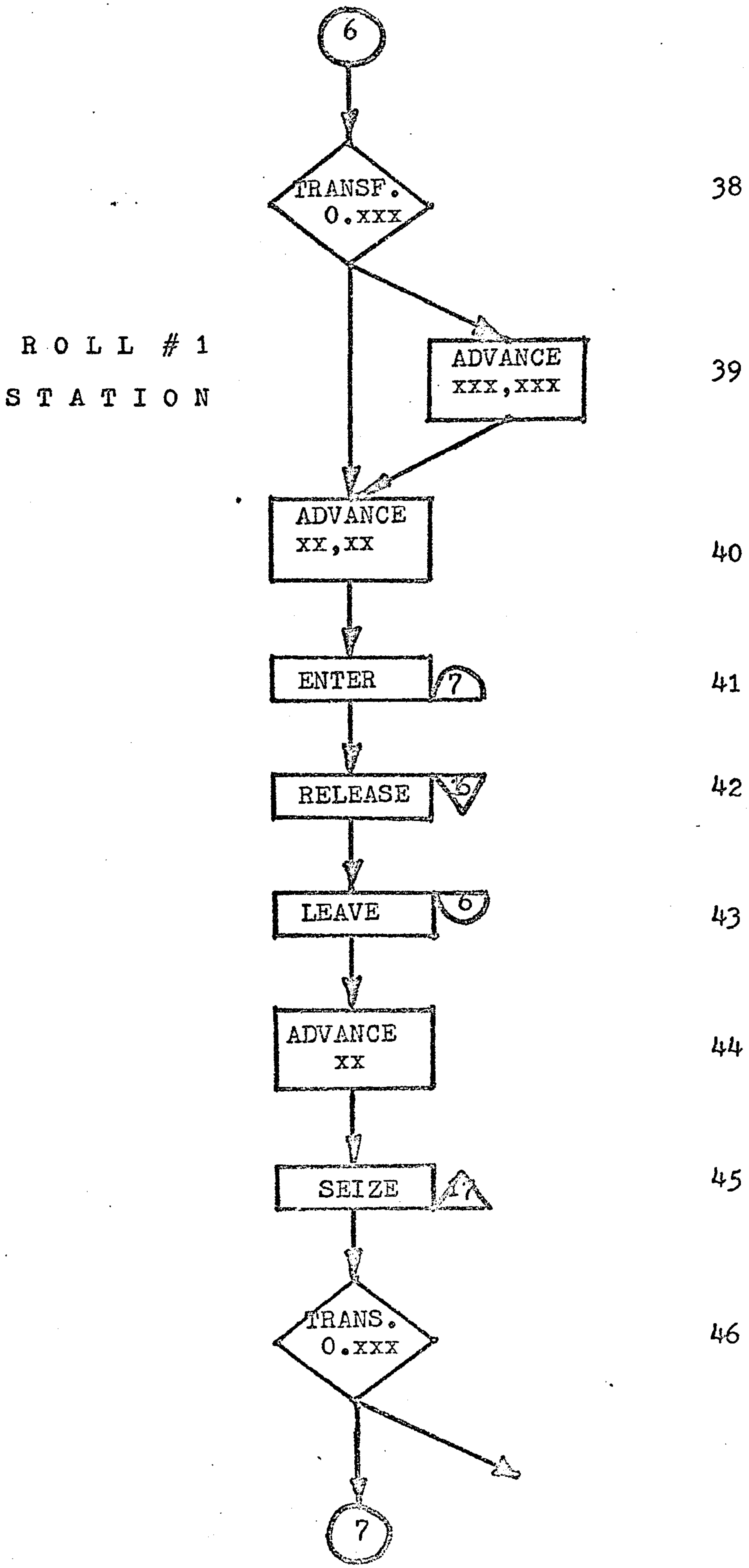

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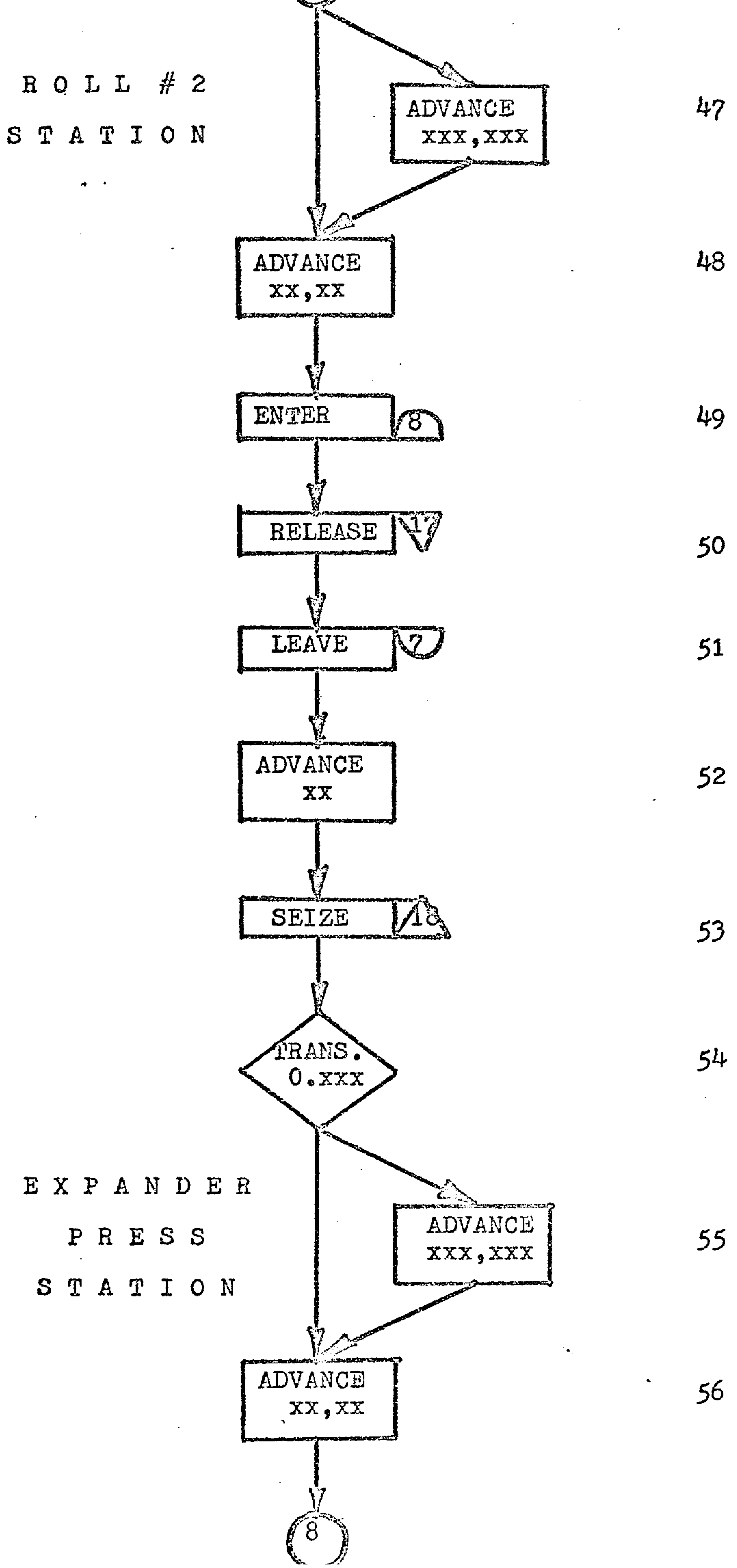

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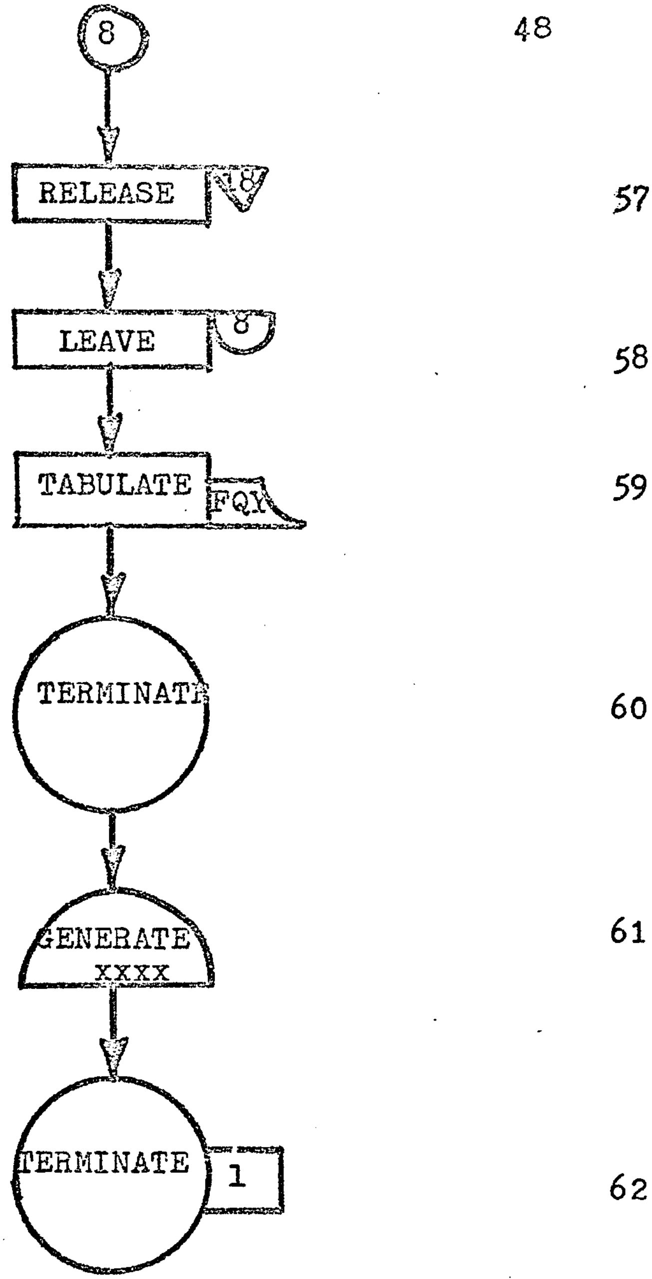

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4.6 PROGRAM PRINTOUT.

The program itself differs from the model of the system in that it includes SEIZE-RELEASE sequences for every machine in the line. The purpose of this is to enable the gathering of statistics on the utilization of the machines in the intervals between breakdowns (i.e. the net production time) rather than their overall utilization which, of course, would be a smaller figure and not representing the true utilization of the machines. These SEIZE-RELEASE sequences do not have any effect on the model itself and so were excluded from the block diagram of Section 4.5

The program is reproduced in Figure 13. All the cards from number 1 to number 149 (column on the right of the printout) are either self-explanatory or have already been discussed in previous sections. Some of the remaining cards are be explained at this point.

Starting with card number 150, we have the following three-card sequence:

```
START     x,NP
RESET
START     xxxx,,xxx
```

The first of these cards is designed to have the simulation run for a certain period of time necessary to fill the line with rims. The NP stands for "No Printout" after this short run. Then the RESET card will wipe out most of the statistics compiled up to this point but will retain the current contents of all the blocks. The following START card will then run the simulation for the designated period of time with printouts

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occuring as indicated by the second figure.

Cards number 153 to number 193 request the desired statistics and graphs to be printed out during the simulation run. These include the following information:

Rim count in all blocks

Program running time

Statistics on the hourly rim production

Graph of the frequency of the hourly rim production

Statistics on the utilization of machines

Graph of the average utilization of machines

Statistics on the utilization of chutes

Graph of the average utilization of chutes.

This required output will be discussed in more detail in Section 4.7.

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```
OCK
MBER   *LOC    OPERATION  A,B,C,D,E,F,G                  COMMENTS
       *
       *       ***** RIM LINE SIMULATION *****
       *
       *       ***** PROGRAM INCLUDING MACHINE BREAKDOWNS *****
       *
       *       ***** JORGE E. MERINO *** UNIVERSITY OF WINDSOR *** 197  *****
       *
       *
       *
               SIMULATE
        FOY    TABLE        RT,50,50,20,60000
        1      STORAGE      7              CHUTE CAPACITY FOR WELDER # 1
        2      STORAGE      30             CHUTE CAPACITY FOR WELDER # 2
        10     STORAGE      37             COMBINED CHUTE CAPACITY FOR BOTH WELDERS
        3      STORAGE      22             CHUTE CAPACITY ELEV. WASHER WELDER #1
        4      STORAGE      7              CHUTE CAPACITY ELEV. WASHER WELDER #2
        5      STORAGE      10             CHUTE CAPACITY MCKAY ROLL
        6      STORAGE      12             CHUTE CAPACITY ROLL # 1
        7      STORAGE      7              CHUTE CAPACITY ROLL # 2
        8      STORAGE      3              CHUTE CAPACITY FOR EXPANDER PRESS
               GENERATE     55,5           PICK UP METAL SHEETS EVERY 0.055 MINUTES
       *
       *       ***** SHEAR AND COIL STATION *****
       *
               ENTER        10
               SEIZE        10
               TRANSFER     .001,OKY1,TRA1   FREQUENCY OF BREAKDOWNS
        TRA1   TRANSFER     .330,OKY1,BDSC
        BDSC   ADVANCE      30250,15000       DURATION OF BREAKDOWN
        OKY1   SEIZE        1
               ADVANCE      52,1           SHEAR AND COIL OPERATION
               RELEASE      1
               TEST G       S2,S1,WEL2 RIM GOES TO WELDER WITH SHORTER QUEUE
       *
       *       ***** WELDING STATION #1 *****
       *
               ENTER        1              WAIT IN CHUTE LEADING TO WELDER
               RELEASE      10
               ADVANCE      35             CHUTE ROLLING TIME
               SEIZE        11
               TRANSFER     .001,OKY3,TRA2
        TRA2   TRANSFER     .667,OKY3,BDW1
        BDW1   ADVANCE      21375,10000
        OKY3   SEIZE        2
               ADVANCE      128,5          WELDING OPERATION
               RELEASE      2
               ENTER        3
               RELEASE      11
               LEAVE        1              RIM LEAVES WELDING STATION
               LEAVE        10
               ADVANCE      100
               SEIZE        13
               TRANSFER     .001,OKY4,TRA4
        TRA4   TRANSFER     .080,OKY4,BDEW1
        BDEW1  ADVANCE      12000,5000
```

Figure 13.- Program Printout.

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OMMENTS	CARD NUMBER
	1
	2
	3
OWNS *****	4
	5
F WINDSOR *** 1970 *****	6
	7
	8
	9
	10
	11
OR WELDER # 1	12
OR WELDER # 2	13
APACITY FOR BOTH WELDERS	14
LEV. WASHER WELDER #1	15
LEV. WASHER WELDER #2	16
CKAY ROLL	17
OLL # 1	18
OLL # 2	19
OR EXPANDER PRESS	20
EETS EVERY 0.055 MINUTES	21
	22
	23
	24
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F BREAKDOWNS	27
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BREAKDOWN	29
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PERATION	31
	32
ER WITH SHORTER QUEUE	33
	34
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DING TO WELDER	37
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ME	39
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NG STATION	49
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.- **Program Printout.**

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```
 OKY4   SEIZE        4
        ADVANCE      90,4          ELEVATOR WASHER OPERATION
        RELEASE      4
        ENTER        5
        RELEASE      13
        LEAVE        3
        TRANSFER     ,MCKAY
*
*       ***** WELDING STATION #2 *****
*
 WEL2   ENTER        2
        RELEASE      10
        ADVANCE      120
        SEIZE        12
        TRANSFER     .001,OKY2,TRA3
 TRA3   TRANSFER     .330,OKY2,BDW2
 BDW2   ADVANCE      24750,15000
 OKY2   SEIZE        3
        ADVANCE      137,13        WELDING OPERATION
        RELEASE      3
        ENTER        4
        RELEASE      12
        LEAVE        2
        LEAVE        10
        ADVANCE      35
        SEIZE        14
        TRANSFER     .001,OKY5,TRA5
 TRA5   TRANSFER     .080,OKY5,BDEW2
 BDEW2  ADVANCE      12000,5000
 OKY5   SEIZE        5
        ADVANCE      90,4          ELEVATOR WASHER OPERATION
        RELEASE      5
        ENTER        5
        RELEASE      14
        LEAVE        4
*
*       ***** MCKAY ROLL STATION *****
*
 MCKAY  ADVANCE      70
        SEIZE        15
        TRANSFER     .001,OKY6,TRA6
 TRA6   TRANSFER     .330,OKY6,BDMC
 BDMC   ADVANCE      14250,10000
 OKY6   SEIZE        6
        ADVANCE      75,5          MCKAY ROLL OPERATION
        RELEASE      6
*
*       ***** ROLL #1 STATION *****
*
        ENTER        6
        RELEASE      15
        LEAVE        5
        ADVANCE      40
        SEIZE        16
        TRANSFER     .001,OKY7,TRA7
 TRA7   TRANSFER     .330,OKY7,BDR1
 BDR1   ADVANCE      22500,15000
```

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RATION	57
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```
OKY7     SEIZE       7
         ADVANCE     75,5           ROLL #1 OPERATION
         RELEASE     7
*
*        ***** ROLL #2 STATION *****
*
         ENTER       7
         RELEASE     16
         LEAVE       6
         ADVANCE     35
         SEIZE       17
         TRANSFER    .001,OKY8,TRA8
TRA8     TRANSFER    .330,OKY8,BDR2
BDR2     ADVANCE     26750,20000
OKY8     SEIZE       8
         ADVANCE     76,5           ROLL #2 OPERATION
         RELEASE     8
*
*        ***** EXPANDER PRESS STATION *****
*
         ENTER       8
         RELEASE     17
         LEAVE       7
         ADVANCE     30
         SEIZE       18
         TRANSFER    .001,OKY9,TRA9
TRA9     TRANSFER    .165,OKY9,BDEX
BDEX     ADVANCE     23500,15000
OKY9     SEIZE       9
         ADVANCE     70,1           EXPANDER PRESS OPERATION
         RELEASE     9
         RELEASE     18
         LEAVE       8
         TABULATE    FOY
         TERMINATE       RIM IS TAKEN TO ANOTHER DEPARTMENT BY CONVEYOR
         GENERATE    1000
         TERMINATE   1
         START       1,NP
         RESET
         START       720,,360
         REPORT
         EJECT
BLO      TITLE       ,RIM COUNT IN ALL BLOCKS
         SPACE       3
CLO      TITLE       ,TIME IN THOUSANDS OF A MINUTE
         EJECT
TAB      TITLE       ,STATISTICS ON HOURLY RIM PRODUCTION
TAB      INCLUDE     T$FOY/2,3,10,11
         EJECT
         GRAPH       TF,FOY
         ORIGIN      50,20
         X           ,3,2,50,,15
         Y           0,1,10,2
40       STATEMENT   15,34,FREQUENCY OF HOURLY RIM PRODUCTION
5        STATEMENT   30,9,FREQUENCY
50       STATEMENT   53,4,RIMS
         ENDGRAPH
```

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```
         EJECT
FAC      TITLE        ,STATISTICS ON UTILIZATION OF MACHINES
FAC      INCLUDE      F1-F9/1,2,3,4
         EJECT
         GRAPH        FR,1,9
         ORIGIN       50,20
         X            ,3,5
         Y            0,.05,20,2
40       STATEMENT    10,31,AVERAGE UTILIZATION OF MACHINES
3        STATEMENT    30,12,UTILIZATION
50       STATEMENT    53,14,MACHINE NUMBER
         ENDGRAPH
         EJECT
STO      TITLE        ,STATISTICS ON UTILIZATION OF CHUTES
         EJECT
         GRAPH        SR,1,8
         ORIGIN       50,20
         X            ,3,5
         Y            0,.05,20,2
40       STATEMENT    10,29,AVERAGE UTILIZATION OF CHUTES
3        STATEMENT    30,12,UTILIZATION
50       STATEMENT    53,12,CHUTE NUMBER
         ENDGRAPH
         END
```

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F CHUTES 183
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CHUTES 189
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4.7 INPUT DATA.

The following is the data that needs to be collected for a simulation run:

a) Chute capacity.-

The maximum number of rims that can be placed in the chutes before causing the preceeding machine to stop has to be measured for the two welders, elevator washers, the McKay Roll, the two finish rolls and the Expander Press.

b) Frequency of breakdowns.-

The frequency with which breakdowns occur in each station has to be calculated from the downtime records kept by the company such as the one shown in Figure 4.

c) Duration of Breakdowns.-

From the downtime sheets, the duration, or approximate average time of a breakdown can be calculated for each station. To randomize these times, an estimated plus or minus range is added to them.

d) Cycle times.-

The cycle time of each machine has to be obtained by means of time study. The variation from cycle to cycle is also aknowledged in the ADVANCE blocks representing the cycle times.

e) Chute rolling times.-

The time that the rim takes moving from machine to machine must also be measured for each chute in the line . The average time is the one expressed in the corresponding ADVANCE block.

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4.8. REQUESTED OUTPUT.

The specific output information requested by the program consists of the following statistics and graphs:

a) Block count.-

The BLOCK COUNTS gives information on the current and total number of transactions in each block, so that we can determine the total production of the line for the period that the program was running as well as the number of breakdowns at the various stations. See Figure 14.

b) Clock statistics.-

The CLOCK STATISTICS indicates the running time of the program since the last RESET card (Relative Clock) as well as the total running time (Absolute Clock) up to that point in the simulation. See Figure 14.

c) Table Statistics.-

The TABLE STATISTICS provides information regarding the frequency of arrival rates, i.e. how often did so many transactions arrive in one-hour intervals. The information printed out includes the number of entries in the table, the average hourly production (mean argument), the frequency classes, and the observed frequency.

Also requested is a graph of the observed frequencies of hourly rim production with the X-axis indicating the quantity of rims and the Y-axis the observed frequency. See Figure 15.

d) Facility statistics.-

The FACILITY STATISTICS contains information on the

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utilization[6] of machines and prints out the number of the machine, the average utilization, and the number of entries.

A GRAPH of the average utilization of machines is to be printed out with the machine number on the X-axis and the utilization on the Y-axis. See figure 16.

e) Storage statistics.-

The STORAGE STATISTICS provides data on the utilization of all chutes in the line. It contains information including: storage number, capacity of the storage, average contents, average utilization, number of entries, average time spent by a transaction in the chute, and current and maximum contents.

A GRAPH of the average utilization of chutes is also requested in the program, with the chutes on the X-axis, and the utilization on the Y-axis, as shown in Figure 17.

---

6 i.e. the fraction of time during which the machine is processing rims; it does not include the time when the machine is waiting for rims or being repaired.

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M COUNT IN ALL BLOCKS
LOCK COUNTS

LOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLO
1	1	6137	11	0	3242	21	0	3238	
2	22	6136	12	0	3242	22	0	3238	
3	0	6114	13	6	3242	23	0	3238	
4	0	6114	14	0	3238	24	0	3238	
5	0	6	15	0	3238	25	21	3238	
6	0	0	16	0	3	26	0	3218	
7	0	6114	17	0	2	27	0	3218	
8	0	6114	18	0	3238	28	0	4	
9	0	6115	19	0	3238	29	0	0	
10	1	6115	20	1	3239	30	0	3219	

LOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLO
51	6	2868	61	0	2862	71	0	6072	
52	0	2862	62	9	6080	72	0	6073	
53	0	2862	63	0	6073	73	11	6073	
54	0	4	64	0	6073	74	0	6062	
55	0	0	65	0	7	75	0	6062	
56	0	2862	66	0	2	76	0	11	
57	0	2862	67	0	6073	77	0	4	
58	1	2863	68	0	6073	78	0	6062	
59	0	2862	69	1	6074	79	0	6062	
60	0	2862	70	0	6073	80	1	6063	

OCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLO
101	0	6057							
102	0	6058							
103	0	6058							
104	0	6058							
105	0	6058							
106	0	6058							
107	0	720							
108	0	720							

E IN THOUSANDS OF A MINUTE

LATIVE CLOCK 720000 ABSOLUTE CLOCK 721000

Figure 14.- Sample Output for Block Count ar

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BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
21	0	3238	31	0	3218	41	0	2868
22	0	3239	32	1	3219	42	0	6
23	0	3238	33	0	3218	43	0	2
24	0	3238	34	0	3218	44	0	2868
25	21	3238	35	0	3218	45	0	2868
26	0	3218	36	0	3218	46	1	2869
27	0	3218	37	0	2872	47	0	2868
28	0	4	38	0	2872	48	0	2868
29	0	0	39	6	2872	49	0	2868
30	0	3218	40	0	2868	50	0	2868

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
71	0	6073	81	0	6062	91	0	6057
72	0	6073	82	0	6062	92	0	6057
73	11	6073	83	0	6062	93	0	6057
74	0	6062	84	6	6062	94	0	6057
75	0	6062	85	0	6057	95	0	6057
76	0	11	86	0	6057	96	0	6057
77	0	4	87	0	7	97	0	6057
78	0	6062	88	1	2	98	0	6
79	0	6062	89	0	6056	99	0	2
80	1	6063	90	0	6056	100	0	6057

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL

721000

Sample Output for Block Count and Clock Statistics.

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```
ATISTICS ON HOURLY RIM PRODUCTION
NTRIES IN TABLE          MEAN ARGUMENT
            12                 504.916
         UPPER      OBSERVED
         LIMIT      FREQUENCY
            50             0
           100             0
           150             1
           200             1
           250             0
           300             0
           350             0
           400             0
           450             2
           500             2
           550             0
           600             1
           650             1
           700             2
           750             1
           800             1
EMAINING FREQUENCIES ARE ALL ZERO
```

Figure 15.- Sample Output for Table Statistics.

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NON-WEIGHTED

le Output for Table Statistics.

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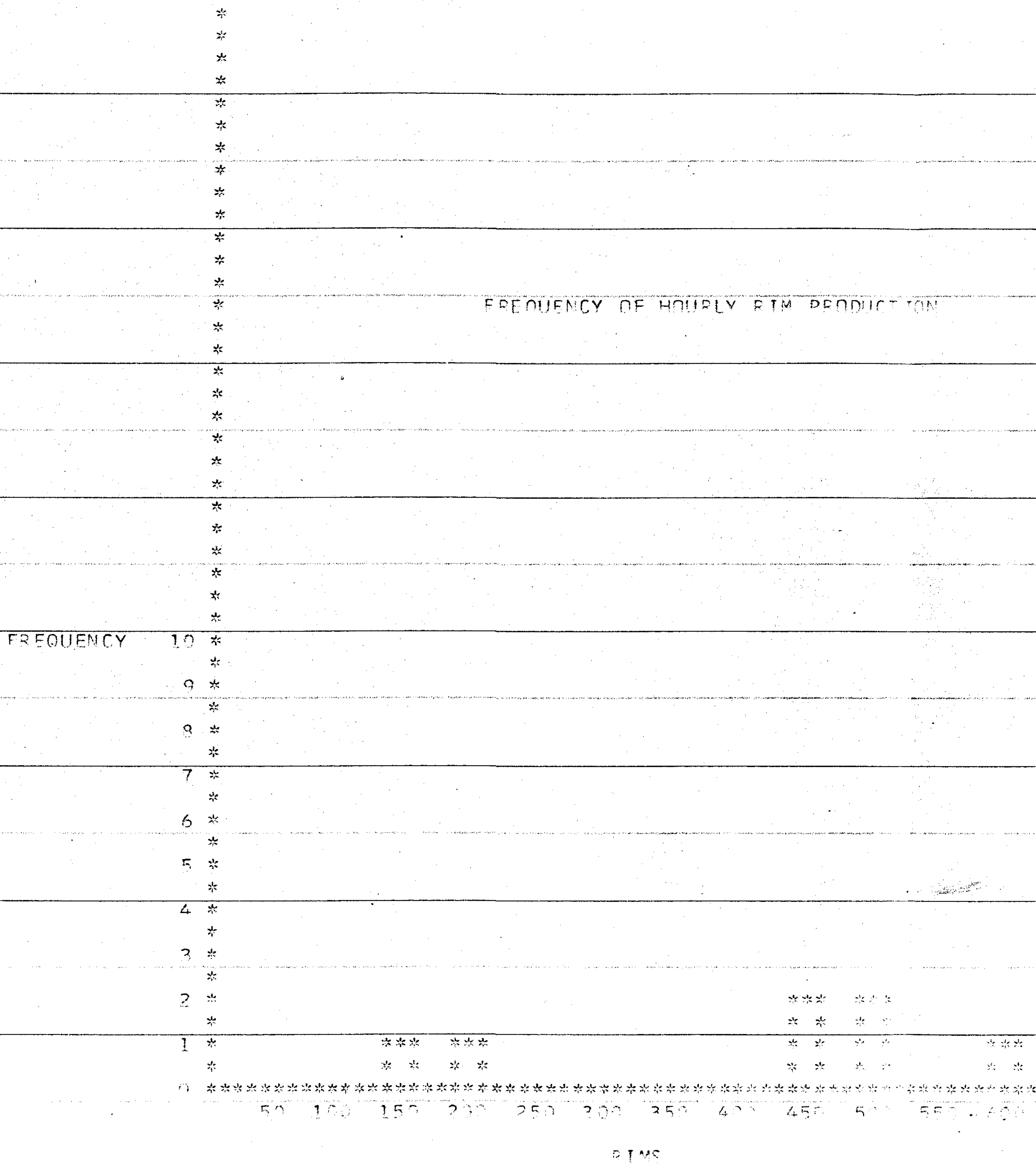

Figure 15(Cont'n).- Sample Graph for Ta

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```
F HOURLY RIM PRODUCTION



           ***  ***                    ***
           * *  * *                    * *
           * *  * *       ***  ***     * *  ***
           * *  * *       * *  * *     * *  * *
**************************************************
 350  400  450  500  550  600  650  700  750

MS
```

(Cont'n).- Sample Graph for Table Statistics.

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TATISTICS ON UTILIZATION OF MACHINES

FACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRAN
1	.441	6115	51.990
2	.575	3239	128.023
3	.545	2869	136.885
4	.402	3219	90.097
5	.357	2863	39.988
6	.675	6074	80.097
7	.631	6063	74.986
8	.639	6057	76.024
9	.589	6058	70.006

Figure 16.- Sample Output for Facility Statisti

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AGE
TRAN
.990
.023
.885
.097
.988
.097
.986
.024
.006

le Output for Facility Statistics.

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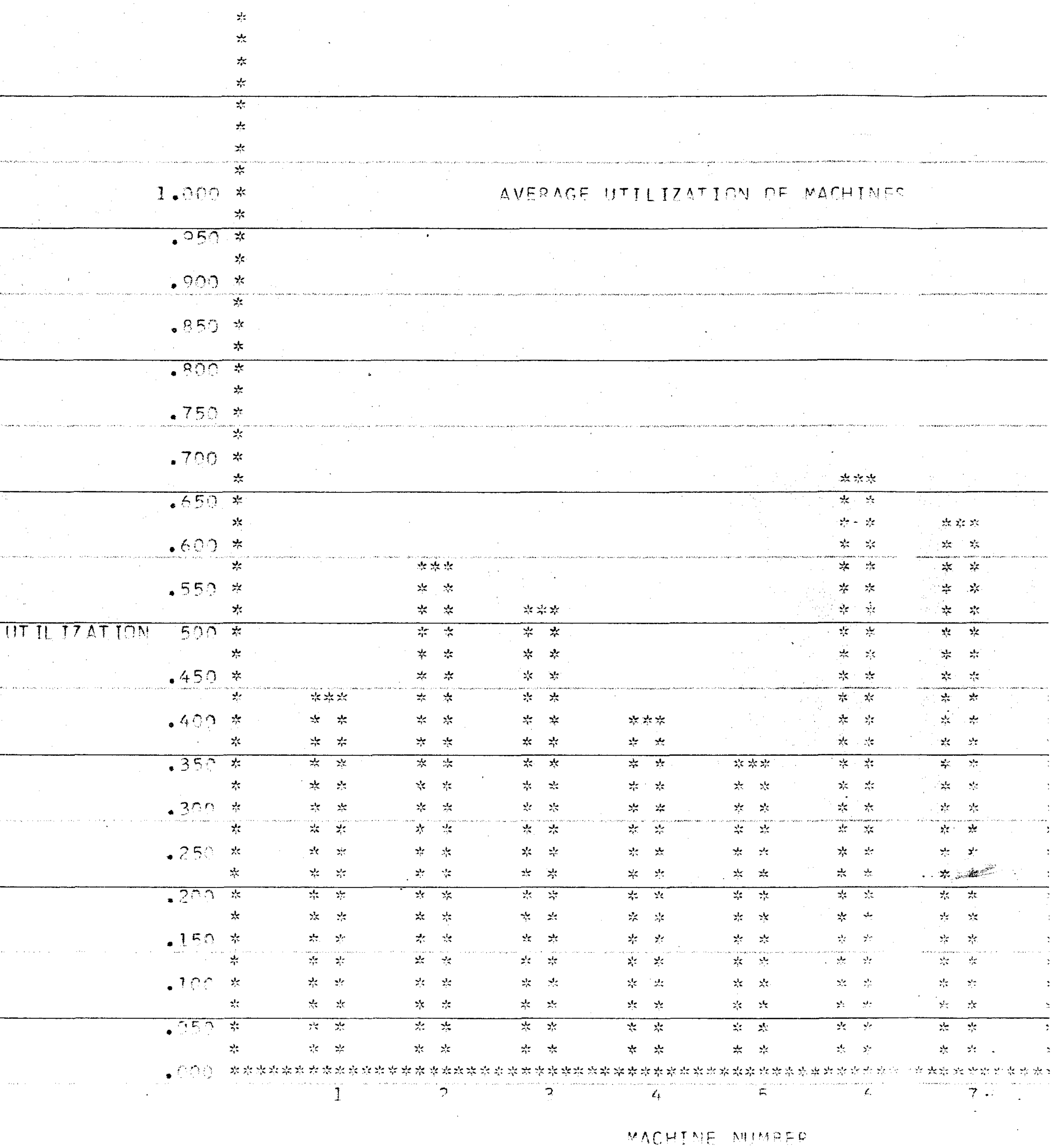

Figure 16 (Cont'n).- Sample Graph for Fac

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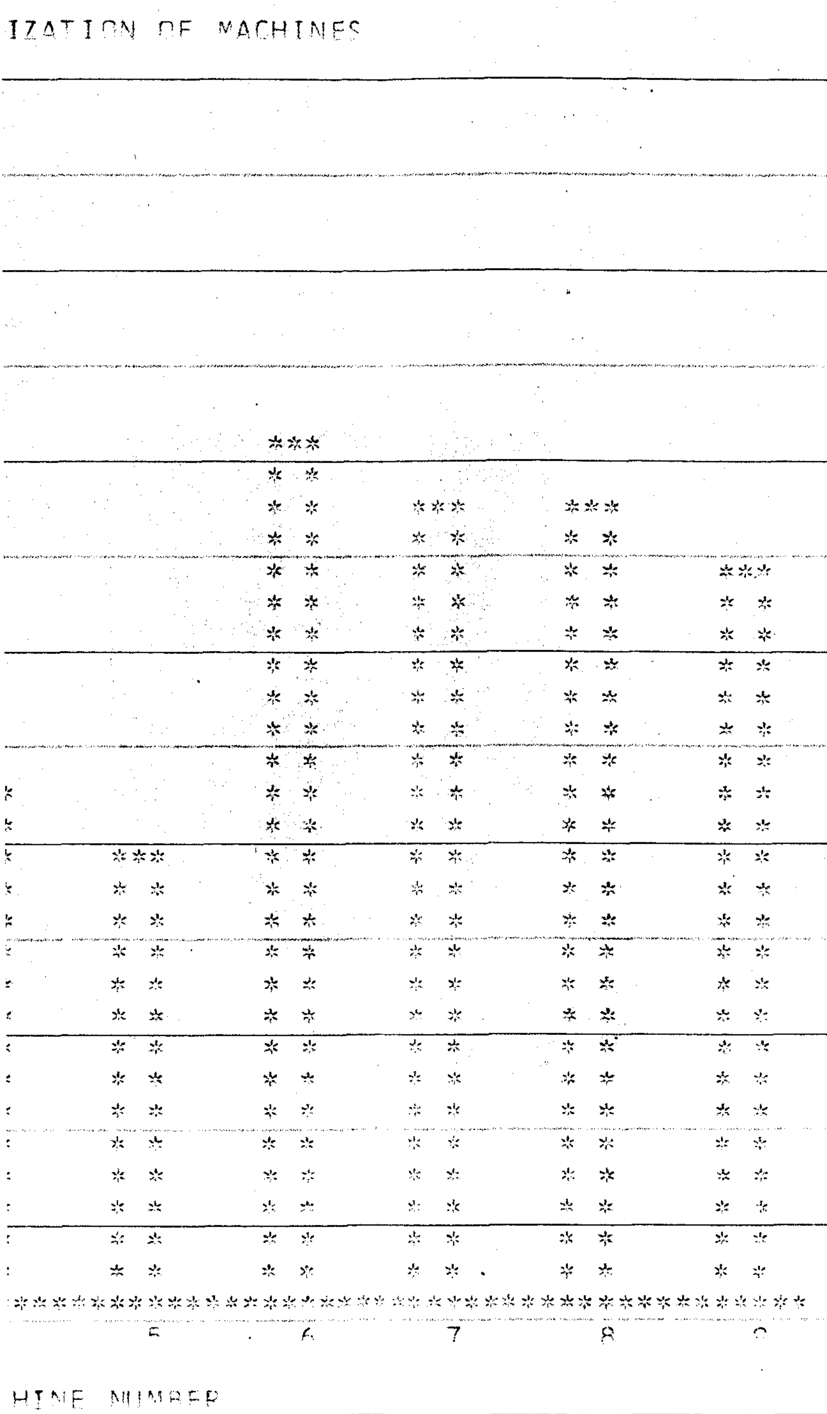

:ont'n).- <u>Sample Graph for Facility Statistics</u>.

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STATISTICS ON UTILIZATION OF CHUTES

STORAGE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILIZATION	ENTRIES	AVERAGE TIME/TRAN
1	7	6.982	.997	3245	1549.180
2	30	7.092	.236	2875	1776.201
3	22	18.859	.857	3240	4190.941
4	7	5.896	.842	2869	1479.691
5	10	9.061	.906	6083	1072.497
6	12	4.172	.347	6074	494.636
7	7	2.037	.291	6064	241.872
8	3	1.064	.354	6058	126.493
10	37	36.787	.994	6143	4311.683

Figure 17.- Sample Output for Storage Statistics.

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ENTRIES	AVERAGE TIME/TRAN	CURRENT CONTENTS	MAXIMUM CONTENTS
3245	1549.180	7	7
2875	1776.291	7	8
3249	4190.941	22	22
2869	1479.691	7	7
6083	1072.487	10	10
6074	494.636	12	12
6064	241.872	7	7
6058	126.483		3
6143	4211.683	37	37

for Storage Statistics.

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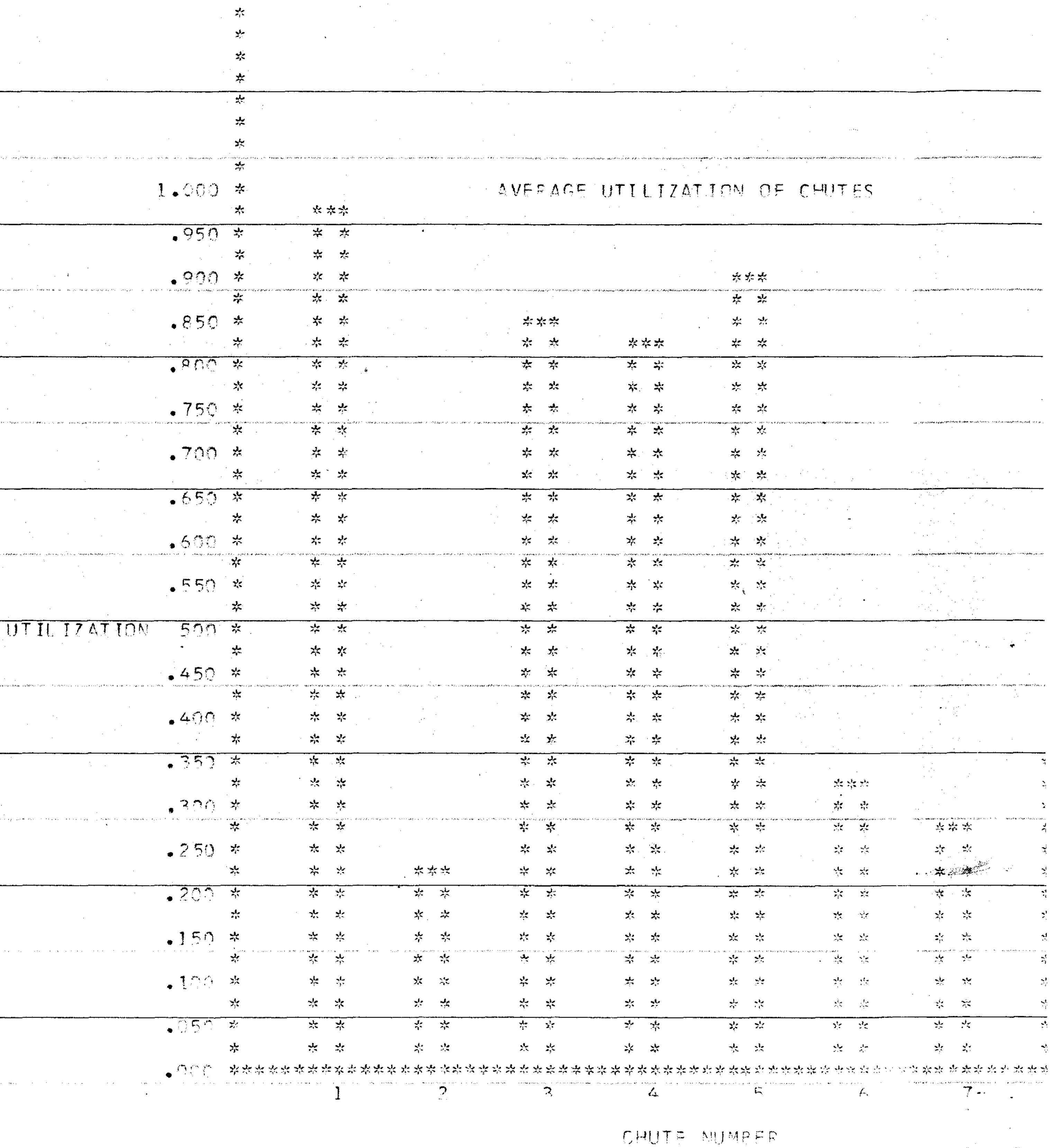

Figure 17 (Cont'n).- Sample Graph for Storage S

END

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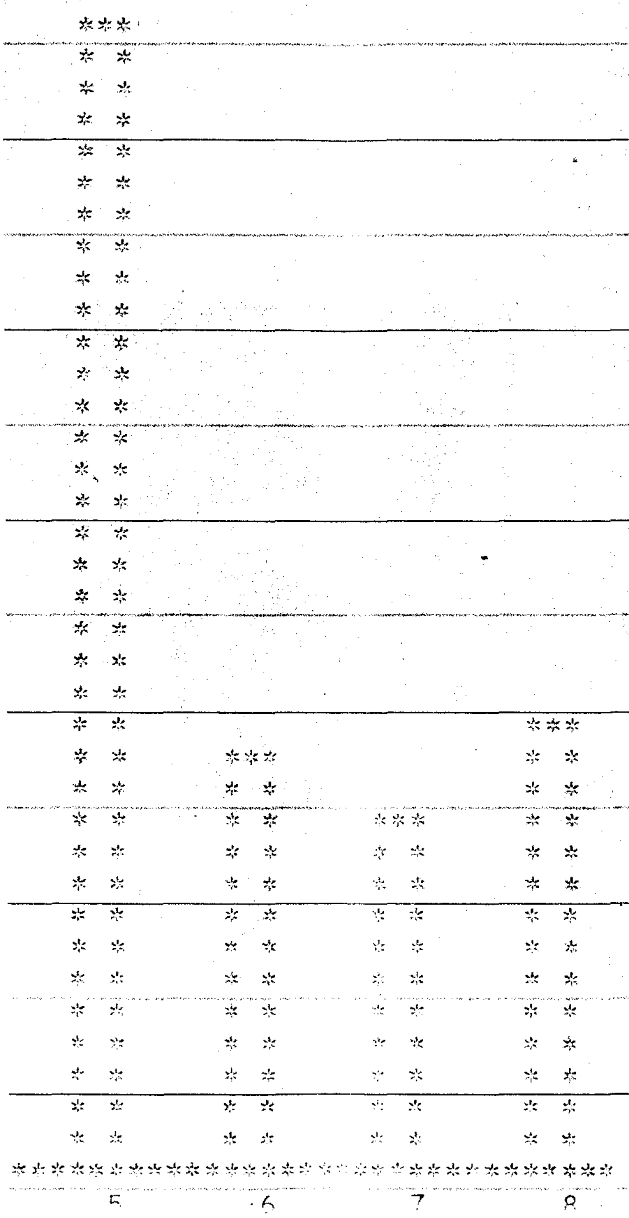
ATION OF CHUTES



NUMBER

- Sample Graph for Storage Statistics.

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CHAPTER V

SIMULATION OF PRESENT SYSTEM

The next step after developing the model is to test it by simulating the real system and correlating the results of the simulation with the available records for the system. In this chapter, one of the rim lines is simulated by using the model of Chapter IV and the data collected from the company's past records, or through personal observation in the plant. The results obtained from the program are compared to the production records for the same period during which the data was recorded. This gives us a good indication of the effectiveness of the model to represent the real system.

Line A is chosen for the simulation because it is considered a typical line and also because it was producing the same type of rim for a long period of time which would keep the cycle times in the rolling machines fairly constant, since although the time standards are the same for all types of rim, this is not true in the actual system and the machine cycle times vary considerably from rim to rim. This fact is rather obvious if we consider the weight and size difference between a 14.5 inch-wide rim and a 16.5 inch one, and it was proved through a quick time study on several lines. All machines in the lines rolling heavier rims had higher cycle times than those in lines with lighter rims.

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5.1 INPUT DATA.

The data requifements have been listed in Section 4.6 of Chapter IV. The following information is needed for a simulation run:

a) capacity of each chute in the system in terms of rims;

b) frequency of breakdowns, in terms of the probability of a breakdown occuring during the passing of any one rim;

c) average duration of each breakdown with a plus or minus range;

d) the average cycle times for all machines, also with a plus or minus range;

e) average time taken by a rim to move from one machine to another via the various chutes.

As mentioned before, the chute capacities were measured in the line, by filling the chutes with rims and recording the maximum capacities. The frequency and duration of breakdowns were calculated from the Downtime Records for that period of time being simulated. The cycle times were originally measured with a brush recorder and later with an electronic counter for the McKay Roll with the intention of using either method for all the other machines. However, upon measuring the same cycles with a stop watch, it was discovered that the stop watch produced more accurate readings than the other instruments; these operated on electrical impulses from the machine, which were not consistent with the operation being performed by the machines themselves. The chute rolling times were also measured with a stop watch. All the data are given in Tables 5.1 to 5.4.

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TABLE 5.1

CHUTE CAPACITIES

Machine	Max. number of rims
Welder #1	7
Welder #2	30
Elevator Washer #1	22
Elevator Washer #2	7
McKay Roll	10
Roll #1	12
Roll #2	7
Expander Press	3

TABLE 5.2

FREQUENCY OF BREAKDOWNS

Machine	Probability of breakdown *
Shear and Coil	0.000330
Welder #1	0.000667
Welder #2	0.000330
Elevator Washers	0.000080
McKay Roll	0.000330
Roll #1	0.000330
Roll #2	0.000330
Expander Press	0.000165

* i.e. the probability of a breakdown occuring during the processing of any one rim.

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TABLE 5.3

DURATION OF BREAKDOWNS

Machine	Total Downtime(min)	Time/bdown and range(min)
Shear and Coil	605	30.25 ± 10
Welder #1	855	21.375 ± 10
Welder #2	495	24.75 ± 15
Elevator Washers	60	12.0 ± 5
McKay Roll	285	14.25 ± 10
Roll #1	450	22.5 ± 15
Roll #2	535	26.75 ± 15

TABLE 5.4

CYLE TIMES

CHUTE ROLLING TIMES.

Machine	Cycle Time and range (milliminutes)	Chute Rolling Time (milliminutes)
Shear and Coil	52 ± 1	-----
Welder #1	128 ± 5	35
Welder #2	137 ± 13	120
Elevator Washer #1	90 ± 4	100
Elevator Washer #2	90 ± 4	35
McKay Roll	80 ± 10	70
Roll #1	75 ± 5	40
Roll #2	76 ± 5	35
Expander Press	70 ± 1	30

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5.2 NET PRODUCTION TIME.

In order to establish the program running time, it was necessary to calculate the actual net production time for the lines, since even though the Production Routing of Figure 2 shows a delay allowance of 7% and a personal allowance of 8%, the actual figure for production time lost, without considering major breakdowns, is much higher. This is explained in the company's Production Standards Procedure sheet, the pertinent sections of which will be summarized in the following subsections.

1.- Delays.-

All the delays encountered in the line are categorized as follows:

- (i) Non-cyclic Delays
- (ii) Inherent Delays
- (iii) Correctable Delays
- (iv) Personal Delays
- (v) Major Delays

Non-cyclic delays are those which are predictable but unavoidable such as disposing of a defective rim or inspecting a rim. Inherent delays are those which are unpredictable as well as unavoidable such as: receiving instructions from the foreman, minor breakdowns (of less than 10 minutes), etc. The Delay Allowance of 7% mentioned above includes all of the inherent delays.

The Correctable delays are those which could be prevented or avoided and should therefore not happen, such as a rim getting stuck in the machine, waiting while the machine is

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oiled, or the operator being idle on the job. These delays are not allowed for but happen nevertheless.

The personal delays are those directly concerning the operator, including coffee breaks, wash-up periods, late starts, etc. The Personal Allowance of 8% covers all these delays.

The major delays are all the machine breakdowns of over 10 minutes of duration. This is estimated at 20 % of the time, however, no allowance is made in the time standard.

2.- Actual Delay Figures.-

A one-week delay study conducted on the Welding stations in the Rim Department showed the following total delay and production times (excluding major breakdowns):

Production Time	1592.25	minutes
Non-cyclic delays	83.47	"
Inherent delays	141.03	"
Correctable delays	30.30	"
Personal delays	272.38	"
Total time	2119.43	"

The production time accounts for only $\frac{1592.25}{2119.45} \times 100 = 75\ \%$ while the non-cyclic and correctable delays represent about 5 % of the total time, the inherent delays approximately 7 %, and the personal delays 13 %. This seems to indicate that the 7 % Delay Allowance does cover all the inherent delays, but the 8 % Personal Allowance does not, this being 13 %. Also, there is a further 5 % time delay not accounted for, deriving from the correctable and non-cyclic delays.

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3.- Program Running Time.-

On the basis of the above figures, the running time for the computer program representing one 8-hour shift is equal to 75 % of 8 hours, or 360 minutes. The program was run for 17 periods of 360 minutes each, representing 17 days of day-shift production. Such a long run is not considered necessary, but it was felt that running the program for an extended period of time would permit the setting of a shorter interval during which the system achieves a steady state, to be applied for the simulation runs of later chapters.

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5.3 DISCUSSION OF RESULTS.

The entire computer output for the simulation of the present system is included in Appendix A. Only some of the results are reproduced and discussed in this section.

The cumulative and daily production figures as well as the cumulative average production for each one of the 17 days are tabulated in Table 5.5. It can be seen that the daily production fluctuates from a very low production of 1957 rims for the third day to a fairly high production of 3834 rims in the fifth day. The average production for the 17 days is of 3090 rims, the total cumulative production being 52534 rims.

The cumulative averages have been plotted in Figure 18. These averages vary from 2588 rims/day at the end of the third day to 3097 rims/day after 14 days. The overall average production after 17 days is 3090 rims/day. A relatively steady average production, fluctuating between 3000 and 3100 rims/day, is achieved after seven days, as can be observed from the graph. However, to ensure that a steady average production is reached for every simulation run, a 10-day period will be used as the standard for all the programs in this paper, and only the results after 10 days of simulation will be discussed for the simulation of the present system.

1.- Rim Count.-

The number of rims produced by the line after 10 days of simulation was of 30,764 rims, or a daily average of 3,076 rims. The total production figure is indicated by the count in block number 106, which is the TERMINATE block represent-

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TABLE 5.5

SIMULATION OF PRESENT SYSTEM

Day	Cumulative Production	Daily Production	Cumulative Average
1	2796	2796	2796
2	5806	3010	2903
3	7763	1957	2588
4	10702	2939	2676
5	14563	3834	2907
6	17314	2788	2886
7	21037	3723	3009
8	24306	3269	3038
9	27211	2905	3023
10	30764	3553	3076
11	33839	3075	3076
12	36623	2784	3052
13	39735	3112	3056
14	43355	3620	3097
15	45960	2605	3064
16	49009	3049	3063
17	52534	3525	3090

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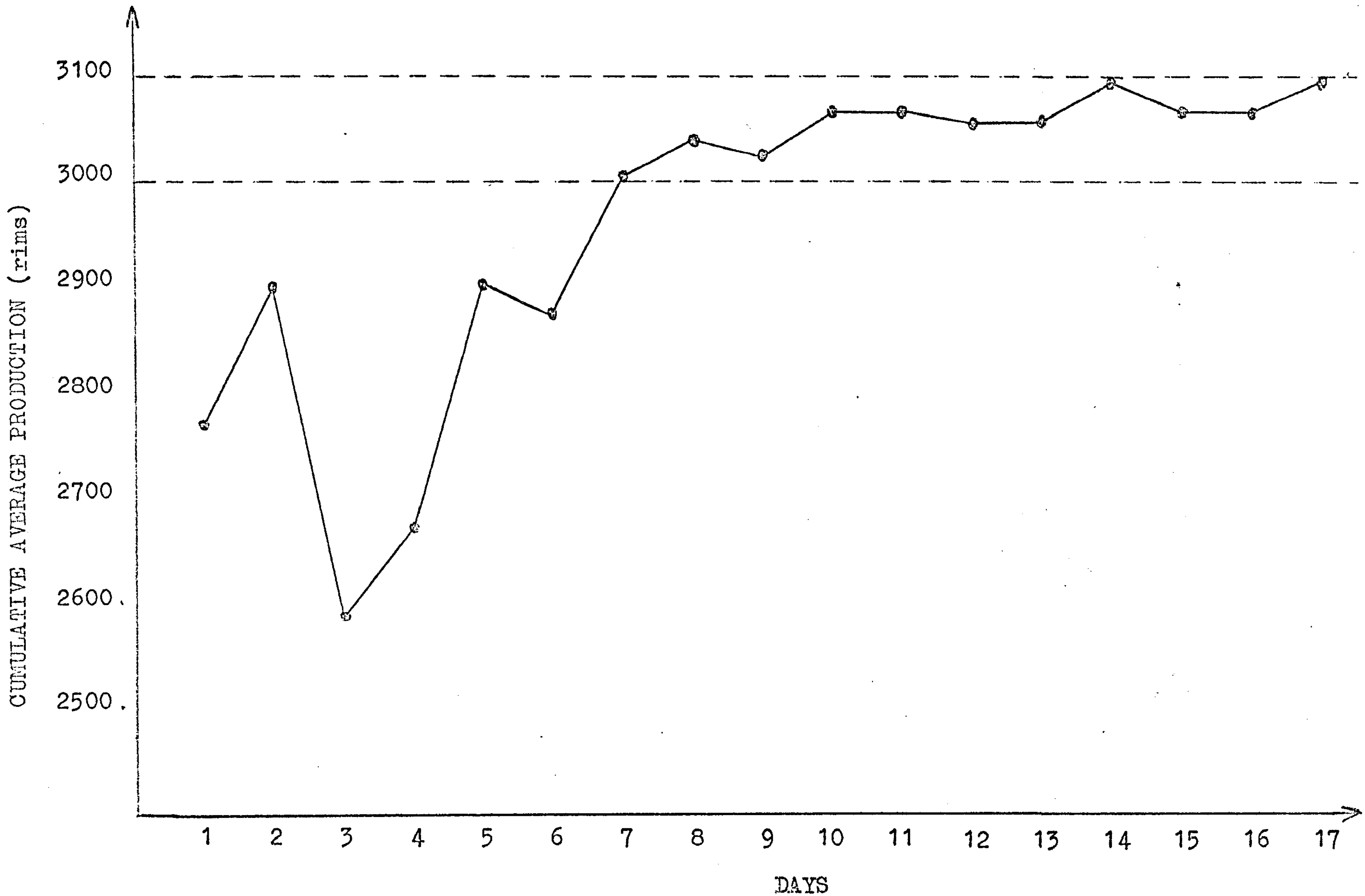

Figure 18.- Simulation of Present System - Graph of daily cumulative ave. production.

ing the exit of rims from the department.

The total time lost due to breakdowns can be estimated for each station from the rim count in the respective blocks. This is done in Table 5.6 The total production time lost during ten 8-hour shifts is 1,281 minutes, over 21 hours.

Of the 30,771 rims that went through the Welding stations, 16,156 came from Welder # 1 and 14,615 from Welder # 2. The difference is accounted for by the longer cycle time for the latter (0.137 min. as compared to 0.128 min. for Welder #1), and was partially balanced by the longer downtime of Welder #1.

2.- Clock Statistics.-

The Relative Clock time shows that the program was run for a simulation period of 3,600,000 thousands of a minute, or 3,600 minutes, the actual working time for ten 8-hour shifts. The Absolute Clock time indicates 3,601 minutes, and includes the one minute required to fill the line with rims.

3.- Table Statistics.-

The statistics on the hourly rim production give information regarding the frequency of arrival of transactions. The lowest hourly production was of less than 150 rims, happening twice in the ten day period. The highest was of less than 800 rims and its frequency was six. The average hourly production for the entire period was of 512.5 rims. The graph of the frequency of hourly rim production is reproduced in Figure 19.

4.- Facility Statistics.-

The statistics on the utilization of machines indicate the average utilization of the machines as well as the number of

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TABLE 5.6

DOWNTIME PER STATION

Station	Frequency of Breakdowns	Ave. duration of breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear & Coil	8	30.25	242.
Welder # 1	11	21.38	235,
Welder # 2	6	24.75	148.5
Elev. Wash. #1	0	12.00	0
Elev. Wash. #2	1	12.00	12.
McKay Roll	7	14.25	99.75
Roll # 1	9	22.50	202.5
Roll # 2	11	26.75	294.25
Expander Press	2	23.50	47.
Totals	55		1281.00

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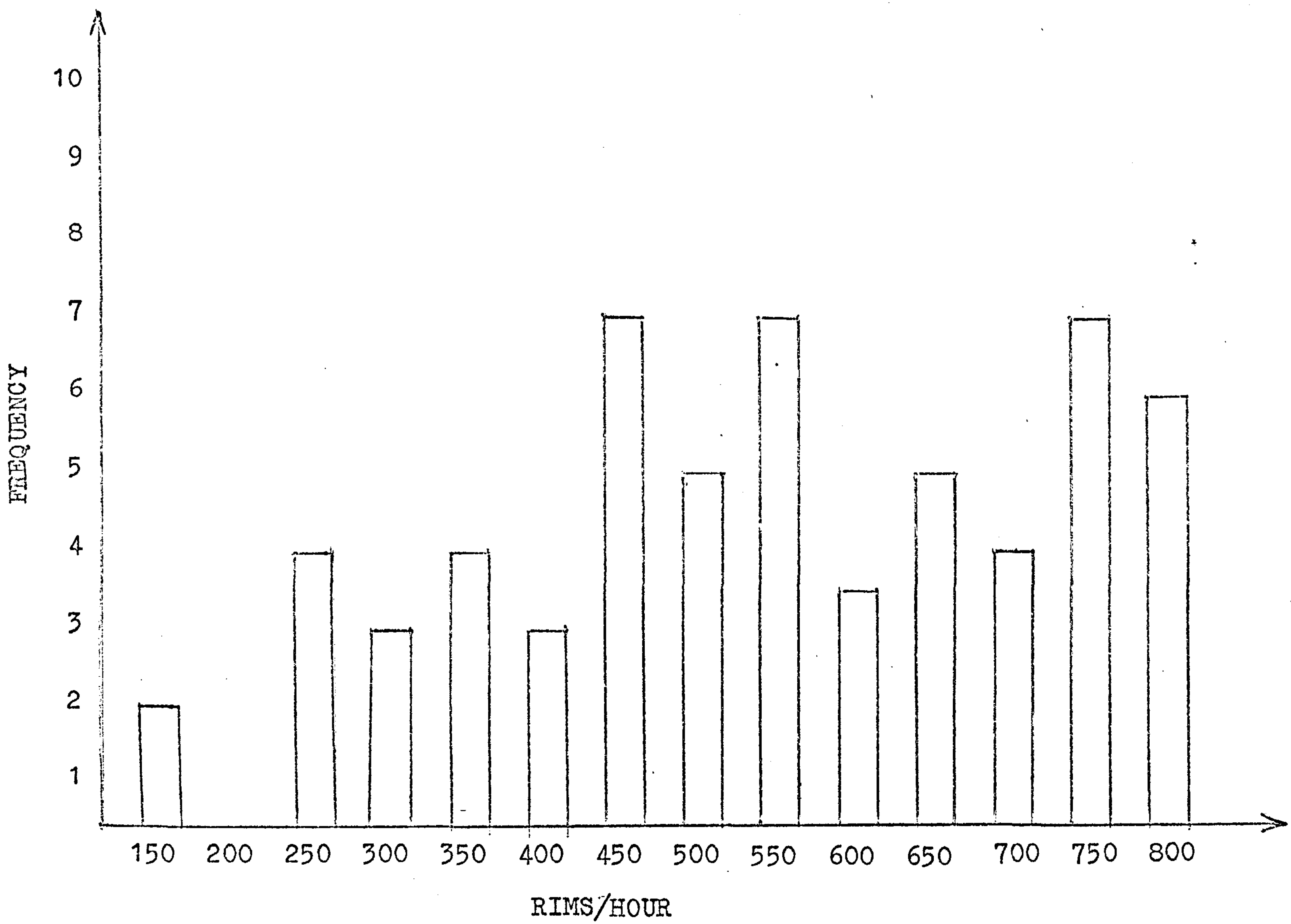

<u>Figure 19</u>.- Frequency of Hourly Rim Production

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entries or rims that have gone through the station and the average time the transactions spent at the station. The average utilization of each machine is as follows:

Shear and Coil	.444
Welder # 1	.575
Welder # 2	.556
Elev. Washer # 1	.403
Elev. Washer # 2	.365
McKay Roll	.684
Roll # 1	.640
Roll # 2	.649
Expander Press	.598

It can be sêen that the McKay Roll is the busiest station, although its utilization is only 0.684, this is due to the large amount of downtime through the whole line. The finish rolls and the Expander Press were utilized almost as much as the McKay, but the stations at the beginning of the line show much lower utilization factors.

5.- Storage Statistics.-

The statistics on the utilization of the chutes gives useful information on the average utilization of the various chutes, the average length of the queues, and the average time per transaction waiting in the queue.(See Table 5.7.) The average contents column shows that the chutes leading to Welder # 1, Elevator Washer # 2, and the McKay Roll, were almost filled to capacities in the average with utilization factors of 0.936, 0.800, and 0.839, respectively. The last column also

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indicates that rims spent more time queueing for the Elev. Washer # 1 (almost 4 minutes) than for any other machine. The other Elevator Washer and both welders also show a long waiting period. Of the rolls, the McKay leads with a wait of almost one minute.

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TABLE 5.7

STATISTICS ON UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction (milliminutes)
Welder # 1	6.552	0.936	1457.745
Welder # 2	6.623	0.220	1630.062
Elev. Washer #1	17.24	0.783	3835.320
Elev. Washer #2	5.602	0.800	1379.256
McKay Roll	8.394	0.839	981.996
Roll # 1	3.320	0.276	388.536
Roll # 2	2.060	0.294	241.106
Expander Press	0.889	0.296	104.082

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5.4 CORRELATION WITH ACTUAL SYSTEM.

The only correlation between the simulation model and the actual system that can be made is the one relating to the average daily production of the line since there is no information available from the present system on the utilization of machines and chutes. Table 5.8 shows the production figures from the company records for the period of simulation, March 2 to March 26. The average daily production from these data is 2,936 rims. The simulation results of Section 5.3 indicate an average production of 3,076 rims/day. This represents a difference of 4.8 % between the two figures.

Since the distribution of the daily production figures is normal (See Appendix I), we can test the hypothesis that the means of the two distributions are equal (assuming that the standard deviations are unknown and not necessarily equal, by using the t' test. The calculations (Appendix I) show that t' = 0.22. This value, when compared to the $t_{\alpha,\nu}$ from the table of percentage points of the t distribution, for $\nu = 20$ degrees of freedom, is not significant at any value of α. Therefore, we might conclude that the model developed in Chapter III represents the system under study with reasonable accuracy.

Now we can proceed with the second part of this paper, consisting of introducing changes in the line to study and evaluate their cost and effects. All simulations in the following chapters will be for ten 8-hour periods and the results will be compared to those of this chapter rather than to the actual production figures.

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TABLE 5.8

PRODUCTION RECORDS

Line A.- March 2 to March 26, 1970

March	2	-	8405 rims
"	3	-	7620 "
"	4	-	3301 "
"	5	-	8072 "
"	6	-	3163 "
"	9	-	3275 "
"	11	-	2440 "
"	12	-	7936 "
"	13	-	5246 "
"	16	-	2945 "
"	17	-	3611 "
"	18	-	4604 "
"	19	-	8258 "
"	20	-	3782 "
"	23	-	8217 "
"	24	-	7240 "
"	25	-	9095 "
"	26	-	8484 "
Totals:	18 days		105694 rims

Average Daily Production (one 8-hour shift) = $\frac{105694}{36}$

Average Daily Production = 2936 rims

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CHAPTER VI

CHANGES IN THE MECHANICAL DESIGN OF MACHINES

6.1. SIMPLICATION OF THE HYDRAULIC SYSTEM IN MCKAY ROLL.

1.- Description of Design Change.-

The simplification of the hydraulic system in the McKay Roll would consist of constructing a specially designed manifold for the McKay hydraulic which would enable all the valves, etc. to be mounted and dismounted simply by bolting. Also, it would simplify the existing piping and reduce vibrations.

2.- Cost.-

The cost involved in tearing down the actual set-up and building and installing the proposed hydraulic system is estimated by the Engineering Department at $ 10,000.

3.- Expected Improvement.-

To determine the benefit to be achieved by this simplified hydraulic system it was necessary to study the new Downtime Records made from the 181 cards (mentioned in Chapter III). The Downtime Record for the McKay Roll of Line A for the period between April 21 and May 21, 1970 (Figure 20) shows that the line was stopped to repair oil leaks 14 times for a cumulative time delay of 15 hours and 11 minutes. It is estimated that at least 10 of these oil leaks accounting for about 10 hours would be eliminated with the proposed hydraulic system. This would reduce the frequency of breakdowns from 54 to 44 for an 18.5 % improvement. The average duration of the breakdowns would remain approximately the same. Applying this percentage to the data being used in the program would bring

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DOWNTIME PER 181 FORMS

"A" LINE McKAY - W 6015

FROM APR. 21 TO MAY 21/70

(25 DAYS)

DESCRIPTION	NO. OF OCCURRENCES	T/TIME
Repair oil leak	14	15.11 hrs.
Repair grease lines	7 (2 cards no time)	9.53 hrs.
Repair hyd. pipes	8	6.03 hrs.
Repair clamp cylinder (loader)	8 (1 card no time)	8.19 hrs.
Loose loader	1	1.00 hr.
Repair hydraulic nipple	3	2.06 hrs.
Broken wire	2	.17 min.
Repair chute	3	2.18 hrs.
Electric eye	1	1.08 hrs.
Replace set screws	1	3.30 hrs.
Pin off clamp	1	.30 min.
Replace toggle arm	1	.30 min.
Repair loader	1	1.30 hrs.
Bent rail	1	.28 min.
Pin in clamp arm	1	.30 min.
Replace broken bolts	1	.30 min.
Panel box	1	.30 min.
Repair "O" Ring	1	.44 min.
Safety guards (weld)	1	No Time
		54.57 hrs.

Note: 4 cards - no description

TOTAL REPAIR TIME. . . 54.57 HRS.

Figure 20.- Downtime Records, McKay Roll.

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the frequency of breakdowns for the McKay Roll from 0.000330 (probability of breakdown during the rolling of one rim) to 0.000260. The average time per breakdown would remain the same at 14.25 minutes. The cycle time also stands at 80 milliminutes, as before.

4.- Simulation Results.-

The computer output for this simulation run is shown in Appendix B. The production figures for the ten days of the simulation are tabulated in Table 6.1. We note that the average daily production after ten days is 3,085 rims. This represents only a 0.3 % increase over the results of the actual system simulation, much too small to be significant. The reason for such a small difference can be at least partially explained from Table 6.2. The total downtime for all stations is 1,308 minutes as compared to 1,281 minutes for the present system.

Tables 6.3 and 6.4 show the statistics for the utilization of machines and chutes. These do not differ significantly from those of the present system.

The statistical test for this simulation is done in Appendix II. This shows no significant difference between the two averages at any level of α.

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TABLE 6.1

SIMPLIFICATION OF HYDRAULIC SYSTEM

Day	Cumulative Production	Daily Production	Cumulative Average
1	2912	2912	2912
2	6058	3146	3029
3	8030	1972	2677
4	10994	2964	2748
5	15017	4023	3003
6	17856	2839	2976
7	21306	3450	3044
8	24877	3571	3110
9	27637	2760	3071
10	30848	3211	3085

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TABLE 6.2

DOWNTIME PER STATION

Station	Frequency of Breakdowns	Ave. Duration of Breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear and Coil	6	30.25	181.50
Welder # 1	10	21.38	213.80
Welder # 2	8	24.75	198.00
Elev. Wash. #1	0	12.00	0
Elev. Wash. #2	1	12.00	12.00
McKay Roll	5	14.25	71.25
Roll #1	12	22.50	270.00
Roll # 2	10	26.75	267.50
Expander Press	4	23.50	94.00
Totals	56		1308.05

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TABLE 6.3

UTILIZATION OF MACHINES

Machine	Utilization	Machine	Utilization
Shear and Coil	0.446	McKay Roll	0.686
Welder # 1	0.582	Roll # 1	0.642
Welder # 2	0.552	Roll # 2	0.651
Elev. Wash. #1	0.408	Expander Press	0.599
Elev. Wash. #2	0.362		

TABLE 6.4

UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction
Welder # 1	6.627	0.946	1456.214
Welder # 2	6.747	0.224	1672.350
E. W. # 1	17.461	0.793	3837.635
E. W. # 2	5.623	0.803	1394.433
McKay Roll	8.481	0.848	988.993
Roll # 1	3.605	0.300	420.506
Roll # 2	2.093	0.299	244.242
Exp. Press	0.936	0.312	109.269

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6.2. ELIMINATION OF GRAVITY FEED IN MCKAY ROLL.

1.- Description of Design Change.-

The McKay Roll has a system of loading by which a gate at the end of the chute opens and the rim rolls by gravity onto the loader arm, with a very fluctuating time delay. To eliminate this problem, a shuttle-type feed mechanism with positive control and no dependance on gravity would be far superior to the actual system, allowing the cycle time of the machine to be set at a constant speed.

2.- Cost.-

The cost to build and install the new loading system would be about $ 10,000, 2,000 of which would be spent on the lubrication system of the mechanism.

3.- Expected Improvement.-

Eliminating the gravity feed in the McKay Roll would not vary neither the frequency nor the duration of the breakdowns, but it would enable the cycle time to be set at a more constant and faster speed. A conservative figure would be a cycle time of 75 milliminutes and a variation of ± 5 milliminutes. The actual times are 80 ± 10 milliminutes.

4.- Simulation Results.-

The computer output for this run is shown in Appendix C. Table 6.5 shows the production figures for the 10-day run. The average daily production is 3,092 rims, a 0.5 % increase over our first simulation. However, the statistical test of Appendix II shows no significant difference at any level

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of $\propto$. Again, the total downtime is greater than for the simulation of the present system (by 23 minutes), and that partially explains the reason for such a small increase in production.

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TABLE 6.5

ELIMINATION OF GRAVITY FEED IN MCKAY ROLL

Day	Cumulative Production	Daily Production	Cumulative Average
1	3149	3149	3149
2	7107	3958	3554
3	11260	4153	3753
4	13555	2295	3389
5	17023	3468	3405
6	19780	2757	3297
7	22396	2616	3199
8	25284	2888	3160
9	28062	2778	3118
10	30924	2862	3092

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TABLE 6.6

DOWNTIME PER STATION

Station	Frequency of Breakdowns	Ave. Duration of Breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear and Coil	4	30.25	121.00
Welder # 1	12	21.38	256.56
Welder # 2	4	24.75	99.00
Elev. Wash. # 1	4	12.00	48.00
Elev. Wash. # 2	2	12.00	24.00
McKay Roll	13	14.25	185.25
Roll # 1	9	22.50	202.50
Roll # 2	12	26.75	321.00
Expander Press	2	23.50	47.00
Totals	62		1304.31

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TABLE 6.7

UTILIZATION OF MACHINES

Machine	Utilization	Machine	Utilization
Shear & Coil	0.447	McKay Roll	0.644
Welder # 1	0.566	Roll # 1	0.644
Welder # 2	0.571	Roll # 2	0.652
Elev. Wash. #1	0.398	Expander Press	0.601
Elev. Wash. #2	0.375		

TABLE 6.8

UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction
Welder # 1	6.677	0.953	1507.155
Welder # 2	6.599	0.219	1580.064
Elev. Wash. #1	17.643	0.801	3983.388
Elev. Wash. #2	5.623	0.803	1346.739
McKay Roll	8.477	0.847	986.094
Roll # 1	6.647	0.553	773.454
Roll # 2	4.321	0.617	503.022
Expander Press	0.894	0.998	104.139

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6.3. NEW DIP TANK.

1.- Description of Design Change.-

The suggested Dip Tank would replace the actual Elevator Washers and would fulfill three necessary functions. First, it would combine the flow of bands from two sources into one exit chute; then, it would be submerged in rolling compound, and finally, it would be elevated to provide ample slope in the chute prior to the loading mechanism of the McKay Roll.

Three components are combined to conform the above features. The rim merger consists of two escapements which stop , and release rims, alternatively while holding back the stock of rims behind. This unit deposits the rims, singly, into a tank of rim rolling compound. From here they are elevated by an elevator, which is submerged into the entrance chute to the McKay. A sketch of this proposal is given in Figure 21.

2.- Cost.-

The cost of removing the Elevator Washers and building and installing the new Dip Tank would amount to $ 5,800, if as much of the work as possible is done using available labour at the plant.

3.- Expected Improvement.-

Upon replacing the existing Elevator Washers with the new Dip Tank, all the statistics and time delays associated with the former would be eliminated. This, of course, includes the breakdowns of the Elevator Washers as well as the operation itself. Since the proposed Dip Tank consists of simple components, the expected downtime would be very small.

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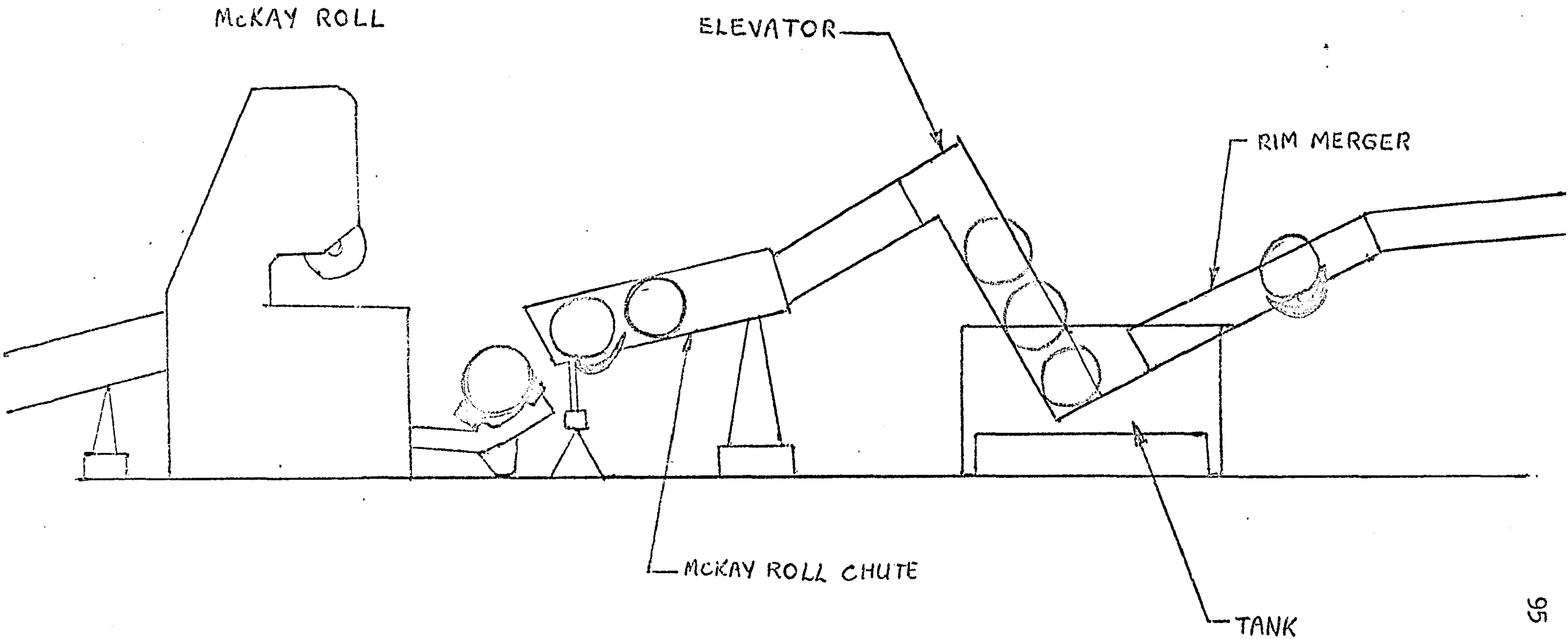
FIGURE 24 .- NEW DIP TANK



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4.- Simulation Results.-

The computer otuput is shown in Appendix D. The various statistics compiled are given in Tables 6.9 to 6.12. The average daily production is 2,950 rims, 4 % less than the simulation of the present system. The statistical test of Appendix II shows no significant difference at the $\alpha = 0.2$ level. The most possible reason for this decrease is the increase of almost 100 minutes in the total downtime over the simulation results of the present system.

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TABLE 6.9

NEW DIP TANK

Day	Cumulative Production	Daily Production	Cumulative Average
1	2887	2887	2887
2	5621	2734	2810
3	9029	3408	3010
4	11398	2369	2850
5	14472	3074	2894
6	18313	3841	3052
7	20994	2681	2999
8	23580	2586	2948
9	26528	2948	2948
10	29503	2975	2950

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TABLE 6.10

DOWNTIME PER STATION

Station	Frequency Breakdowns	Ave. Duration of Breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear and Coil	13	30.25	393.25
Welder # 1	13	21.38	277.94
Welder # 2	4	24.75	99.00
McKay Roll	13	14.25	185.25
Roll # 1	9	22.50	202.50
Roll # 2	9	26.75	240.75
Expander Press	3	23.50	70.50
Totals	64		1379.19

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TABLE 6.11

UTILIZATION OF MACHINES

Machine	Utilization
Shear and Coil	0.425
Welder # 1	0.658
Welder # 2	0.417
McKay Roll	0.655
Roll # 1	0.614
Roll # 2	0.622
Expander Press	0.573

TABLE 6.12

UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction
Welder # 1	6.213	0.887	1207.759
Welder # 2	6.413	0.213	2103.984
Rim Merger # 1	11.202	0.509	2177.333
Rim Merger # 2	5.387	0.769	1767.385
McKay Roll	8.150	0.815	994.667
Roll # 1	2.982	0.248	364.005
Roll # 2	1.871	0.267	228.324
Expander Press	0.886	0.295	108.204

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6.4. MAGNETIC LOADER FOR THE MCKAY ROLL.

1.- Description of Design Change.-

The actual loading mechanism in the McKay Roll consists of a mechanical arm which clamps the rim as it falls by gravity from the chute. Then it raises the rim and places it in between the rolls releasing it as soon as the rolls move in close enough to hold the rim in place for the rolling operation. The magnetic arm on the other hand would eliminate the delay caused by the mechanical arm in clamping the rim and would consist of an arched base, electrically magnetized, which would secure the rim the moment it hits the arm.

2.- Cost.-

To change the actual mechanical loaders and replace them with magnetic arms would cost about $ 2,000 per McKay Roll.

3.- Expected Improvement.-

It is estimated that the time taken for the mechanical loader to clamp the rim will be eliminated, causing a time saving of approximately 0.005 minutes, and that, because of its lighter weight the time of lifting the rim to the rolls can be decreased by another 0.005 minutes, making a total time saving in the cycle time of the machine of 0.010 minutes.

Also, most of the down time in the loading mechanism will be eliminated with the installation of a magnetic arm. In the Downtime Record of Figure 19, the following breakdowns are felt would be eliminated with the new loading system:

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Repair clamp cylinder	Replace toggle arm
Loose loader	Bent Rail
Replace set screws	Pin in clamp arm
Pin off clamp	Replace broken bolts

These breakdowns account for 14 delays amounting to a total production time lost of 15 hours and 17 minutes. The percentage reductions would equal 2.5 % in the average duration of the breakdowns and 26 % in the frequency of the same. Thus, the figures in the program of Chapter V would change for the McKay Roll as follows:

Average breakdown time - from 14.25 minutes to 13.89 minutes/bdown

Cycle Time - from 80 milliminutes to 70 milliminutes

Frequency of breakdowns (probability of machine failure for one rim) - from 0.000330 to 0.000240.

4.- Simulation Results.-

The entire program and output is shown in Appendix E. The statistics are on Tables 6.13 to 6.16. The average daily production is 3,098 rims, a slight 0.7 % increase over the average from the simulation of the present system, in spite of the fact that the total downtime for the former is 112 minutes larger than that for the present system. Thus, although the statistical test of Appendix II shows no significant difference between the two averages, this mechanical change is, so far, the best among the four studied up to this point.

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TABLE 6.13

MAGNETIC LOADER FOR MCKAY ROLL

Day	Cumulative Production	Daily Production	Cumulative Average
1	2849	2849	2849
2	5587	2738	2794
3	9297	3710	3099
4	12353	3056	3088
5	14784	2431	2957
6	18291	3507	3048
7	21433	3142	3062
8	24636	3203	3080
9	27942	3306	3105
10	30985	3043	3098

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TABLE 6.14

DOWNTIME PER STATION

Station	Frequency of Breakdowns	Ave. Duration of Breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear and Coil	10	30.25	302.50
Welder # 1	13	21.38	277.94
Welder # 2	4	24.75	99.00
Elev. Wash. # 1	2	12.00	24.00
Elev. Wash. # 2	2	12.00	24.00
McKay Roll	7	13.89	97.23
Roll # 1	15	22.50	337.50
Roll # 2	6	26.75	160.50
Expander Press	3	23.50	70.50
Totals	62		1393.17

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TABLE 6.15

UTILIZATION OF MACHINES

Machine	Utilization	Machine	Utilization
Shear and Coil	0.448	McKay Roll	0.602
Welder # 1	0.569	Roll # 1	0.645
Welder # 2	0.570	Roll # 2	0.654
Elev. Wash.#1	0.400	Expander Press	0.602
Elev. Wash.#2	0.374		

TABLE 6.16

UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction
Welder # 1	6.351	0.907	1426.240
Welder # 2	6.349	0.211	1522.194
Elev. Wash. #1	16.124	0.732	3621.777
Elev. Wash. #2	5.133	0.733	1231.235
McKay Roll	8.034	0.803	932.715
Roll # 1	9.095	0.757	1056.065
Roll # 2	3.911	0.558	454.312
Expander Press	0.914	0.998	106.193

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6.5. COMBINED CHANGES.

Several combinations of the various design changes mentioned in previous sections of this chapter can be simulated. However, merely as an example , all of these changes have been combined into one program to observe their combined effect in the productivity of the line.

Upon combining the individual expected improvements of the various changes, the expected overall effect can be summarized as follows:

the cycle time would be reduced from 80 to approximately 68 milliminutes, with a variation of $\pm$ 7 milliminutes;

the frequency of breakdowns would decrease from a probability of failure for one rim of 0.000330 to 0.000185; and

the average duration of breakdowns would change from 14.25 minutes to 13.78 minutes/breakdown.

Also, the Elevator Washers would be eliminated along with the statistics on breakdowns for that station as well as the operation itself.

1.- Simulation Results.-

The program and output are included in Appendix F, and the statistics are listed on Tables 6.17 to 6.20 The average daily production from this run is equal to 3,294 rims, a 7 % increase over the figure from the present system simulation. The statistical test of Appendix II shows a significant difference between the two means at the α =0.20 level, even though the amount of downtime for this run was 122 minutes larger than the total downtime for the first

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TABLE 6.17

COMBINED CHANGES

Day	Cumulative Production	Daily Production	Cumulative Average
1	2946	2946	2946
2	6092	3146	3046
3	8933	2841	2978
4	12894	3961	3224
5	16912	4018	3382
6	19565	2653	3261
7	22654	3089	3236
8	26351	3697	3294
9	29641	3290	3293
10	32940	3299	3294

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TABLE 6.18

DOWNTIME PER STATION

Station	Frequency of Breakdowns	Ave. Duration of Breakdown (minutes)	TOTAL DOWNTIME (minutes)
Shear and Coil	12	30.25	363.00
Welder # 1	11	21.38	235.18
Welder # 2	8	24.75	198.00
McKay Roll	4	13.78	55.12
Roll # 1	4	22.50	90.00
Roll # 2	12	26.75	321.00
Expander Press	6	23.50	141.00
Totals	57		1403.30

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TABLE 6.19

UTILIZATION OF MACHINES

Machine	Utilization	Machine	Utilization
Shear & Coil	0.475	Roll # 1	0.686
Welder # 1	0.700	Roll # 2	0.695
Welder # 2	0.503	Exp. Press	0.640
McKay Roll	0.622		

TABLE 6.20

UTILIZATION OF CHUTES

Station	Average Contents	Average Utilization	Average Time per Transaction
Welder # 1	6.219	0.888	1136.957
Welder # 2	6.642	0.221	1086.316
Rim Merger # 1	9.519	0.432	1740.137
Rim Merger # 2	4.999	0.714	1359.523
McKay Roll	7.826	0.792	855.592
Roll # 1	9.379	0.781	1025.214
Roll # 2	4.801	0.685	524.834
Expander Press	1.019	0.339	111.397

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simulation. This indicates, as expected, that the simulation of all the mechanical design changes combined results in a larger increase in production than any one of the changes singly.

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6.6. EVALUATION OF DESIGN CHANGES.

Although the increase in production shown by the simulation runs of Sections 6.1, 6.2, and 6.3 is not statistically significant, it is assumed otherwise in this section in order to compare the profitability of the various changes studied.

1.- Cost Calculations.-

To calculate the total cash flow , be it in the form of a profit or a loss, deriving from investing on any one of the proposed mechanical design changes mentioned in previous sections, the following formula was used:[7]

$$CF = -D_0(CAF\ i\%\ 10) + R_1(CAF\ i\%\ 9) + R_2(CAF\ i\%\ 8)$$
$$+ R_3(CAF\ i\%\ 7) + R_4(CAF\ i\%\ 6) + R_5(CAF\ i\%\ 5)$$
$$+ R_6(CAF\ i\%\ 4) + R_7(CAF\ i\%\ 3) + R_8(CAF\ i\%\ 2)$$
$$+ R_9(CAF\ i\%\ 1) + R_{10}$$

where: D_0 = Initial investment (Cost of change),

CAF = Compound-Amount Factor = $(1 + i)^n$

i% = interest rate = 7 % ,

10, 9, 8,...,1 = years that the respective investments and receipts will be earning interest,

R_i $i=1,10$ = Yearly receipts from investment.

To determine the amount of the yearly receipts from each investment, the expected increase in rim production for one

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7 De Garmo, E. P. Engineering Economy, 4th ed. The Macmillan Company, New York, N.Y. 1967. Ch. 10.

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year was calculated by assuming a 50-week year of ten 8-hour shifts each. This amount was then multiplied by 10 cents, the estimated profit shared by the rim in a single finished wheel. The yearly receipts are extended over a period of ten years which is the expected life of the equipment and machines involved.

The effect of income taxes has not been considered here, and it is assumed that maintenance costs will remain the same after the implementation of the different changes, and also that the scrap value of the equipment and machinery after ten years will be negligible.

A sample calculation for the total cash flow is shown in Appendix III. Table 6.21 summarizes all the results.

2.- Profitability of Studied Changes.-

Table 6.21 shows that, although the Combined Changes require the largest investment ($ 27,800), it yields the best profit after ten years ($ 95,911.69). The Magnetic Loader for the McKay Roll, on the other hand, requires an initial investment of only $ 2,000 and results in a profit of $ 11,263.75 at the end of ten years.

The implementation of the Simplified Hydraulic System or the Elimination of the Gravity Feed for the McKay Roll would result in losses of $ 13,454.58 and $ 8,618.80, respectively.

Calculations for the installation of a New Dip Tank could not be made since the results of the simulation run indicated a decrease in production.

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TABLE 6.21

COMPARISON OF DESIGN CHANGES

Design Change	Initial Investment	Actual Cost (end of 10 yrs)	Increase in Production		Total Receipts (10 yrs)	Cash Flow*
			One day	One year		
Simplified Hydraulic Syst. McKay	$ 10,000	$ 19,672.58	18 rims	4500 rims	$ 6,217.42	-$13,454.58
Elimination Gravity Feed McKay Roll	$ 10,000	$ 19,672.58	32 rims	8000 rims	$11,053.20	-$ 8,618.80
New Dip Tank	$ 5,800	$ 11,409.76	---	---	---	---
Magnetic Loader for McKay Roll	$ 2,000	$ 3,934.40	44 rims	11000 rims	$15,198.15	+$11,263.75
Combined Changes	$ 27,800	$ 54,688.16	436 rims	109000 rims	$150,599.85	+$95,911.69

* - = loss
+ = profit

CHAPTER VII

MACHINE REPLACEMENT STUDY

Although the items discussed in this chapter do not make use of the simulation model developed in Chapter III, and do not have a direct bearing on the paper itself, they have been inserted in this chapter to make the work complete and also as a contribution to the company.

7.1. AUTOMATIC WELDER.

1.- Description of Machine.-

The automatic welders would provide for the rims to be loaded automatically on the Welders, by first clamping and lifting the band from the chute and then placing it into the welding machine and welding the rim. The actual set-up consists of a man performing these tasks manually.

2.- Cost.-

The cost of replacing one of the actual manual welders by an automatic welder would amount to about $ 58,000. The expected life of the new machine is 10 years.

3.- Expected Improvement.-

With the labor costs for this operation amounting to approximately $ 18,000 a year ($ 4.30 an hour, 80 hours a week for 52 weeks), the automatic welder would pay itself in a little over three years and a net profit of $ 122,000 could be expected at the end of the life of the machine, without considering the scrap value of the welder at that time. It must be mentioned, however, that the maintenance costs would probably increase with the automatic welder, and

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that some union problems might arise from replacing the manual labor, and possibly, a relocation of the men might be necessary, in which case the savings would be reduced.

7.2. NEW McKAY ROLL.

1.- <u>Description of Machine</u>.-

The new machine would be similar to the ones being used at present.

2.- <u>Cost</u>.-

The cost of a new McKay Roll would be equal to $ 165,000, with a 10-year life expectancy.

3.- <u>Expected Improvement</u>.-

The only advantage of acquiring a new McKay Roll would be the reduction of downtime and maintenance as compared to the fairly old, rebuilt machines now being used. The exact time that would be saved by this investment can not be calculated, but it is doubtful that it would be enough to warrant such a costly investment.

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CHAPTER VIII

OTHER SIMULATION RUNS

Some miscellaneous simulation runs have been grouped in this chapter for the purpose of illustrating the applications of the model of Chapter IV, with and without slight changes, and its accuracy when used to simulate other systems.

8.1. SIMULATION OF ANOTHER RIM LINE.

1.- Description of Simulated System.-

It has been shown that the model developed worked for the statistics compiled for one of the rim lines in the factory. This simulation was carried out to check if the model would also work for another line of similar characteristics with its own statistical data. For this purpose, Line D was chosen, and the necessary data was collected for the simulation run.

2.- Input Data.-

The chute capacities and Chute rolling times remain unchanged from the previous run of Chapter V . The cycle times for the various machines are listed in Table 8.1. The frequency of breakdowns as estimated from the data obtained are given in Table 8.2. and the average duration of the breakdowns for each station is tabulated in Table 8.3.

3.- Simulation Results.-

The entire output obtained from the simulation run is given in Appendix G. At this point we are only interested in the correlation with the actual system rather than the other statistical output. The simulation yields an average daily production of 3428 rims, while the production records for the same period as compiled in Table 8.5 show an average

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of 3617 rims/day. This represents a difference of about 5.2 %. The statistical test of Appendix II shows no significant difference between the two averages at any level of α.

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TABLE 8.1

AVERAGE CYCLE TIMES FOR

LINE D

Machine	Cycle time and variation (milliminutes)
Shear and Coil	56 ± 5
Welder #1	128 ± 5
Welder #2	130 ± 10
Elev. Washers	90 ± 4
McKay Roll	80 ± 10
Roll #1	77 ± 8
Roll #2	79 ± 9
Expander Press	70 ± 1

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TABLE 8.2

FREQUENCY OF BREAKDOWNS

LINE D

Machine	Prob. of breakdown (for 1 rim)
Shear and Coil	0.000500
Welder #1	0.000285
Welder #2	0.000285
Elev. Washers	0.000022
McKay Roll	0.000657
Roll #1	0.000071
Roll #2	0.000342
Expander Press	0.000114

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TABLE 8.3

AVERAGE DURATION OF BREAKDOWNS

LINE D

Machine	Total Downtime(min)	Time/Bdown and range(min)
Shear and Coil	223	10.61 ± 6
Welder #1	130	10.83 ± 5
Welder #2	190	15.80 ± 5
Elev. Washers	20	20.00 ± 5
McKay Roll	677	24.00 ± 5
Roll #1	32	10.70 ± 3.5
Roll #2	295	21.00 ± 5
Expander Press	68	14.00 ± 4

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TABLE 8.4

SIMULATION OF ANOTHER LINE

Day	Cumulative Production	Daily Production	Cumulative Average
1	3473	3473	3473
2	7102	3629	3551
3	10498	3396	3499
4	13682	3184	3420
5	16977	3295	3395
6	20928	3951	3488
7	24185	3257	3455
8	26950	2765	3369
9	30766	3816	3418
10	34283	3517	3428

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TABLE 8.5

PRODUCTION RECORDS

Line D.- April 22 to May 2, 1970

April	22	-	6930	rims
"	23	-	7724	"
"	24	-	7730	"
"	27	-	7857	"
"	28	-	6560	"
"	29	-	4915	"
"	30	-	4418	"
May	1	-	8480	"
"	4	-	7632	"
"	5	-	6945	"
"	6	-	9582	"
"	7	-	8054	"
Totals:	12 days		86827	rims

Average Daily Production (one 8-hour shift) = $\frac{86827}{24}$

Average Daily Production = 3617 rims

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8.2. RIM LINE WITH A FORM PRESS AND THREE ROLLS.

The data for this simulation run was obtained thanks to the cooperation of the Kelsey-Hayes plant of Romulus, Michigan. They allowed the author to visit the plant and collect all the information needed for the program input.

1.- Description of the System.-

The lines in the Romulus plant are basically the same as the ones in Windsor, and most of the stations are identical in both plants. However, the former differ in that they have automatic welders as well as a sequence of one form press and three finish rolls instead of the McKay roll and the two finish rolls in the previous system studied in preceeding chapters. The function of the form press is to give the rim the general form with the basic contour, and the three finish rolls refine this shape much in the same way as the two finish rolls in the Windsor plant. It can be said, then, that the form press performs the same function as the McKay roll, although in a rough way since the finish obtained by the McKay roll is better than that of the form press, thus the need for an extra finish roll.

The remaining stations, the Shear and Coil, Elevator Washers, and Expander Press are the same as the previous system.

2.- Input Data.-

The data on the cycle times, frequency of breakdowns, and duration of breakdowns was obtained from a three-day Delay Study conducted at the plant at the end of last year. This

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study included information regarding the nature of each breakdown, the frequency of each, and the total production time lost due to each breakdown. (See Figure 22).

Information on the chute capacities, and some of the cycle times were obtained from the Industrial Engineering Dept., the chute rolling times for the various station were estimated from observation of the line.

The statistics compiled for the program are shown in Tables 8.6 through 8.9 .

3.- Simulation Results.-

The complete program is shown in Appendix H . The only results quoted are those relating to the rim production for the ten-day period, in Table 8.10. The average daily production was of 4912 rims. In the actual system, the average production for the 3-day study was 4754 rims/day. This represents a 3.3 % difference between the actual system and the simulation results. The statistical test between the two means indicates no significant difference at any level of α .

Note: The program running time for this simulation run was set at 80 % of the actual time to account for the personal and delay allowances (15 %) plus 5 % for correctable delay. The 5 % charged to previous runs due to extra personal delays was not included since it was estimated non-existent in the Romulus plant.

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Delays - Rim Line #2

	12/1		12/2		12/3	
Total Production	4708		4734		4220	
Rate per Hr.	860		842		845	
Run Time	210 Min		400 Min		480 Min	
	F	Min	F	Min	F	Min
Jam in Rolls	11	3.60	43	32.42	2	.48
Jam in 1st Form Press	14	7.74	15	5.15	15	3.36
Jam at Expander Elev.	-	-	7	4.05	-	-
Stop by Inspector	1	1.16	6	10.43	3	2.30
Adjust Roll	-	-	4	4.77	1	4.29
Recycle 1st Form	5	.98	-	-	-	-
3rd Roll Slow	-	-	15	13.37	-	-
Coiler Down	1	1.04	3	5.41	1	2.91
Burr Cutter Down	-	-	-	-	11	8.11
"One of A Kind" Maint	5	8.35	2	15.51		
Adjust welder			3	2.82	3	1.76
Polish Rolls			3	5.27	1	2.81
Adjust Shear			3	3.40	1	1.06
Change Rolls					1	17.20
Misc	3	2.14	1	.73	1	.77
Total		25.01		103.33		45.05

Figure 22.- Delay Study Summary

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TABLE 8.6.

AVERAGE CYCLE TIMES

ROMULUS LINE

Machine	Cycle Time and variation (milliminutes)
Shear and Coil	57 ± 5
Welder #1	112 ± 5
Welder #2	115 ± 5
Elevator Washers	90 ± 4
Form Press	68 ± 5
Roll #1	71 ± 5
Roll #2	69 ± 5
Roll #3	67 ± 5
Expander Press	67 ± 3

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TABLE 8.7

DURATION OF BREAKDOWNS

ROMULUS LINE

Machine	Total Downtime(min)	Time/Bdown and range(min)
Shear and Coil	19.72	1.80 ± 0.8
Welder #1	14.08	0.74 ± 0.2
Welder #2	14.80	1.50 ± 0.5
Elevator Washers	0.83	0.415 ± 0.2
Form Press	33.99	0.64 ± 0.3
Roll #1	6.23	0.39 ± 0.15
Roll #2	43.68	1.10 ± 0.5
Roll #3	38.03	1.27 ± 0.5
Expander Press	4.05	0.56 ± 0.2

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TABLE 8.8

FREQUENCY OF BREAKDOWNS

ROMULUS LINE

Machine	Frequency	Prob. of breakdown (for 1 rim)
Shear and Coil	11	0.000940
Welder #1	19	0.001600
Welder #2	10	0.000851
Elevator Washers	2	0.000170
Form Press	53	0.004500
Roll #1	16	0.001400
Roll #2	39	0.003300
Roll #3	30	0.002600
Expander Press	7	0.000600

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TABLE 8.9

DATA ON THE CHUTES

ROMULUS LINE

Chute to	Chute Capacity	Chute Rolling Time (milliminutes)
Welder #1	7	35
Welder #2	14	120
Elev. Washer #1	22	100
Elev. Washer #2	7	35
Form Press	5	35
Roll #1	7	50
Roll #2	6	40
Roll #3	6	40
Expander Press	8	30

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TABLE 8.10

ROMULUS LINE

Day	Cumulative Production	Daily Production	Cumulative Average
1	4855	4855	4955
2	9785	4930	4392
3	14661	4876	4887
4	19712	5051	4928
5	24563	4851	4913
6	29522	4959	4920
7	34395	4873	4914
8	39296	4901	4912
9	44297	5001	4922
10	49125	4828	4912

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8.3. SIMULATION OF AN IDEAL LINE.

To determine the maximum possible output that could be obtained from the rim line if there were no breakdowns, the basic program of Chapter V was run through the computer to study this particular hypothetical situation. The cycle times, chute capacities, and rolling times, and program running time remained as before, however, all the data concerning the breakdowns was deleted from the program.

The results (See Appendix J) show that the total rim production possible without breakdowns is, in the average, 4498 rims/day. (See Table 8.11). This indicates an increase of 1,422 rims over the figure of Chapter V , or about 46 %, which is an indication of the considerable amount of production time lost with the low efficiency of the present system. Of course, it would be practically impossible to have a line working without breakdowns, but it is a goal for which to strive.

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TABLE 8.11

AN IDEAL LINE

Day	Cumulative Production	Daily Production	Cumulative Average
1	4491	4491	4491
2	8989	4498	4494
3	13485	4496	4495
4	17991	4506	4498
5	22491	4500	4498
6	26991	4500	4498
7	31489	4498	4498
8	35987	4498	4498
9	40487	4500	4498

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CHAPTER IX

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

9.1 CONCLUSIONS.

While gathering the data for the study it was found that, although the company has set the personal delay allowance in the rim lines at 8 % of the production time, this figure in fact is as high as 13 %. In addition, there is a further delay of 5 % caused by the correctable and non-cyclic delays not accounted for in the time standards.

The model for the production line, developed in Chapter IV and the computer program for this model represent the actual system with reasonable accuracy. The results of the simulation run show that, for a 10-day period of 80 production hours, the total downtime amounted to 21.35 hours, that is, over 25 % of the total production time. The statistics on the utilization of machines and on the utilization of chutes show the McKay Roll to be the bottleneck station. As a result of the numerous breakdowns, the utilization of machines is quite low, ranging from 0.365 for the Elevator Washer # 2 to 0.684 for the McKay Roll. The daily average production for the line is 3,076 rims, almost 33 % below the figure of 4,571 rims estimated by the Standards Dept.

The study on the mechanical design changes show that, in terms of profitability, they can be ranked as follows:

(1) Magnetic Loader for the McKay Roll,

(2) Combined Changes,

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(3) Elimination of the Gravity Feed in the McKay Roll,

(4) Simplification of the Hydraulic System in the McKay Roll, and

(5) New Dip Tank.

The first two would be profitable to the company if implemented; the last three, however, indicate a loss in the long run.

The machine replacement study shows the automatic welder to be a desirable investment while the new McKay Roll is not.

The simulation of an ideal line, i.e. one with no breakdowns, shows a 46 % increase in production from 3,076 rims per day from the actual system to 4,498 rims per day. This gives an indication of the large amount of production time lost in the rim lines due to breakdowns.

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9.2 SUGGESTIONS FOR FURTHER STUDY.

With the basic model now developed and tested, it would be interesting to attempt the simulation of the entire plant to analyze the functioning and operation of the same.

Also desirable would be to simulate single bottleneck stations, like the McKay Roll, including data on the various types of breakdowns separately, to find ways to improve their operation either by reducing, or by eliminating, the major causes of breakdowns.

In addition to the suggested feasible simulation projects, a study on indirect labor and its effect on production would be of benefit to the company.

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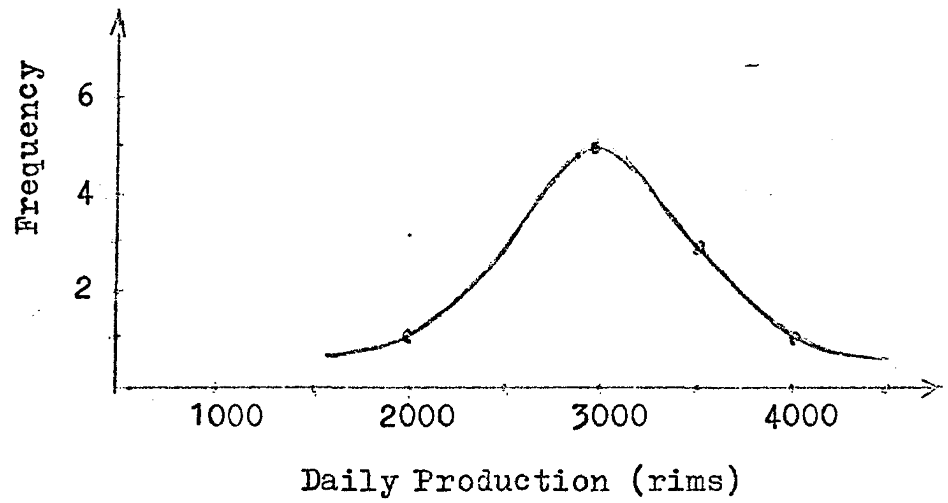
APPENDIX I

SIGNIFICANCE TEST FOR THE SIMULATION OF THE PRESENT SYSTEM.

1.- Distribution of Production Figures.-



2.- Significance Test.-[8]

Testing the hypothesis that the means of two normal distributions are equal, assuming that the standard deviations are unknown and not necessarily equal. Use the test statistic t', given by:

$$t' = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{s_x^2}{n_x} + \frac{s_y^2}{n_y}}}$$

and the associated degrees of ffeedom, ν, given by:

8 Bowker, A. H., and Lieberman G. J. Engineering Statistics. Prentice Hall. Englewood Cliffs, N.J. 1960.

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$$\nu = \frac{\left(s_x^2/n_x + s_y^2/n_y \right)^2}{\frac{(s_x^2/n_x)^2}{(n_x + 1)} + \frac{(s_y^2/n_y)^2}{(n_y + 1)}} - 2$$

3.- t' Test for the Simulation of Present System.-

For the present system:

$$\sum x_i = 105{,}694$$

$$\left(\sum x_i\right)^2 = 11{,}171{,}221{,}636$$

$$\sum x_i^2 = 724{,}932{,}836$$

$$s^2 = \frac{\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n - 1}$$

$$s^2 = 6{,}135{,}848$$

For the Simulation of the present system:

$$\sum x_i = 30{,}764$$

$$\left(\sum x_i\right)^2 = 9.46 \times 10^8$$

$$\sum x_i^2 = 9.74 \times 10^7$$

$$s^2 = 3.0 \times 10^5$$

Therefore:

$$t' = \frac{2936 - 3076}{\sqrt{\frac{6.13 \times 10^6}{17} \quad \frac{3.0 \times 10^5}{10}}}$$

$$t' = 0.22$$

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$$\nu = \frac{\left(\frac{6.13\times10^{6}}{17} + \frac{3.0\times10^{5}}{10} \right)^{2}}{\frac{\left(\frac{6.13\times10^{6}}{17}\right)^{2}}{18} + \frac{\left(\frac{3.0\times10^{5}}{10}\right)^{2}}{11}} - 2$$

$$\nu = 20$$

$$t_{.4,20} = 0.257$$

Since $t' < t_{\alpha,\nu}$, the hypothesis that the two means are equal is accepted.

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APPENDIX II

OTHER SIGNIFICANCE TESTS.

1.- <u>Simplification of Hydraulic System in McKay Roll</u>.-

$$\sum x_i = 30{,}848$$

$$(\sum x_i)^2 = 9.49 \times 10^8$$

$$\sum x_i^2 = 9.79 \times 10^7$$

$$s^2 = 3.3 \times 10^5$$

$$t' = 0.04$$

$$\nu = 20$$

$$t_{.4,20} = 0.257$$

$$\therefore t' < t_{\alpha,\nu}$$

$\therefore$ We fail to reject the hypothesis that $\mu_x = \mu_y$

2.- <u>Elimination of Gravity Feed in the McKay Roll</u>.-

$$\sum x_i = 30{,}924$$

$$(\sum x_i)^2 = 9.56 \times 10^8$$

$$\sum x_i^2 = 9.88 \times 10^7$$

$$s^2 = 3.54 \times 10^5$$

$$t' = 0.06$$

$$\nu = 20$$

$$t_{.4,20} = 0.257$$

$\therefore$ $t' < t_{\alpha,\nu}$ and we fail to reject the hypothesis.

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3.- New Dip Tank.-

$$\sum x_i = 29{,}503$$
$$(\sum x_i)^2 = 8.70 \times 10^8$$
$$\sum x_i^2 = 8.76 \times 10^7$$
$$s^2 = 6.42 \times 10^5$$
$$t' = 0.58$$
$$\nu = 19$$
$$t_{.2,19} = 0.861$$
$$\therefore \quad t' < t_{.2,19}$$

$\therefore$ We fail to reject the hypothesis at the $\alpha = 0.20$ level.

4.- Magnetic Loader for the McKay Roll.-

$$\sum x_i = 30{,}985$$
$$(\sum x_i)^2 = 9.60 \times 10^8$$
$$\sum x_i^2 = 9.72 \times 10^7$$
$$s^2 = 1.38 \times 10^5$$
$$t' = 0.10$$
$$\nu \doteq 17$$
$$t_{.4,17} = 0.257$$
$$\therefore \quad t' < t_{.4,17}$$

$\therefore$ We fail to reject the hypothesis.

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5.- Simulation of Combined Changes.-

$$\sum x_i = 32{,}940$$
$$(\sum x_i)^2 = 1.08 \times 10^9$$
$$\sum x_i^2 = 1.10 \times 10^8$$
$$s^2 = 2.11 \times 10^5$$
$$t' = 0.96$$
$$\nu = 19$$
$$t_{.2,19} = 0.861$$
$$\therefore \quad t' > t_{.2,19}$$

$\therefore$ We reject the hypothesis at the $\alpha = 0.20$ level.

6.- Simulation of Another Line.-

For the present System:

$$\sum x_i = 86827$$
$$(\sum x_i)^2 = 7.54 \times 10^9$$
$$\sum x_i^2 = 6.51 \times 10^8$$
$$s^2 = 2.3 \times 10^7$$

For the simulation:

$$\sum x_i = 34283$$
$$(\sum x_i)^2 = 1.186 \times 10^9$$
$$\sum x_i^2 = 1.175 \times 10^8$$
$$s^2 = 1.13 \times 10^5$$
$$t' = 0.136 \qquad \nu = 11$$
$$t_{.4,11} = 0.260$$

$\therefore$ Since $t' < t_{.4,11}$, we fail to reject the hypothesis.

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7.- Simulation of Romulus Line.-

For the present system:

$$\sum x_i = 14262$$
$$(\sum x_i)^2 = 2.03 \times 10^8$$
$$\sum x_i^2 = 6.78 \times 10^7$$
$$s^2 = 3436$$

For the simulation:

$$\sum x_i = 49,125$$
$$(\sum x_i)^2 = 2.41326 \times 10^9$$
$$\sum x_i^2 = 2.41373 \times 10^8$$
$$s^2 = 5220$$
$$t' = 0.061$$
$$\nu = 6$$
$$t_{.4,6} = 0.265$$
$$t' < t_{.4,6}$$

We fail to reject the hypothesis.

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APPENDIX III

SAMPLE CALCULATION OF TOTAL CASH FLOW FOR INVESTMENTS.

Installation of the combined changes in the rim line.-

D_o= Initial Investment = $ 27,800.00

Life-expectancy of equipment = 10 years.

Increase in production in one day = 436 rims.

Increase in production in one year = 436 rims/day x 50 wks/yr x 5 days/wk = 109,000 rims.

Estimated profit from one rim = 10 cents.

Expected profit in one year = 109,000 rims x $ 0.10/rim =$10,900.00 = R

% interest on investment = 7 %, compounded anually.

Total cash flow:

$$CF = -D_o(CAF\ i\%\ 10)^{*} + R_1(CAF\ i\%\ 9) + R_2(CAF\ i\%\ 8) + R_3(CAF\ i\%\ 7) + R_4(CAF\ i\%\ 6) + R_5(CAF\ i\%\ 5) + R_6(CAF\ i\%\ 4) + R_7(CAF\ i\%\ 3) + R_8(CAF\ i\%\ 2) + R_9(CAF\ i\%\ 1) + R_{10}$$

$$CF = -27800\ (1.9672) + 10900\ (1.8385) + 10900\ (1.7182) + 10900(1.6058) + 10900\ (1.5007) + 10900\ (1.4026) + 10900(1.3108) + 10900\ (1.2250) + 10900\ (1.1449)$$

* $CAF = (1 + i)^n$ where: i= interest rate per period(year)
n= number of periods (years)

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+ 10900 (1.0700) + 10900

CF = - 27800 (1.9672) + 10900 (13.8165)

CF = - 54,688.16 + 150,599.85

CF = + $ 95,911.69

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VITA AUCTORIS

1946 Born in Trujillo, Peru, on November 10.

1953 Entered Colegio San Andres of Lima, Peru.

1962 Graduated from Colegio San Andres after completing elementary and secondary education, in December.

1963 Received a scholarship from the American Field Service to study for one year in the United States.

1964 Graduated from Greece Olympia High School of Rochester, New York, in June.

Enrolled in Preliminary Year at the University of Windsor, in September.

1969 Graduated from the University of Windsor with the degree of Bachelor of Applied Science in Mechanical Engineering (Industrial Option), in May.

Accepted to the Graduate School of the University of Windsor as a candidate for the degree of Master of Applied Science in Industrial Engineering.

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