1989

Job-shop scheduling with labor and machine limited systems

Mansoor Afshinpour
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Afshinpour, Mansoor, "Job-shop scheduling with labor and machine limited systems" (1989). *Master's Theses*. 3174.

DOI: <https://doi.org/10.31979/etd.jt5d-jaza>
https://scholarworks.sjsu.edu/etd_theses/3174

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 1339600

Job-shop scheduling with labor and machine limited systems

Afshin(pour), Mansour, M.A.

San Jose State University, 1989

U·M·I

300 N. Zeeb Rd.
Ann Arbor, MI 48106

JOB-SHOP SCHEDULING WITH
LABOR AND MACHINE
LIMITED SYSTEMS

A Thesis
Presented to the
Faculty of Division of Technology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Arts
in
Industrial Technology

by
Mansoor Afshin(pour)
December 1989

APPROVED FOR THE DIVISION OF INDUSTRIAL TECHNOLOGY

DR. SETH P. BATES Major Advisor

Dr. MOHAN KIM Co-Advisor

JIM LAWHON Committee Member

APPROVED FOR THE UNIVERSITY

San Jose State University

ABSTRACT

JOB-SHOP SCHEDULING WITH LABOR AND MACHINE LIMITED SYSTEMS

by Mansoor Afshinpour

This study is an analysis of Job-Shop scheduling problems with personnel constraints, Job-Shop scheduling with labor and machine limited systems, and comparative analysis of two different types of computer simulation methods. Their specific objectives were to find out a way for assigning jobs to machine centers, a way for assigning workers to machines that would give OPTIMUM results in terms of certain criteria, and to compare two different types of simulation methods.

The simulation process is divided into two phases. The first phase generates job files, and the second one reads the files and processes the jobs. Because the researcher had no access to computer, the simulation was not actually done by computer, but was instead conducted theoretically as it would be done by a computer.

The research design was made for two cases: (a) the case where efficiency is 100% for all workers, and (b) the case where efficiency is not 100%. For each case the experiment was conducted theoretically for both random and non-random routing.

TABLE OF CONTENTS

CHAPTER I. Introduction

A.	Production Planning and Control Systems	1
1.	Strategic Planning	2
2.	Managerial Control	2
3.	Operational Control	3
B.	Work Flow Structures	3
1.	Line Layout	5
2.	Group Layout	5
3.	Functional Layout	5
C.	Classification of Job Shop Decisions	6
1.	Decisions Made at Top Management Levels	6
a.	Production Process	6
b.	Plant Capacity	6
c.	Work Force Requirements	6
d.	Information Systems	7
e.	Aggregate Inventory Level	7
f.	Production Plan	7
2.	Decisions Made at Middle Management Levels	8
a.	Small Capacity Adjustments	8
b.	Scheduling	8
c.	Overtime and Undertime	8

d.	Procedures for Production Control	8
3.	Decisions Made at Lower Management Levels	9
a.	Releasing Individual Orders to the Shop	9
b.	Machine Loading	9
c.	Labor Assignment	9
d.	Expediting	9
D.	Where Does the Job-Shop Scheduling Problem Fit?	
E.	Significance of Job-Shop Problem	10

CHAPTER II. Review of the Literature

A.	A Simplified Model	17
1.	The System	18
2.	Arrival Process	18
3.	Routing	18
4.	Service Times	19
5.	Due-Date Assignments	19
6.	Performance Criteria	19

CHAPTER III. Design of the Experiment 20

A.	Where Efficiency is 100%	20
1.	Random Routing	21
2.	Non-Random Routing	22
B.	Where Efficiency is Not 100%.	24

CHAPTER IV.	Methodology of the Study	
A.	Computer Model	26
B.	Simulation Media	27
C.	Permanent and Temporary Entities . . .	29
CHAPTER V.	Results of the Study	
A.	Results for the Queuing and Labor Rules	32
1.	Random Routing	33
2.	Non-Random Routing	33
3.	Random Routing With Labor Efficiencies Different	37
CHAPTER VI.	Conclusion and Recommendations for Future Research	
A.	Conclusion	40
B.	Recommendations for Future Research . .	40
	References	44
	Terminology	45

LIST OF TABLES

Table	page
1. Labor Rules vs. Queuing Rules	21
2. Labor Rules vs. Queuing Rules (efficiency=100%) . . .	24
3. Labor Rules vs. Queuing Rules (efficiency≠100%) . . .	25
4. Random Routing Results	34
5. Non-Random Routing Results	34
6. Results for Efficiencies different from 100%	38

LIST OF FIGURES

Figure	page
1. Different Types of Layout	4
2. Job Structure	26
3. Simulation Flow Chart	28
4. Work Flow Structure	35
5. Efficiency of Laborer at Work Center	37
6. Labor Configuration	42

CHAPTER ONE

Introduction

The purpose of this thesis is to research a special case of job-shop scheduling problems with personnel constraints and job-shop scheduling with labor and machine limited systems. These problems may briefly be stated as: There is a flow of jobs arriving at a shop according to a certain interarrival time distribution. The shop consists of machines and workers. Each worker has an efficiency factor for each machine center. Every job requires a sequence of operations, and each operation requires a specific machine center. Jobs are competing for machines, and machines are competing for workers.

The specific objectives of this study are to find out (a) a way to assign jobs to machine centers, (b) a way to assign workers to machines that will give OPTIMUM results in terms of certain criteria, and (c) to compare two different types of simulation methods. Before going further into the definition and analysis of the problem, a framework will be presented to give a broader perspective.

Production Planning and Control Systems

Anthony (1985) has proposed a framework for the analysis of planning and control systems based upon the level of management involved in making the decisions. That scheme is useful for the designer and practitioner

in the area of production planning and control. The framework is broken into: Strategic Planning, Managerial Control, and Operational Control.

Strategic Planning

This involves decisions such as plant location, plant capacity, product mix, production process, and manpower skills. In general, strategic planning commits the company to a certain specification for a long period of time. Decisions are made at the top management level, and information used in this process includes demand forecasts, market analyses, and technological forecasts.

The outputs of these decisions are in the form of general guidelines or policies that a lower level of management will have to implement. The objectives or criteria of these decisions are to maximize profit, share of the market, growth of company, and so on. Since it is unlikely that the forecasts coincide precisely with reality, these long-term decisions need frequent reviews, which often lead to changes in plant capacity, product mix, and manpower skills.

Managerial Control

Once a long-range plan is set, the next step is to establish the procedures for the implementation of the long-range plan. In this case a production system involves

assigning capacity for different products, determining the inventory of each product, hiring and firing personnel, and subcontracting.

These types of decisions are made at the level of vice-president of manufacturing, and usually the objective of such decisions is the minimization of costs. A decision that is made at this level, but sometimes thought to be made at the operational control level, is the determination of rules and procedures to be followed by operation control personnel. For example, inventory policies and dispatching rules are usually determined by staff departments at the managerial control level, and are followed by the operational control personnel (Nelson, 1981).

Operational Control

These decisions involve very precise procedures. The time spans involved are short, and they are done at the lower level of management. In the case of production systems, sometimes the decision-making process is developed by staff departments, and the decisions at this level are limited to exceptions to the rules.

Work Flow Structures

The layout of most job-shops is functional. In order to get a better idea of what that means, three different types of layout have been developed (Figure 1).

Figure 1. Different Types of Layout

Line Layout

In line layout, a product is routed through a series of machines located one after another. This is the most economical way of producing a large volume of a single product, since the utilization of equipment and labor is maximized, and there are few setups. This type of production is used when there is a stable and clearly defined product mix and volume is sufficient to justify the product-specific layout.

Group Layout

In group layout, the plant consists of groups of machines arranged in a way that each group has all the machines required to perform all the operations of a certain family of products. This method of production is usually more expensive than production by line layout but it allows a wider range of products at smaller volumes than are required to justify a line layout. This layout is used when it is possible to form a relatively small number of product families that require mostly the same operations but do not have the same sequence as in the case of line layout.

Functional Layout

In this case, all the machines that perform the same operations are grouped into a machine center and jobs are routed through the different machine centers of

the shop. In general, this layout is the most expensive type of production since many set-ups are involved; it is used where there is a very unstable and unpredictable product mix exist (Magee & Boodman, 1980).

Classification of Job-Shop Decisions

Decisions Made at Top Management Levels

Production Process. For the job-shop, the decision to have a functional layout is mainly based on the expectation that the product mix will be large and highly variable.

Plant Capacity. This is one of the most difficult decisions since, in most cases, the total demand and the demand for each machine group is very uncertain. Functional layout as used by most job-shops is very flexible and permits relatively easy adjustments in capacity; therefore the decision-maker usually considers a multistage capacity expansion plan. In other words, he adjusts the capacity to the changes in demand.

Work Force Requirements. Another variable in the design of a job-shop is the flexibility of the labor force that will be contracted. In many shops the product mix is changing frequently. This means that the demand for some work centers will increase, while the demand for others will decrease. If there is no labor flexibil-

ity (if the workers are only trained to operate one type of machines), then some workers will be idle while others will be working with a large backlog. On the other hand, if some workers are trained to operate several machines, that will help in adjusting the shop to the changes in product mix.

Information Systems. Many shops are characterized by having thousands of different jobs in the plant, and the problem of sequencing and keeping track of them is complex. A decision must be made to determine what kind of information system should be used.

Aggregate Inventory Level. Before designing the job-shop, a rough estimate has to be made about the levels of raw material inventory, subassembly inventory, work in process inventory, and finished goods inventory. The level of these inventories will considerably affect the shop performance. For example, high work in process inventory means low idle time and long lead time.

Production Plan. This consists of determining the aggregate level of production in following months and determining the aggregate inventory and work force levels.

All decisions except the production plan are made only once, but are reviewed when the conditions upon which the decision were based changed (Wilson, 1981).

Decisions Made at Middle Management Levels

Small Capacity Adjustments. When there is an increase in demand for certain machine centers, capacity in those centers must be increased. This decision is usually made at the level of vice-president of manufacturing.

Scheduling. Based on production plan for the following months, the capacity is assigned to the different products and orders, and an estimate of lead time is made for each product.

Overtime and Undertime. The production plan determines the work force level for the next few months. In general, it is necessary to make adjustments to the plan. One way to adjust the manpower capacity is through overtime and undertime.

Procedures for Production Control. One of the responsibilities of middle management is establishing procedures for production control. This involves determining lot sizes, inventory policies, and sequencing procedures.

Decisions Made at Lower Management Levels

Releasing Individual Orders to the Shop. Once the capacity is assigned for each product, the next step is to release the orders to the shop. Sometimes there are clearly defined procedures to determine when each order should be released to the shop; and to some extent, this task might be reduced to clerical work.

Machine Loading. In a typical job-shop there are many jobs competing for a single machine, and therefore they will have to be sequenced according to certain procedures.

Labor Assignment. Most of the real job-shops are labor limited. In other words, there are fewer operators than machines and the machines are competing for operators. Therefore, it is necessary to define a procedure for assigning operators to machines.

Expediting. For some important jobs, the scheduling procedure will produce lead times that are unacceptable. Therefore, in some cases it is necessary to make exceptions to the rule in order to speed up processing of some jobs. This is usually called expediting.

Where Does the Job-Shop Scheduling Problem Fit?

As mentioned before, the solution of the dynamic job-shop scheduling problem with personnel and machine constraints consists of finding a machine and a labor

assignment procedure that will give optimum results in terms of some stated criteria. The job-shop scheduling problem is concerned with finding procedures that will help to pre-develop the decisions that will be carried out by lower-level management. In general, these procedures will be established by middle-level management and carried out by operating personnel (Nelson, 1980).

Significance of the Job-Shop Problem

Decisions that most affect the performance of a company are strategic decisions; and ones that affect it least are operational control decisions. Nevertheless, most of research on job-shop has been concentrated in the area of operational control decisions. One of the reasons for lack of research on upper management problems is that strategic decisions are difficult to model and are therefore unattractive to researchers. On the other hand, operational control decisions are more suitable to model and more attractive to researchers. In spite of the relatively slight effect of scheduling decisions compared with strategic decisions, there are several reasons why the practitioner might be interested in scheduling procedures:

- a. Clearly defined rules will simplify the decision-making process at the operational control level.

- b. Different scheduling procedures might affect shop utilization, in terms of labor and machines, work-in-process inventory, and the ability to meet due-dates.

CHAPTER TWO

Review of the Literature

Job-shop scheduling research has been done for machine limited systems, but little has been done to consider machine and labor limited systems. The main reason is that when considering machine and labor limited systems, many variables are added to the problem, and the experimentation through simulation becomes very expensive.

One of the first studies of dual constrained job-shops was done by Allen (1973). His model was based on a one department real job-shop with 78 machines classified into 18 work centers. The work force consisted of 40 men classified into several working classes. A laborer could perform at 100% efficiency within his working class but could not perform in any other class. The shop was essentially static, since he considered a shop initially loaded but with no new orders arriving. The objective of the research was to study the effect of dispatching rules, of alternate routing, and of the labor flexibility on the labor utilization and on the time to empty the shop. Allen found out that the SOT (shortest operation time) rule was effective in increasing labor utilization and also found that a small increase in labor flexibility was as effective as 100% labor flexibility in terms of increasing labor utilization.

Nelson (1981) proposed a model for a machine and labor limited shop of one department. In his research he considered a random-routed job-shop with two work centers of two machines each. He studied three dispatching rules FCFS (First Come First Served), FIFS (First In System First Served), and SOT, combined with five labor assignment procedures (RANDOM, FIFS, FCFS, SOT, and LQ), for four sizes of the labor force ($n=1,2,3,4$). The SOT rule combined with the SOT labor assignment rule and the SOT dispatching rule combined with the LQ (Longest Queue) rule were best in terms of minimizing the mean flow-time. The FIFS dispatching rule combined with the LQ labor rule were the best in minimizing the variance of the flow-time.

Nelson (1981) studied the effect of labor efficiency, of the degree of centralized labor control, and of the dispatching rules on the shop performance. He considered again a shop with two work centers with two machines each. The experiments were performed for random routing and for serial routing. The labor force consisted of two laborers with an efficiency E each. The labor assignment rule used throughout the experiment was to assign a laborer to the service center where he could perform most efficiently, unless there was no work for him in that center. The dispatching rules used were FIFS,

FCFS and SOT, and various degrees of centralized control were tested ($g=0, 0.5, 1$). The parameter g measured the probability that the laborer will be reassigned after finishing an operation. With respect to labor efficiency, each worker performed with efficiency 1 at his work center and with efficiency x on the other center. Several values of x were tested ($x=0, 0.25, 0.5, 0.7, 0.9, 1$). It was found that the mean flow-time and the variance were reduced by increasing the degree of centralized control (g), and the efficiency (x). SOT minimized the mean flow-time and FIFS minimized the variance of the flow time.

Fryer (1983) considered a shop of three departments with four work centers each. Two identical machines were in each work center. The routing of jobs through the shop was random and the interarrival and services times were exponential. There were twelve workers to serve the 24 machines and all the workers were 100% efficient on all machines. The experiment consisted of studying the effect of labor assignment rules and dispatching rules in terms of the mean flow-time, the variance of the flow-time, and the number of labor transfers. There were two levels of labor control. One was at the shop level $D(L)$, and the other at the department level $d(L)$. Two functions of central control of labor were tested:

$D1(L)$: A worker is eligible to be transferred to

the department with most jobs as soon as he finishes an operation.

D2(L): A worker will never be reassigned to another department.

With respect to the control of labor at the departmental level, two functions $d(L)$ were tested:

$d1(L)$: A worker will be eligible for reassignment to another machine center within the department as soon as he finishes an operation.

$d2(L)$: A worker will be eligible for reassignment when there are no more operations in his work center.

With respect to the dispatching rules, FIFO and SOT were tested.

Fryer (1984) found that the $D(L)$ had the greater effect on the mean flow-time, variance of the flow-time, and intradepartmental labor transfers. The function $d(L)$ had some effect on the variance of the flow-time and on the intradepartmental transfer, but the effect on the mean was negligible. As usual, SOT performed best in terms of variance of the flow-time, but their effects on those performance criteria were relatively small compared with the effect of the function $D(L)$.

Using the same model, Fryer studied the effect of various levels of intradepartmental and interdepartmental labor flexibility on shop performance. He defined intra-

departmental flexibility as the number of time units that a worker has to be idle in his own department before becoming eligible for transfer to another department. Intradepartmental flexibility was defined as the maximum number of jobs that must be in a queue before a worker becomes eligible for transfer to another work center. It was found that the major effects of the intradepartmental and interdepartmental flexibility were concentrated in the lower part of the scale of flexibility. In other words, the transition from no flexibility to a relatively small value of flexibility considerably affected the behavior of the shop, but the transition from that value to total flexibility had little effect on shop performance.

Holstein and Berry (1981) have studied a one department shop where the routing of the jobs in the shop were non-random. In other words, they considered a shop where a few paths accounted for a major portion of the work flow. The purpose of their research was the design of a "work flow rule" that would minimize the number of labor transfers. The shop consisted of ten work centers with four machines in each. The arrival of jobs into the shop occurred at a rate of eight jobs per day, and the processing times were exponentially distributed. The labor force consisted of ten laborers, each equally efficient at operating any of the 40 machines in the

shop. The idea of the work flow rule was to attract the workers to the most traveled work centers. The work flow labor assignment rules were compared with Nelson's (1981) longest queue rule for the SOT, FIFS and MS/OP (Minimum Slack per Remaining Operation) dispatching rules. The work flow rules gave some reduction in the number of labor transfers when compared with the longest queue rule for all three dispatching rules, but that improvement was made at the expense of an increase in the means and variances of the flow-time.

A Simplified Model

As Wilson (1981) stated "there are many variables that the researcher can vary in working with dual constrained job-shops. Some of these are:

- number of departments in the shop;
- number of work centers in each department;
- number of machines in each work center;
- interarrival time distribution;
- processing time distribution;
- type of routing of the jobs;
- number of laborers in the shop;
- efficiency of the laborers in the shop;
- labor assignment procedures;
- dispatching rules;
- utilization level of the shop."

Since the method of the experimentation is hypothetical simulation, it becomes necessary to fix most of the variables and perform experiments varying a few of them. For this research, the specific model can be described as follows:

Model System

There is considerable evidence that the number of work centers does not affect the ranking of the queuing disciplines in machine-constrained job-shops. For that reason and with the objective of having a sufficiently large number of regeneration points, and because of problems of not having access to computer, the simulation will not be done actually by computer but will be conducted theoretically as it would be done by computer. Therefore, the model will be designed with three work centers with two identical machines in each. The number of laborers available to operate the six machines will be set at three.

Arrival Process

The interarrival time follows an exponential distribution, truncated at 10, with mean arrival rate $\lambda=1$. the truncated distribution is used for convenience in the input formats.

Routing

Two types of routing are explored, random routing and routing according to a specific transition matrix. The

number of operations for a job was limited to 40.

Service Times

The service times are exponential, truncated at ten, with a mean, $\bar{z}$, such that the utilization of the shop is kept at 90%.

Due-Date Assignments

The due-dates will be assigned multiplying a constant K by the number of operations of the job and by a uniform random variable between 0 and 1. The constant K will be selected in such a way that the mean lateness under FCFS for labor and FIFS for jobs, (FCFS, FIFS), would be near zero.

Performance Criteria

The criteria that will be used are the mean flow-time, the variance of the flow time, the work-in-process inventory measured as the number of jobs in the system, the mean lateness, and the mean tardiness.

CHAPTER THREE

Design of the Experiment

Where Efficiency is 100% For All Workers

Many one-department shops are under the small labor supervision. That is especially true for the case where the number of machine centers in the department is relatively small. Under those circumstances, the cost of labor transfers is almost fixed. For example, the cost of labor transfers will be almost the same for an average of 50 transfers per 100 operations as for 40 transfers per 100 operations. Under these circumstances, the performance of the shop would be measured in terms of the mean flow-time, the work-in-process inventory (which is highly correlated with the mean flow-time), and the lateness and tardiness of the jobs.

In the machine-constrained job-shop all the jobs in each queue are ranked by a dispatching rule, and when a machine becomes idle, the job with the highest priority in the queue is processed. In the labor-and-machine limited job-shop there are fewer workers than machines and it becomes necessary to define a procedure for assigning any idle workers to work centers. For example, suppose SOT (Shortest Operation Time) is used for jobs and LQ (Longest Queue) is used for workers. Under these priority rules, when a job arrives at a work

center, it will be ranked according to its processing time; and when a worker becomes idle, all the non-empty queues will be checked, and the worker will be assigned to the work center which has the longest queue.

It is interesting to observe that when the same rule is used both for workers and jobs, the jobs and workers can be viewed as linked together. For example, suppose that SOT is used for both laborers and jobs. Then the highest priority job of each queue will be one with the lowest processing time in the queue. When a laborer becomes idle, the processing time of all the highest ranked jobs of each non-empty queue will be checked and a laborer will be assigned to the job with shortest processing time. As we can see, the job with the shortest operation in the shop is the one that draws a man and gets dispatched.

The experiments have been conducted theoretically for both random and for non-random routing.

Random Routing

Table 1 shows Labor Rules vs. Queuing Rules and the

Table 1. Labor Rules vs. Queuing Rules

		Queuing Rules		
Labor Rules		FCFS	SOT	MS/OP
	FCFS	*	*	*
	SOT		*	
	MS/OP			*
	LQ	*	*	*

element of the diagonal represents the experiments under a single dispatching rule. For example, $q=FCFS$ is equivalent to $q=SOT$ applied to all jobs in shop since from all jobs in queue, the one that has been in queue for the longest time is selected for processing.

The job dispatching rules tested were FCFS, SOT, MS/OP and LQ. FCFS was tested since it is the rule most widely used and the easiest to apply. SOT was tested since it has given good results in terms of the flow-time, the work-in-process inventory, and the mean lateness. LQ was chosen for labor since Nelson obtained good results with it; and MS/OP was tested because it has given good results under some conditions.

Non-Random Routing

In this case, a transition matrix was used for generating the routings of the jobs. The elements of the matrix represent the probability that a job will be routed from one work center to another.

Under the conditions of a non-random work flow structure, some work centers will be more loaded than others; and since manpower is limited, it is important to keep the more heavily loaded centers working as much as possible. Thus it is important to compute the expected

average utilization of each work center. The value P_i obtained from each work center was calculated in developed formula as follows:

$$P_i = \frac{\sum_{k=1}^n \sum_{j \in W_{Ci}} P_{Tkj}}{\sum_{k=1}^n \sum_{j \in W_{Ci}} NOP_k P_{Tkj}}$$

Where P_{Tkj} is the processing time of the j th operation of the k th job, n is the number of jobs in the job file, W_{Ci} stands for work center i , and NOP_k is the number of operations on the k th job. The summation in the numerator is of all the processing times of all the operations that are going to be processed at work center i and over all the jobs in the job file. The summation in the denominator is taken of the processing times of all the operations of the jobs and over all the jobs in the job file.

The value P_i is used by the SSP (Steady State Probability) labor assignment rule. When a laborer becomes idle the SSP rule assigns that laborer to work center i with probability P_i . With this labor assignment procedure we would expect that the more loaded centers will more easily attract laborers than the less loaded centers and will thus distribute the laborers in proportion to the load of each work center. This labor assignment procedure might reduce the blocking among jobs and hence increase the output of the shop.

Since the results obtained in the random routing case with MS/OP were not good, that rule was eliminated from further experimentation. Table 2 shows the (1,q) rules that were tested in the experiment.

Table 2. Labor Rules vs. Queuing Rules (efficiency $\neq$ 100%)

		Queuing Rules	
		FCFS	SOT
Labor Rules	FCFS	*	*
	SOT	*	*
	LQ	*	*
	SSP	*	*

Where the Efficiency is Not 100% For All workers

For the case where the labor force is not completely flexible, the labor assignment procedures become very important. A labor assignment procedure should try to assign men to the machines where they can perform efficiently; otherwise the effective labor capacity of the shop will be seriously limited. For this purpose, a labor rule, MEF (Maximum Efficiency), that assigns workers to the work centers where they can perform most efficiently has been tested. Table 3 shows the Labor Rules vs Queuing Rules (efficiency=100%).

Table 3. Labor Rules vs. Queuing Rules (efficiency≠100%)

		Queuing Rules	
		<u>FCFS</u>	<u>SOT</u>
Labor Rules	FCFS	*	*
	SOT	*	*
	MEF	*	*

The efficiency matrix was chosen in such away that all the diagonal elements were 1 and the other elements were either 0.9 or 1.1. In that way the average efficiency of each worker will be kept at 100%.

CHAPTER FOUR

Methodology of the Study

Computer Model

The simulation process is divided into two phases. The first one generates the job file, and the second one reads that file and processes the job. Each job in the job file has an arrival time and a number of operations. Each operation has a code for the machine center where the job is going to be processed and a processing time for that operation. Figure 2 gives an illustration of a job structure.

Figure 2. Job Structure.

The input data for the job generator are:

- the number of jobs to be generated;
- the number of jobs that will arrive at time zero in order to preload the shop;
- the number of work centers;
- the mean processing time of the operations;

- the transition matrix used to generate the routing.

Figure 3 shows a simplified flow diagram of the simulation model. The input data for the simulator program are:

- the queuing and labor rule to be used to assign priorities;
- the constant used to assign due-dates;
- the upper and lower bounds used to define the regeneration sets;
- the factor used to assign processing times;
- the number of laborers;
- the number of work centers;
- the number of machines per work center and the corresponding state probability of each work center;
- the number of jobs to be processed;
- the efficiency matrix.

Simulation Media

As pointed out by Juncker and Garcia (1974), when one is interested in comparing the difference between operating policies, it is advisable to keep as identical as possible the experimental conditions under which the different policies are going to be tested.

Figure 3. Simulation Flow Chart

In this simulation model, it is possible to generate in advance the arrival time of each job, its routing through the shop, and the processing time of each operation; and therefore it is possible to have exactly the same sequence of random events for all the experiments within a given class. That homogeneity in the experimental medium would not be possible to achieve if we would have to wait until the arrival of a job at a work center to generate the processing times. The processing time assigned to a given operation of certain job would change from run to run, since different queuing rules would change the sequence of jobs arriving at the work centers. This would affect their processing times since different random numbers would have been used to generate the processing times.

Permanent and Temporary Entities

Using the Simscript vocabulary, the system can be defined in terms of permanent and temporary entities. The first ones exist throughout the whole simulation, while the second ones are active only during some portion of the simulation time. The attributes of the permanent entities are time dependent. For example, an attribute of a queue is the number of jobs it contains, and a parameter of interest is the time average of those values, defined as:

$$1/(t_2-t_1) \int_{t_1}^{t_2} N(t)dt$$

Where t_1 is starting time, t_2 is ending time, and $N(t)dt$ is the function of time.

On the other hand, the attributes of temporary entities are usually defined immediately before the entity becomes inactive. For example, in the model studied each job had an attribute called flow-time that is defined as the total time that the job spends in the system. The flow-time of each job is considered as an individual sample from an unknown distribution of flow-time, and one is interested in estimating parameters of that distribution based upon samples of flow-times.

As pointed out by Conway (1982), the way in which the attributes of permanent entities are measured plays an important role in the results. For example, if the mean flow-time is the parameter to be measured, different results will be obtained if the statistics are collected for the first N jobs that went out of the system than if they are collected for the first N jobs that entered the system. The first case will be biased to report a lower mean, since jobs with longer flow-times are more likely to remain in the system than jobs with shorter flow-times. In the model studied each job has an identification number, and the statistics of jobs are

collected on the basis of the first N jobs that entered the system, rather than on the first N jobs that went out of the system.

CHAPTER FIVE

Results of the Study

Results for the Queuing and Labor Rules

The various combinations of queuing and labor rules have been evaluated in terms of:

- mean number of jobs in system;
- standard deviation of the mean number of jobs in system;
- mean lateness;
- mean tardiness.

In our model the mean arrival rate was set at one job per unit of time. Under this condition the numerical value of the steady state average number of jobs in system is equal to the numerical value of the steady state mean flow-time. Since for all experiments the numerical difference in the estimators of the mean flow-time and the mean number of jobs in the system was of the order of 1%, it was decided to report only one of those estimators. The mean number of jobs in the system was chosen since it had a smaller variance than the mean flow-time in all experiments.

The experiments described in previous section were conducted using transition matrix to generate the routing. The statistics for the means and standard devia-

tions of the means reported in this section were calculated using the estimators. For purposes of comparison, the means were also estimated using the classical definition but, no significant differences were obtained.

Random Routing

Table 4 reports the results for the random routing case. We observe that the effect of the queuing rules under the four criteria was greater than the effect of the labor rules. As usual, the ranking of the queuing rules is SOT, FCFS, and MS/OP under the four criteria. (SOT, SOT) was the best combination of (1,q) rules under the mean number of jobs in the system and mean lateness. (LQ,SOT) was the best combination in terms of the standard deviation of the mean number of jobs in the system and in terms of mean tardiness.

The above results substantiate the hypothesis that the results obtained in previous studies of machine limited job-shops may also be applied to labor and machine limited job-shops when the routing is random.

Non-Random Routing

Figure 4 shows the work flow structure and the corresponding transition matrix used in these experiments. The numbers over the arrows between work centers represent the transition probabilities between the work

Table 4. Random Routing Results

STAT	MEAN NUMBER OF JOBS IN SYSTEM			STD DEV OF THE MEAN NUMBER OF JOBS IN SYSTEM			MEAN LATENESS			MEAN TARDINESS		
	FCFS	SOT	MS/OP	FCFS	SOT	MS/OP	FCFS	SOT	MS/OP	FCFS	SOT	MS/OP
FCFS	11.54	8.94	12.15	3.01	1.70	3.18	0.36	-2.42	1.05	4.81	3.24	4.86
SOT		8.46			1.61			-2.95			3.21	
MS/OP			11.57			2.71			0.39			4.17
LQ	11.50	8.81	12.48	2.94	1.51	3.28	0.20	-2.55	1.35	4.56	3.13	5.33

TIME(SECONDS)

Table 5. Non-Random Routing Results

STAT	JOBS IN SYSTEM		STD. DEV OF MEAN JOBS IN SYSTEM		MEAN LATENESS		MEAN TARDINESS	
	FCFS	SOT	FCFS	SOT	FCFS	SOT	FCFS	SOT
FCFS	10.17	7.75	1.45	0.74	3.37	0.79	5.20	3.52
SOT	10.17	7.70	1.63	0.88	3.36	0.71	5.37	3.62
LQ	10.49	8.36	1.57	0.87	3.66	1.40	5.54	3.85
SSP	11.30	8.69	1.92	0.95	4.35	1.66	6.20	4.35

TIME(SECONDS)

Figure 4. Work Flow Structure

Transition Matrix

	TO			
	1	2	3	OUT
START	.6	.3	.1	0
1	0	.5	.3	.2
2	.5	0	.2	.3
3	.1	.1	0	.8

TIME(SECONDS)

centers. For example, given that a job is at work center 1, there is a 0.5 probability that it will go to work center 2, a 0.3 probability that it will go to work center 3, and 0.2 probability that it will go out of the shop. The steady state probabilities shown in that figure represent the percentage of the total work load that each work center is going to process. For example, work center 1 will process 42% of all the work, measured in units of processing time, that enter the shop.

Table 5 shows the hypothetical simulation results for this experiment. We observe here, as in table 4, that the queuing rules played a more important role than the labor rules, and we also see that (SOT,SOT) was, again, the best combination under the mean number of jobs in the system and mean lateness. (FCFS,SOT) was the best in terms of standard deviation of the mean number of jobs in the system and in terms of mean tardiness.

The SSP labor rule did not perform as well as originally expected. The poor performance of that rule can be attributed in part to its randomness with respect to the processing times of the jobs. Another cause of the poor performance of the SSP rule is that the priorities are determined on the basis of the expected state of the system rather than on the basis of the actual state of the system at the time of calculating the priorities. Since the number of the jobs per queue is highly variable, the use of the steady state

value of the mean number of jobs per queue to determine priorities might have caused many misassignments of labor. For example, it could have happened that many times a worker was assigned to work center 1, even though there were more jobs in work center 3. In summary we can say that the SSP behaved as a random rule.

Random Routing With Labor Efficiency Different From 100%

In this set of experiments the efficiency matrix shown in Figure 5 was used.

Figure 5. Efficiency of Laborer at Work Center.

		1.0	.9	1.1
E_{kj}	$\neq$	1.1	1.0	.9
		.9	1.1	1.0

The element K_j of the matrix represents the efficiency of laborer " k " at work center " j ". The numbers were chosen in a way that the average efficiency of each worker was 1.0. The processing times were determined by dividing the previously generated processing times by the efficiency of the laborer at the work center where he was going to perform the operation.

Table 6 shows the hypothetical simulation results of the experiment. For this case it was observed that the

Table 6. Results for Efficiencies Different From 100%

STAT	JOBS IN SYSTEM		STD. DEV OF MEAN JOBS IN SYSTEM		MEAN LATENESS		MEAN TARDINESS	
	FCFS	SOT	FCFS	SOT	FCFS	SOT	FCFS	SOT
FCFS	8.09	7.04	0.91	0.55	0.18	-0.87	3.14	2.51
SOT	7.98	6.70	0.89	0.53	0.00	-1.27	3.16	2.48
MEF	6.30	5.95	0.55	0.47	-1.69	-1.99	1.99	1.90

TIME(SECONDS)

role of the labor rules is roughly as important as the role of the queuing rules. The best $(1,q)$ combination under all criteria was (MEF,SOT). The better results obtained with the MEF labor rule can be attributed to the fact that the use of this rule increases the labor capacity of the shop by assigning the operators to the work centers where they can perform most efficiently. This increase in labor capacity means that the actual labor utilization of the shop is less than 90%.

Since the results of previous studies of machine limited cases cannot be applied for this case, there is a need for more research in this area.

CHAPTER SIX

Conclusions and Recommendations

Conclusions

Two problems have been studied in this research. The first one is concerned with the study of the labor and job assignment procedures in job-shops, and the second one with the comparison of two different types of simulation methods.

For the case where the efficiency of all the workers of the shop is 100% at all the work centers, we found that the effect of the queuing rules under the four selected criteria was greater than the effect of the labor rules.

For the case where the efficiency of the workers is different from 100%, the effect of the labor rules was as important as the effect of the queuing rules. We also found that the MEF labor assignment rule gained a substantial improvement over the SOT rule.

For both cases, when labor efficiency is at 100% and when labor efficiency is not at 100%, the ranking of the queuing rules was in agreement with the results obtained in previous studies of machine limited job-shops.

Recommendations for Future Studies

In the present study, nothing was said about how "optimal" the regeneration sets were. An interesting

area for future research would be to find a method that would produce "optimal" regeneration sets. A starting point for this research would be to determine a good definition for "optimal".

In the experiment with the efficiency of the laborers not equal to 100%, it was found that the MEF rule for labor combined with the SOT for jobs was the best combination. It would be interesting to test other labor assignment rules, since it is very likely that some rules may produce even better results. For example, it would be possible to design a labor rule that considers the labor efficiency of the workers and the processing time of the operations. Another possibility might be to try to design "look ahead" rules that determine which workers will become idle soon, and on that basis make the labor assignments.

As was mentioned earlier, in general strategic decisions are more important than operational control decisions in terms of the overall performance of a shop. One such strategic decision is the flexibility of the labor force that must be contracted. An interesting area for research is to study the effect of labor flexibility on the performance of the shop. For that purpose it might be interesting to test a configuration of the efficiency matrix where all the elements of the diagonal are 1's and all outside the diagonal are zero, except for 1, 2, ..., p

operators who will be able to work at all of the machine centers with efficiency 1. Figure 6 is an example of a labor configuration where the first two operators can perform with efficiency 1 at all work centers, while rest of operators can work only at one work center (Berstorm and Smith, 1979).

Figure 6. Labor Configuration.

1	1	1	.	.	.	1
1	1	1	.	.	.	1
0	0	1	.	.	.	0
.	.	.	1	.	.	.
.	.	.	.	1	.	.
.	.	.	.	.	1	.
0	0	0	.	.	.	1

With this experiment, it might be possible to find a break point, where a shop with a given number of "utility" workers might perform as well as a shop with laborers 100% efficient on all machines.

Finally, another interesting area for future research is the study of input/output analysis for job-shops. Most of the research done for the dynamic job-shop has concentrated on finding the steady state values of certain variables of the shop for a given arrival process, and little research has been done to investigate the input/output behavior of the shop.

Usually the researcher of job-shop scheduling problems complains about the instability of queuing problems

that require very long simulation runs to obtain meaningful results. One possible way to overcome this problem is to perform an input/output analysis of the simulation process. The advantage of doing this is that a major portion of the variations of the output may be explained by the variations of the input. Another advantage of the input/output analysis (when comparing the performance of two different policies) is that it may show under which conditions one decision is better than another.

References

- Allen, M. (1973). Efficient Utilization of Labor Under Conditions of Fluctuating Demand. New York: Prentice-Hall.
- Anthony, R. (1985). Planning and Control Systems. New York: Academic Press.
- Conway, R. W. (1982). An Experimental Investigation of Priority Assignment in a Job-Shop. New York: McGraw-Hill.
- Fryer, J. S. (1983). Operating Policies in Multiechelon Dual Constraints Job-Shops. Management Science, 6, 65-87.
- Fryer, J. S. (1984). Labor Flexibility in Multiechelon Dual Constrained Job-Shops. Management Science, 20, 1-15.
- Holstein, W. K. & Berry W. L. (1981). Work Flow Structure: An Analysis for Planning and Control. New York: Plenum Press.
- Juncker, J. V. & Garcia, J. (1974). Comparing Simulation Experiments; Design and Analysis. New York: McGraw-Hall.
- Magee, J. F. & Boodman, D. (1980). Production Planning and Inventory Control. New York: Prentice-Hall.
- Nelson, R. T. (1981). Labor and Machine Limited Systems. Management Science, 20, 10-18.
- Nelson, R. T. (1980). A Simulation of Labor Efficiency and Centralized Assignment in a Production Model. Management Science, 12, 19-44.
- Wilson, T. (1981). Production Inventory Systems. Irwin: Homewood.

Description of Job and Labor Rules

Queuing Rules

- FCFS** First Come First Served. The highest priority goes to the job that first arrived in the queue.
- FIFS** First in System First Served. The highest priority goes to job that first arrived to the system.
- MS/OP** Minimum Slack per Remaining Operation. The slack of a job is defined as its due-date minus the current time. To determine the priority of a job its slack is divided by the number of remaining operations. The job with minimum coefficient is the one with highest priority.
- Random** The priority of the job is randomly selected.
- SOT** Shortest Operation Time. The highest priority goes to the job with the shortest imminent operation time.

Labor Rules

- FCFS** First Come First Served. The highest priority goes to the work center which has a job that has the longest time in queue among all the jobs which the highest queuing priority in each queue.
- FIFS** First in System First Served. The highest priority goes to the work center which has the job that has the longest time in system among all the jobs with the highest queuing priority in each queue.
- LQ** Longest Queue. The highest priority goes to the work center that has the most jobs in queue.
- MEF** Maximum Efficiency. The highest priority goes to the work center which contains the job that can be served with the maximum possible efficiency by available laborers among all the jobs with highest queuing priority in each queue.
- MS/OP** Minimum Slack per Remaining Operation. The highest priority goes to the work center which contains the job with the minimum slack per remaining operation among all the jobs with highest queuing

priority in each queue.

Random The priority of a work center is randomly selected.

SSP **Steady State Probability.** The priority of work center is determined by a uniform random variable between 0 and the steady state probability of the work center. Therefore whenever a laborer is available, work center i has a probability of p_i of having the assignment made to it, on the average.