APPLICATION OF TWO COMPLEMENTARY SEQUENCING RULES TO CONTROL THE JOB SHOP BY SWITCHING

by

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Industrial Engineering and Operations Research

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July, 1982
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ACKNOWLEDGEMENTS

I am deeply indebted to Dr. Timothy J. Greene for being, first of all, a teacher and a friend, and second of all the inspirer of this thesis. Dr. Greene deserves special thanks for his patience, creative insight and his invaluable suggestions and guidance throughout this study.

I am also indebted to Dr. Robert P. Davis and Dr. Richard A. Wysk for providing invaluable recommendations for the excellence of this thesis.

My grattitude is also for every other professor and classmate I have had during my education here at Virginia Polytechnic Institute and State University.

Finally, special thanks are due to my wife Leonor and my children, Patricio and Christian, for the time taken in doing my thesis, instead of being with them.

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INTRODUCTION

1.1 GENERAL INTRODUCTION

Though one of the easiest problems to understand, scheduling is one of the most complex production problems to model. At nearly every factory in the world, every day, schedulers must determine a timetable that indicates which job goes into which machine and allocate available resources. This schedule has to reflect the general production plan because the daily schedule is a realization of the master production schedule. This plan, at the end, is part of and an expression of the general management's production department policies. Mainly, the scheduler has to make decisions concerning priorities, dispatching rules, sequences, and manpower assignments over time. These decisions, which represent the production plan in the short run, will in reality determine, to a great deal, the performance of the manufacturing facility.

The scheduler is confronted with a great multiplicity of formal and informal requests and/or constraints. He is also involved with a large set of variables. Typical real world examples are:

- Machine break down

- Pieces not meeting quality control specifications
- Pieces needing rework
- Tool breakage
- Jobs with longer than expected operation times
- Changes in customer priorities
- Raw material delays

These intangibles, as well as others ,become the real scheduling problem and make the scheduling decision very difficult. This is why management is demanding far more research and seeking development of better tools to deal with these problems.

The main responsability of the scheduler in a job shop is to determine which job from each queue has to be processed next. The scheduler has N! ways to sequence (assuming that N is the queue size), without considering other factors such as machine and/or job dependancy, failures, customer priorities, overtime and many others. The decision will represent a manner to select jobs from the queue. In other words, the decision is formulated by a dispatching rule. Every dispatching rule will have a different influence on the cost factors in each different shop. Therefore, it can not be said that there is one rule better than all others for every case [6].

The researcher and the production control manager in industry are now beginning to receive the benefits of powerfull and low cost computer technology through the implementation of computer based methodologies.

Techniques such as Gantt charts, PERT, CPM and other graphical techniques, linear programming, dynamic programming, and branch and bound, are being integrated into computer models to create a versatile tool to evaluate many variations of the same problem. The computer age has brought to the scheduler a broader, more flexible, and faster tool to help him in his decision making activities.

In addition, today's computer technology provides the user with the facilities needed to create interactive scheduling models or systems. This means that if the facility could actually be modelled, the model could include any of the previously named techniques and integrate many informal factors through their inclusion by the experienced scheduler. The resulting interactive analysis should provide a better and more realistic solution to a scheduling problem.

Interactive scheduling computer models create a symbiosis between the human and the machine in which they share their capabilities. The computer has the speed and capacity for data processing and the man has ability to learn, to use his previous experiences, and to make complex qualitative decisions. The first application of this approach appeared in the early 1960's [35]. Since then, many other applications have been reported and, in many cases, they have been proven to represent a better solution than the one obtained by the computer or the human acting alone [24].

The experience of the scheduler seems to be something that cannot be easy integrated into computer software systems. Currently, it is not known how to teach computers to perform general inference and/or to recognize complex patterns from data. The creation of procedures for recognizing such patterns and choosing alternatives for meeting the scheduler's goals will be a first step in constructing a more intelligent system in job shop scheduling. In addition, the interactive model for scheduling can be complemented with formalized, known facts to comform a very usable and practical Decision Support System (DSS). The DSS should provide real-time status report showing an image of the current system plus information such as: idle times, machine utilization, job tardiness, and bottlenecks. At the interruption time (the time in which the scheduler is interacting with the system), the Decision Support System for Interactive Scheduling (DSS-IS) should point out critical situations, further tendencies of variables, and indicate directions to follow according to the goals of the overall schedule.

Therefore, IS and DSS-IS pose several problems to solve, such as:

- Which variables to integrate in the status report.
- How to indicate the tendencies of some basic variables.
- Necessary manual override.
- When to make the interaction.

To answer the question, "when to interact", is equivalent to determining the point at which a predetermined sequencing rule would be implemented to obtain the goals represented by the current scheduling objective. The computer program should then stop and advise the scheduler of the necessity for corrective action to take place. The scheduler could, at this moment, change to a complementary sequencing rule to improve the objective function or to start an automatic procedure. It is better to have a procedure to use for switching between two or more rules than to have confidence in a trial and error procedure. This research deals with this point: the determination of how sequencing rules interact, and how and when to incorporate a corrective action.

One approach to the solution could be through the use of certain sequencing and/or heuristic rules that can balance the effect of each complementary rule in use. These rules would be incorporated into an evaluation model of the scheduling problem. These sequencing and/or heuristics rules should be suggested to the scheduler by the computer model. This would provide a better environment for a useful dynamic decision making model. To determine when it is necessary to change from one rule to another will be equivalent to knowing when the computer should send a suggestion and/or a warning message to the scheduler.

Therefore, it is required to know the effects of some dispatching rules over the performance measure of the shop or its components. This knowledge will permit the control of the shop by balancing the effect of one sequencing rule with its complementary. This control could be achieved by planning in advance the use of the rules (static approach) or by switching when required (dynamic approach).

This research will develop both approaches in a practical manner, using two dispatching rules which are normaly used in today's industrial environment.

1.2 PROBLEM STATEMENT

Scheduling with a processing time related rule (PTR) typically will minimize the mean flow times in a job shop but will provide a large variance in flow time and tardiness. A due date oriented (DDO) sequencing rule typically will minimize the number of tardy jobs and the mean tardiness (this with a small variance). Unfortunately PTR rules do little for, and actually can detract from, the number of jobs tardy and mean tardiness. A due date oriented sequencing rule, on the other hand, does little for mean flow time. In many job shop facilities, it is necesary to try to minimize both mean flow time and tardiness. Therefore, it may be feasible to alternate between both types of rules (PTR and DDO) over time to obtain the benefits from both sequencing techniques while minimizing their disadvantages.

The scheduler's objectives are:

- to have each job completed just before or at its due date, and
- to move each job through the shop in the minimun amount of time.

The first objective is to avoid situations such as tardy or early job completion. Late completion results in customer dissatisfaction, penalties , and/or non acceptance of the product. Early completion means storage costs if the product can not be delivered ahead of time. Considering the money factor, a low average flow time means immediate cash to the company while a longer flow time normally penalizes the company and results in a lack of confidence by the customers. These objectives can not be underestimated by the scheduler. Instead, he has to balance them; to attain a good mean tardiness and a good mean flow time with an acceptable number of tardy jobs.

Based on the literature review, the shortest operation time rule (SOT) was chosen as the PTR rule, and the SLACK rule was chosen as the DDO rule. These sequencing rules have been shown to be the best in their respective areas. The other reason to choose SOT and SLACK was because their marked complementary behavior to each other.

It is hypothesised that sequencing by switching between two sequencing rules should eliminate the problems created by each sequencing rule alone. SOT processes first those jobs with small processing times and holds jobs with long processing times making them late. SLACK processes first those jobs that are closest to their due date without any regard to the throughput of the system.

1.3 RESEARCH OBJECTIVES

The objectives of this research are the following:

- To study the feasibility of using two sequencing rules and switching them over time, to control the job shop.
- To define an objective function which reflects the goal of the scheduler. Such a goal is the balancing of the best properties derived from the use of two complementary rules.

- To develop a procedure for dynamically controling a job shop.
- To provide an insight into problems associated with the design of a control system for the job shop.
- To develop and study a control system based upon static and dynamic switching of the two complementary sequencing rules.

With the accomplishment of the above objectives, the knowledge gained can be integrated into and used in an IS, to build a DSS-IS system.

1.4 NEED FOR THE RESEARCH

During this last 15 years, people responsible for planning, design, control and evaluation in every area have been more and more deeply involved with computer technology. The trend to automation is increasing daily due to factors such as decreasing computer costs, increasing processing speed, decreasing prices of computer memory, popularity of easy to use micro-computers and an increase in available software.

The scheduling area in manufacturing system control is one of the places in which the integration of computer technology, resources, machines and men are needed. This flexibility, adaptability and human integration will create a new type of manufacturing facility utilizing automation and human skills. The automation of the system will depend on two main factors. The first factor is the degree of standardization of the factory procedures and the second factor is the degree of informal information to be use in the decision procedures.

Any mechanism in an automatic shop scheduling system should be based upon current information coming from the shop floor and from the planning, sales or forecasting department. The automatic system should evaluate and look for an optimal solution. Up to now, there is no such operations research model available. Therefore, the actual method for solving the problem is through prediction of the behaviour of the system. With this research, knowing how certain rules behave in the system, the automatic scheduler should be able to balance the effect of one sequencing rule with its complementary one.

Indeed, to have a switching mechanism for two sequencing rules applied in scheduling will complement the control system of actual automatic factories and diminish the uncertainty in trial and error mechanisms of interactive scheduling (informal system).

This research provides an insight into a sequencing rule switching mechanism applied to scheduling control systems. Also, it gives a stopping procedure for an interactive scheduling system. Typical suggestions or helpfull information that could be presented at this time will be: trend of tardiness, work content, flow time average, and machine utilization.

1.5 SCHEMATIC FOR THE THESIS

A schematic for the thesis will be briefly presented here. Chapter II, the literature review, presents the major points related to this research (IS, DSS-IS, scheduling and sequencing rules). Chapter III presents the simulation model. Chapter IV develops the methodologies to be followed and the objective function to compare them. Chapter V presents the experiment using the methodologies presented in Chapter IV and the comparison between the approaches. Finally, Chapter VI gives the final conclusions obtained from the research.

Chapter II

LITERATURE REVIEW

Since this research originated from a study of a basis for a decision support system for interactive scheduling, the literature review includes the following topics: interactive scheduling, decision support system, and primarily, scheduling studies. Also included is a brief summary of Monte Carlo simulation techniques for the validation of sequencing rules.

2.1 INTERACTIVE SCHEDULING

The first studies and applications of interactive scheduling date to the early 1960's. At that time, computers were becoming widespread and it was soon realized that its use could provide certain advantages [36]. This approach then is relatively new and can combine man's intuitive skills and computer's computational power to search for better solutions to highly complex problems.

Today's hardware, software, and graphical display developments have contributed, to a great degree, in the implementation of IS systems. All of the aforementioned improvements can facilitate and speed up the interaction between the computer and the scheduler.

Many studies addressing IS have been completed in the last 40 years; where each has tried to solve specific real world problems. Haider et al., [25] list applications of various topics such as plant layout, power generating units, routing in transit systems, maintenance of electric power generating units, planning and controlling power systems, line balancing, and mathematical models.

Godin's [23] survey presents a very complete list of papers up to 1977. There are 46 references covering various applications in the scheduling area. Some example cases include: performance of a interactive scheduling model, the enrichment of the participants' understanding, hardware use evaluation, time reversal evaluation, real problem solving, and heuristic rule evaluation. Also, a discussion of the advantages and disadvantages of interactive sheduling is presented at the end of the survey.

Rogers et al.,[46] describe some developmental work concerning the concept of a computer simulation model and desirable characteristics that could be used in interactive simulation of a job shop scheduling. Haider et al.,[25] hypothesized and showed that man/computer scheduling generally is superior to automatic scheduling. Hurrion [28] studied the minimization of the maximun flow time, and he also found that IS compared very favorably with automatic scheduling. In addition, some of the obtained solutions were optimal.

Other illustrative applications and related studies are: Smith [53], applying cyclical rotational schedules for nursing personnel; Lankford [35], scheduling of a job shop where production is at the limit of capacity; Chan [8], applying IS in printing presses, Haider and Moodie [26], balancing paced assembly lines, and Wiest [56] addressing project scheduling. Other papers in this area include : [47],[50],[31],[49],[52],[42].

2.2 DECISION SUPPORT SYSTEMS

A decision support system for interactive scheduling is an information system created with the main purpose of helping and supporting the unstructured scheduling problem. It is necessary to recognize that the scheduler is responsible for and interested in having a flexible scheduling tool. This is because the scheduler should be able to test and evaluate any thougthful approach or trial and error based approach.

A DSS-IS system will represent a real benefit to scheduling because of the combinatorial nature of the solutions. Decisions such as accept or reject orders, select sequencing rules, and desicions concerning overtime; could be done very easy interactively. Actually, time reversal, look ahead, backtracking, and tree searching techniques could be incorporated to evaluate the, "what if...", hesitations of the scheduler.

The question arises as to where the DSS-IS should be located in the decision process. The decision process could be separated into four levels of difficulty;

- Observation, raw data is collected, encoded and stored.
- Inference, data is analyzed and prepared for inference and prediction.
- Evaluation, identification of goals, constraints and efficiency.
- Choice, the preferred alternative is selected from the aforementioned step.

DSS-IS is the expression of the last two levels of this decision process. The scheduler will not need to collect, analyze or prepare data for formalising his choice. Nor is the scheduler required to identify goals and determine effectiveness as in the second level process. Instead, there will have to be pre-programmed procedures to evaluate alternatives against assigned goals. The scheduler will implement his decision based on the recommendation given by the DSS-IS or he will have to return to the last interruption (decision) point and start again. The last level implies that everything is automatic, but only very standardized procedures can be automated in scheduling. The most general case which includes informal data, will require the scheduler's presence. Hence, one of the answers to the scheduling problem is DSS-IS.

The interested reader should refer to articles by Alter [1], Keen and Wagner [32], Moore [38] and Vazsonyi [55] to address questions such as: necessity of a IS, what is a DSS, problems in modeling a DSS, approaches to a DSS, and advantages of a DSS-IS.

Desired characteristics of a DSS for interactive scheduling should be:

- The system should rely on the scheduler's insight and judgement.
- The DSS should be flexible enough to support new requests from the scheduler.
- The scheduler should have total control over the system.
- The communication has to be an easy process.
- The system should point out actual tendencies and forecast trends.
- The DSS should supply storage capacities, retrieval capabilities, on-line access and real time evaluations.

- The DSS should be an Operation Research/Management Science (OR/MS) model [11].

2.3 SCHEDULING STUDIES

Scheduling can be defined as a set of decisions that the production control engineer has to perform for a set of activities which require scarce resources in a finite timeframe. In general terms, scheduling is an information system and it should be a decision support system whose main function is to answer typical questions, such as:

- When should an order be released to the system?
- Which job goes into which machine next?
- How are changes in the shop coped with?
- Is there enough capacity?

Thus, the set of decisions attempts to attain a maximum or a minimum of an specific objective function (Ø). This Ø has to represent a factor or a weighted set of factors which will further determine the answer to the questions raised above.

Many researchers, starting with H.L.Gantt in 1917, have studied different variations of the scheduling problem. The scheduling models developed reflect, in every case, distinct degrees of difficulty by varying restrictions of the real world problem. By the 1950's, researchers started to formalize their findings and published articles that actually classified the techniques based on the various topics they covered.

Conway et al.,[15] proposed a method of describing scheduling problems. They established a notation of four parameters A/B/C/D :

A : describes the job arrival process. For dynamic problems A will identify the probability distribution of the times between arrivals and for static problems A will specify the number of jobs simultaneously arriving.

B : describes the number of machines in the shop.

C : describes the flow pattern of the shop.

D : describes the criterion by which the schedule is to be evaluated.

Day et al.,[16] indicates the principal factors involved in typical scheduling problems. Based on these factors, he established a tree classification system described in Figure 1. Factors that were considered include:

Number of component parts comprising a job.

- Single component jobs
- Multi-component jobs which require assembly and/or subassembly operations

Production factors possessed by the shop.

- Machines

A/B/C/D.	Sequencing Problems
01000.	Static Case
01100.	MxN (Fixed Batch Size)
01110.	One Machine
01120.	Muti-Stage
01121.	Parallel Routing
01122.	Series
01123.	Hybrid Shop
02000.	Dynamic Case
02100.	One Machine
02200.	Muti-Stage
02210.	Parallel Routing
02220.	Series
02230.	Job Shop

Figure 1: Types of Scheduling Problems

  - Labor and Machines

Jobs availables for processing.

  - N jobs where N is finite
  - Undeterminated number of jobs.

2.3.1 Static Problems

The static problem can be briefly described as follows: N jobs having simultaneous starting times in a shop composed of M machines. Every time a planning period ends ,the accumulated orders are released to the shop for processing. In consequence, a static scheduling environment implies that the problem's definition will not change before the solution can be implemented [22].

This problem can be further subdivided into two subproblems; the single machine case (m=1), and the multiple machine case (m>1). For the single machine case, there are numerous papers which address different approaches and 0., such as :

- Penalties cost evaluations
- Inventory analysis
- Number of shifts
- Job routing dependancy
- Throughput time.

Referring to the single machine case, it must be pointed out that techniques have been developed to optimize the following situations:

- maximun tardiness
- weighted sum of completion times
- weighted sum of tardiness
- total cost of tardiness
- total cost of production.

The study of multiple machine systems is usually divided into serial, parallel and hybrid machine systems. In the serial case, there are N jobs available for processing at time zero, and every job has to pass through all machines before leaving the system. Therefore a serial system is a pure flow shop.

In the parallel case, there are N jobs available for processing at time zero which must be processed at once on anyone of M machines. The hybrid case combines serial and parallel systems and is in effect a job shop system.

There are many procedures to obtain optimal or near optimal solutions for many objective functions in static problems.

2.3.1.1 Methodology in Static Sequencing

According to Day [16], there are four general approaches to the scheduling problem which this research summarizes into three by joining the Combinatorial approach and Reliable Heuristics together.

- Combinatorial
- Mathematical programming
- Monte Carlo Simulation

To complement this approach, it seems to be necessary to consider new methods which involve one or more of the sequencing techniques. Such a method could be a OR/MS model with interactive capabilities. This is another very realistical way of looking for a near optimal solution incorporating informal data to the scheduling decision process.

The aforementioned three approaches are presented and illustrated with the papers and the surveys found in each area.

2.3.1.2 Combinatorial Approaches for Static Scheduling

This approach is based on changing from one permutation to another by reordering those jobs that satisfy a given criteria.

Branch and Bound is a typical type of combinatorial programming or controlled enumeration. This procedure eliminates solutions which are known from dominance, bounding and feasibility considerations to be unacceptable. If there is a solution for the given problem, this method will provide a good or an optimal solution. Otherwise, it will indicate that there is no feasible solution. Even though branch and bound algorithms are the only methods that offer a real possibility for obtaining optimal solutions; their computational demands are prohibitively high making them impractical to use in the real world.

General references to these techniques can be found in the survey by Baker [2], and papers published by Baker [3], Bradley [6], McMahon [37], Lageweg [33], Gupta [24], and Panwalkar [40].

2.3.1.3 Mathematical Programming Approach for Static Scheduling

All the known analytical models are included in this approach. Examples include: linear, dynamic, convex, quadratic, integer and mixed programming, networks of flow, and Lagrange's methods. Included in this approach are many papers developing different concepts and utilizing different objective functions. A brief list of includes Lambrecht [34], Burns [7], and Smith [54].

2.3.1.4 Monte Carlo Simulation for Static Scheduling

A Monte Carlo simulation model permits the evaluation of static sequencing problems utilizing variables such as; expected flow time, expected waiting time, output distributions, as well as many others. In the area of simulation as applied to static sequencing, available references include Elmaghraby [19] and Pristker, Miller and Zinkl [44].

2.3.2 Dynamic Sequencing

In a dynamic environment jobs are continuosly arriving and leaving the shop. This situation forces dynamic sequencing procedures to achieve better efficiency in the scheduling process. Although these kind of problems can be solved as if they were static problems, the cost of updating the solution depends on the frequency that the decisions are being made.

If the problem considers only one machine [43], it will be a single channel problem. Otherwise, it will be a multistage queueing problem. The latter, can be subdivided into three classes:

- Parallel-channel queues, m identical machines working in parallel to provide a single type of service [48].
- Tandem queues , or queues in series.
- General network queues, or the job shop case.

2.3.2.1 Research in Dynamic Scheduling

During the 1950's and 1960's, the recognition of the fact that a job shop could be represented as a system or network of queues inspired a great deal of fundamental research which is still continuing. Since the research started, priority dispatching rules have surfaced as one of the most important variables which can be manipulated and monitored in sequencing models.

One of the most powerfull analytical tools developed up to now in dynamic job shop studies is Jackson's Decomposition Principle [30]. It can be summarized as follow; jobs' arrival times to the system and processing times at its machines are exponentially distributed, jobs are routed to a machine by a transition matrix, and the priority rule used is first come first served. Given these assumptions, the system can be decomposed into a network of independent individual machine queues. An example of this decomposition principle can be found in Yamamoto [57].

Because of the stocastic nature of the parameters in dynamic jobs shops, Monte Carlo simulation has proved to be one of the strongest methods of analysis. Scheduling of a job shop is one of the many possible applications of simulation. The model of the shop, including the specification of variables and parameters can be changed very easily with a simulation model. With these changes, the behaviour of the simulation model can be observed under different decision rules, probability distributions, and starting conditions. The simulation model can be used for analysis without interfering with the real world situation. Also, if the system does not yet exist, it can be tested in advance before it is implemented. Finally, new methodologies can be proposed, together with the study of other variables or combinations thereof. Therefore the simulator can always be searching for a better solution to actual scheduling problems. Published research in the simulation scheduling related area can be found in papers by Baker [4], Hurrion [29] and Shannon [51].

Sequencing research is normally done using simulation, as it can be seen in Panwalkar's survey [41]. In his survey, most of the job shop simulation models are developed to study different sequencing rules under various shop conditions, thereby making each experimental simulation unique. Usually the experiments differ from each other in the shop load parameters, arrival ratios of jobs to the shop, mean processing rates at the machine or machine centers, shop size, generation of routings, due date assignment, sequencing rules and measures of the system effectiveness.

2.4 SEQUENCING RULES

Once a job is released to the system, it has two alternatives; the first and the easiest alternative, to go straight through the system without competing for machine resources. The second alternative is to queue in front of a machine. This second alternative requires a procedure to select the next job to be processed. This procedure is called a dispatching rule. If the selection procedure orders all jobs in each queue; the selection procedure is called a sequencing rule.

The sequencing rules can be classified according with the following fact; if the order of the jobs changes over the time, the rule can be considered dynamic and if the order does not change, the rule can be considered a static rule. As an illustration, SOT is a static rule and the SLACK is a dynamic rule.

The sequencing rules can be separated into four areas.

- Rules involving processing times.
- Rules involving due dates.
- Simple rules involving neither processing times nor due dates.
- Rules involving two or more of the first three categories.

2.4.1 Sequencing Rules Involving Processing times

The rules herein classified have as a decision factor in the function or evaluation procedure of the priority factors the processing times of each job. The Shortest Operation Time (SOT), also called the Shortest Imminent (SI^X), and the Shortest Remaining Processing Time (SR) are the best known. Many researchers have studied the pure SOT rule or a modification there of, integrating other factors such as due date, and arrival times. Literature mostly refers to SOT studies because SR behaves very similarly but a little worse.

In 1962, Conway and Maxwell determined that SOT was optimum with respect to certain measures of peformance, such as; mean flow time and mean lateness in the single server case. Later, they extended their study to a job shop and they found that SOT retained its advantage [14].

The principal results when using SOT, as determined in the literature, can be summarized as follows: SOT is best for average flow time, average lateness and tardy jobs when due dates are exogenously and internally established at less than seven times total processing times [5]. The comparisons were made against due date based rules. However, SLACK/OPN was found better than SOT when using total work content due date methods [14].

Conway [12] and later Rochette and Sadowski [45] found that as the shop load increased, the SOT rule produced a much lower tardiness. When Conway employed a simulation with a machine utilization of 88.4%, the SLACK/OPN produced fewer tardy job. The effect was reversed in two other simulations in which the machine utilization were 90.4% and 91.9%. The same result were obtained with shop loads of 80% and 90% by Rochette and Sadowski. Chern and Blackstone [5] suggested, based upon this data, that there must exist some high shop load, above which it is better to use the SOT rule.

The SOT rule has one limiting factor, it forces some jobs, with very long operation times, to be very late. To remedy this problem many researchers have modified SOT trying to eliminate this disadvantage. The published literature indicates two procedures to attack the problem. First, to alternate SOT with some other rule, so that the alternative forces out those jobs which have been in the system for a long period of time. Second, to truncate the SOT rule which means to use an alternate procedure to over-ride the priority already assigned.

An attempt to use the first alternatives was SOT and FIFO [13]. The result presented a large increase in the mean lateness variance, so it was not considered very good.

Another attempt was made by Gere [21] when he alternated SOT with the SLACK. The results indicated that the variance of the lateness was better than the one in the SOT case but worse than SLACK and SLACK/OPN.

The second alternative, where SOT is truncated, has three principal versions. Eilon and Cotterill [17], truncated SOT with FIFO and SLACK. They did not find an attractive advantage over using SOT by itself. The same researchers defined the Shortest Imminent processing time rule (SI^X). SI^X is a SOT rule with an alternative procedure that establishes a F factor defined as:

$$F = SLACK - U$$

where U is an arbitrary constant.

Those jobs having an $F < 0$ receive higher priority. Otherwise, SOT is used. Eilon and Cotterill found that depending on the U value, the rule behaved differently. When U approached infinity, the system employed only SOT, and in the other extreme when U approached to zero, the rule used was SLACK.

The SLACK ratio , another truncated rule, shows better results than the SOT, but it was not compared against any slack-based rule. Another very similar version was developed by Oral and Malouin [39], it was called the SPT-T rule. This rule selects the minimum over all jobs of the minimum of each job of (SOT + γ). Here, varying the gamma value, SLACK, SOT and the combination of them can be very easily compared. As gamma approaches to infinity, SLACK/OPN is produced. The result using this methodology were better than the either of the used rules. The Chern and Blackstone' survey [5] is suggested for an indepth survey into dispatching and sequencing rules.

2.4.2 Sequencing Rules Involving Due Dates

The principal advantage of the due date based sequencing rules over processing time rules is the smaller variance of job lateness [5]. A due date based sequencing rule considers the accomplishment of the due date as the major goal. So, as a job gets closer to its due date, its priority increases.

The concept of time remaining to the due date is defined as slack time. This slack can be defined in two different ways using either the release time of the job to the shop or the actual current time in the shop. The first option is named static slack since it never changes while the job is in the system or on the machine. The second option is called dynamic slack and this changes with time.

The slack time obtained can be used in four different ways in due date based rules:

- Pure slack, which measures the amount of time remaining for processing the jobs.

The first option gives origin to the Earliest Due Date rule, DDATE

$$Pr_{ij} = d_i$$

The second option gives origin to the SLACK rule:

$$Pr_{ij} = d_i - TNOW - p_{i*}$$

- Slack assigned per operation, where the slack time is divided by the number of operations. It measures the potential amount of time to execute an operation. If this value is lower than the average operation time, it can be assumed that the job will be tardy. it can also include the SLACK/OPN

$$Pr_{ij} = (d_i - TNOW - p_{i*}) / n_i$$

where:

Pr_{ij} : priority number for job type i in operation j.

n_i : number of operation per job type i the other variables will be defined in Chapter 3.

- Slack assigned per job, in this case the slack time is divided by the expected job operation time.

- Slack assigned per the dynamic allowance of the job. This ratio is the result of dividing the slack time of the job by its allowance. This option includes Job SLACK ratio rule.

$$Pr_{ij} = SLACK/(d_i - TNOW).$$

Regarding to the job tardiness measure, Gere [21] classified the effectiveness of the due date type rules in the following order:

1. SLACK/OPN
2. SLACK
3. Modified job slack ratio (This rule considers the expected waiting time of the job in the current machine given a current queue).
4. Job slack ratio.

Finally, Conway [14] found that Slack-per-operation produced a smaller variance of the job lateness and smaller number of tardy jobs than either SLACK or DDATE.

2.4.3 Rules Involving Neither Processing Times Nor Due Dates

Some examples of rules that involve neither processing times nor due dates are:

- Random selection.
- First Come First Serve (FIFO).
- First Arrived at Shop, First Served (FASFS).
- Shortest Number in the Next Queue.

Papers using these rules include [13],[45].

2.4.4 Combinatorial Rules

Cliffe and Mac Manus [9] and Hershauer [27], are two examples of researchers who have used and tested combinatorial rules. The general feeling in these area is that the use of a weighted combinatorial rule is not any better than using a single rule.

2.5 DUE DATE ASSIGNMENT

Conway [13] defines four methods of assigning due date to arriving jobs:

I Exogenously determined

- Constant - Salesmen quote delivery at a uniform period in the future.
- Random - The buyer establishes the due date.

II Internally determined

- Based on total work content.
- Based on the number of operations.

Eilon and Chowdhury [18] studied four possibles procedures to forecast due dates. Their procedure determines the due date for a given job incorporating the job arrival time, the number of operations to be done, the expected processing time, the general congestion in the shop, and the congestion at each machine. Their study established that some due date methods are more favorable for certain sequencing rules than others. The least affected of all the rules was SOT and the best of the four forecasting rules was the one that considered the processing times and the waiting times.

Chapter III

METHODOLOGY

3.1 RESTATEMENT OF THE PROBLEM

One of the critical points in interactive scheduling is the time at which the interaction between man and machine takes place. Although the scheduler might decide freely, using his intuition or his experience; the DSS-IS should have the option to indicate when it is suitable to change the sequencing rule in use. The sequencing rule will be changed in order to modify the tendency of a variable in the objective function (Ø). The main reason for such an option is that it will permit the scheduler to better satisfy all of the "What if ..." questions. Thus, the scheduler will be capable of weighting his approaches to better solve his problems.

The main purpose of the switching mechanism is to change from one sequencing rule to another, complementary, sequencing rule. The switching is necessary to control the tendencies of the variables in the objective function (in this case mean job tardiness and flow time). To switch signifies an alteration in the current tendency of Ø where the behavior of Ø was due to the rule in use. The switching of sequencing rules should result in a better value of Ø. In consequence, to activate the switching mechanism will mean to recognize and/or interpret the current status of the system to further balance the evaluation measures.

3.1.1 Concept Definitions

Before presenting the simulation scenario, it is necessary to explain the concepts and terminologies used to define the performance measures, the sequencing rules and the switching concepts.

r_i : release time or arrival time of job i to the shop. It is the earliest time in which the first operation of a given job can start.

d_i : due date. It is the time at which the processing of the last operation of job i should be completed.

d_* : overall due date, is the summmation over i d_i.

a_i : $(d_i - r_i)$ total time that a job i can be in the system without being tardy (allowance).

TNOW : current time of the shop.

p_{ij} : processing time of job i for operation j.

p_{i*} : summation of all the processing times for job i.

p_{**} : summation of all the processing times for all jobs in the system.

C_i : completion time for job i.

F_i : flow time for job i, it is the total time a job spends in the shop or (Ci-ri).

L_i : (d_i-TNOW), lateness of job i. It is the difference in time between the completion of the jobs and its due date.

T_i : Max(0,-L_i), tardiness of job i, it is the amount of time that job i is overdue.

all_* : (d_* -TNOW) total dynamic allowance.

WK : work content is the sum of the processing times of all jobs in the system.

WKR : work remaining to be done. It is WK minus the sum of the processing times of all operations completed at time t.

COE_i : ratio of all_* to WKR for job i.

All definition are over the same time frame.

3.1.2 Assumptions

To analyze scenarios developed for switching control, a simulation model was built. The assumptions for the system are described as follows.

3.1.2.1 Critical Assumptions

1. Jobs arrive continuosly to the system and the arrival distribution is Poisson,ie; the inter-arrival time between two consecutives jobs is negative exponentially distributed.
2. There are six different types of jobs and five nonidentical machines
3. Each machine can process only one job at a time.
4. Every job has j different operations, where j can vary from one to five operations.
5. The routing of each job through the machines is prespecified by the type of job.
6. Two consecutive operations on one machine by a job is not allowed, but the job may return to the machine on the third or subsequent operation.
7. Operation times are generated from a normal distribution previously assigned to the type of job where the mean and the standard deviation are different and fixed.
8. When a job arrives, a due date is assigned internally by the system. The customer has no influence on the due date assignment.

3.1.2.2 Secondary Assumptions

Beside the above assumptions, the job shop is constrained using the following assumptions:

1. Job Related
    - a) Jobs are independent of each other.
    - b) The batch size is one.
    - c) There are only perfect operations, no scrap.
    - d) The product being processed has infinite life.
2. Machine Related
    - a) There are no machine failures.
    - b) There is no machine maintenance.
    - c) There are no machine set up times.
    - d) Machines process only one job at the time with a 100 percent efficiency.
    - e) Alternate routings are not considered.
    - f) No tolerance or capabilities are considered.
3. Manpower Related

    All operations are machine dependent, not manpower dependent.
4. Queue related

    The queue capacities are infinite.
5. System Related
    - a) The status of the system at time zero is known.

   b) The system is dynamic and its evaluation in steady state condition is to be discrete.
   c) The material handling time is negligible.
   d) A period, or cycle, is statistically determined.
   e) The system capacity is known
   f) The system is a job shop.
6. Control Related
   a) No Bumping (break priorities).
   b) No lap-phasing.
   c) No job acceleration.
   d) No unscheduled slack times.
   e) No push-out or external buys.
   f) The arrival rate of jobs is calculated according to the shop load desired.

3.2 MODEL DESCRIPTION

This model was created to carry out an experimental investigation of the behavior of the shop described above under different sequencing rules. In addition to that, it was created to evaluate the feasibility of using a switching mechanism to alternate between two sequencing rules in order to balance the variables in an objective function.

Even though it is not possible to establish the optimality of a particular procedure through simulation, experiments can be used to progressively evaluate and to obtain more powerful procedures. This is the main purpose of this simulation model, to get some insight into the use of the control mechanisms applied to job shop scheduling. The description of the model is divided into six specific topics and then the integration of the six topics is considered.

3.2.1 Job Arrival Pattern

Many studies aimed at evaluating the effectiveness of different job shop sequencing rules assume that the arrival process can be described with a Poisson distribution whose interarrival times are negative exponentially distributed [4]. The influence on, or sensitivity of, the effectiveness of job shop sequencing rules with respect to various arrival distributions has been studied by Elvers [20]. He concluded that the shape and the range of the arrival rate of incoming jobs did not have a significant effect on the system. Hence, this study has used a negative exponential distribution because it is typicaly used in many simulation models.

3.2.2 Shop Load

Even though the arrival time distribution is not significant,the arrival ratio does define the shop load level. To carry out the comparisons in this study the aggregate shop load was set at 80 % of total capacity. This means that the arrival ratio is 1.79 units of time per job. The formula necessary to calculate the shop load is :

$$SH.LO. = M * X\% / E(WK)$$

where;

M : it is the number of machines.

X% : it is the machine utilization required.

E(WK): WK expected value.

To illustrate, calculations are given in Appendix A.

3.2.3 Operation Times

Exponential distributions have been used for generating service times in many dynamic job shop investigations. Other researchers have suggested Erlang, hyper-exponential, lognormal and normal distributions.

In this research, the normal distribution has been selected to avoid another possible source of variability. Therefore, each type of job has its own normal distribution for its operations.

3.2.4 Routing

There are six different types of jobs. Each job type has its own routing. The job routing used is presented in Appendix B.

Nanot [10] has found shop size to be an insignificant factor, when simulating a job shop. Therefore, a small shop can be implemented without losing generality of the results.

The complexity of having five types of machines is enough to recreate any scheduling problem. To illustrate the situation, the number of schedules which could be generated, if one allows the possibility of a different sequence on each machine is at least $(5!)^6$.

3.2.5 Due Dates Assignment

The prespecified date for completion of a job is a very important parameter when utilizing different due date assignment procedures. This is because sequencing rules can vary in their relative quality depending on the due date assignment procedure utilized. Specifically, SOT and SLACK are very sensitive to the work content due date assignment approach [5]. Eilon and Chowdhury [18] established that the mean lateness is highly affected by the due date allowance, so that the mean completion time can be controlled by choice of the appropiate parameters.

In this research, it was decided to use a constant factor multiplied by the total expected operation time for every job. The reason was to eliminate another possible source of variability.

The due date was fixed as follow:

Due Date= (Pi*)*(C) + TNOW

where:

C : it is a fixed parameter.

3.2.6 Sequencing Rules

SLACK was selected as the due date based sequencing rule because of two main reasons. First, it is generally classified as the best due date sequencing rule and secondly, it is a complemetary rule for SOT with respect to the tardiness and flow time.

As it was noted in the literature review, SOT is one of the best rules, particularly when due dates are exogenous, and/or endogenous with up to six times the WK and with a moderate machine utilization [5]. These properties were used to establish a significant difference with SLACK, its complementary rule. See Appendix C.

3.3 THE SIMULATION RUN

To find out the effects of the switching procedures, it was necessary to define an appropiate scenario for taking the statistical sampling. The shop used was loaded to a 80 per cent of its capacity. To reach a loaded system which approaches steady state before starting the sampling, 000 units of time were used to load the system from its empty state. This means that at least 150 jobs went through the system before the sampling took place. The simulation was then run for 1 00 more time units.

3.3.1 Simulation Model

The simulation model was written with the purpose of studying job shop behavior. Based on this idea, any new static or dynamic rule or procedure could be easily incorporated in the model. The model was implemented in FORTRAN IV in a IBM 370/158.

3.3.2 Summary

Jobs arrive to the system under an exponential distributed interarrival rate. Once a job is released to the system the job type and the operation times are assigned. If the first required machine is idle, the job goes into the machine immediately to be processed, otherwise, the job goes into the queue. No parallel routings are allowed. This competition for scarce machine resources continues until all the operations are completed. The selection procedure for the jobs in each queue is the sequencing rule being applied at that point in time. This sequencing rule is either SOT or SLACK.

3.4 APPROACHES FOR SWITCHING SEQUENCING RULES

The objective of the switching mechanism is to modify an existing tendency of the control variable using a complementary sequencing rule. The general assumption here is that if a sequencing rule has a positive tendency over time it can be controlled using a sequencing rule with a negative tendency. The sequencing rule with a negative tendency will balance the effects of the other sequencing rule, irregardeless of the interaction between the two sequencing rules. The objective function will get better and better as it captures the best from each individual complementary rule.

Chern and Blackstone [5] suggest that there must exist some high shop load, above which it is better to use the SOT rule. So, the shop load can force a change of sequencing rules. The assumption in this research goes further than that. It suggests the use of different rules depending on not only the shop load but also on the composition of jobs in the shop.

This suggests some kind of switching mechanism based on the current status of the shop variables or based upon measures of the output of the shop. It could also be possible to create a complete control mechanism that will switch rules accordingly with preset requirements. However, in the case that informal information is included, the presence of the scheduler is highly recommended. Then, the switching solution could be used as a stopping point, to update and warn the scheduler about what will be happening if he does not take inmediate actions. Also, given that the shop has a dynamic behaviour, a trace of the variables over time will permit the human element to learn more about the shop and to have better control over time.

The control by switching could be done dynamically with time, or planned in advance, knowing the types of job that could arrive. This research has referred to these approaches as dynamic and the static switching procedures.

3.4.1 Static Switching Approach

For the static switching control approach, the switching of the complementary rules (SOT and SLACK) is done only based upon time. This case does not consider the internal situation of the shop. Instead, this approach assumes that the type of jobs arriving is similar or constant over time. Therefore, to alternate the sequencing rules will balance the variables in the Ø.

3.4.2 Dynamic Switching Approach

For the dynamic switching approach, the switching of the complementary rules is done based upon some current characteristics of the shop. Therefore, it will be necessary to choose some control measure to represent the changes in the shop. SOT and SLACK will be alternated when the control measure passes a specified lower or upper bound. These lower and upper bounds are choosen in such a way as to produce the best value for the scheduler's wishes.

3.4.3 Rationale of the Two Approaches

The hypothesis is that the sequencing rules behave differently depending on the content of the shop. This is partially substantiated by Blackstone [5].

The rationale is the following. The mean flow time and the mean tardiness are the mean of distributions that represent the effects and the behavior of the sequencing rules under the system conditions at that particular time. If the measures are going away from the objective (outside of limits), a change in the sequencing rule is required. That is the purpose of the complementary rule, to change the order in which the jobs are processed on all machines, and ultimately change the order that jobs are being completed.

In this research, suppose SOT is being used; this procedure will take a biased sample of jobs being held because of their large operation times. Those jobs need to be processed to meet a due date and that is the function SLACK will perform. If there is no complementary rule to accomplish that function, those jobs will become late and the WKR will increase, eventually resulting in an increase in the mean flow time.

It is assummed that if there is a decreasing effect in the mean flow time; it is because the work content remaining in the shop is increasing. It is also assumed that if the work content remaining is increasing, it is because some jobs are held-up due to the sequencing rule in use or because the system is actually overloaded. The result of this will produce a further increase in the mean tardiness and a progressive increase in the mean flow time.

On the other hand, if the throughput produced by the rule decreases the WKR, the complementary rule will not be needed. This means that there will be no job held in the system long enough to affect $\emptyset$.

Another way to explain the same concept would be the following; the mean WKR should be a function of the mean flow time. If WKR increases, mean tardiness and mean flow time will increase. Also, if the allowance is decreasing it can be assumed that the tardiness will be increasing.

In both Static and Dynamic switching approaches, the concept is to determine the tendency of Ø, caused by employing SLACK and SOT alone and the corrective action to apply. Two ways are considered :

1. static switching, to change sequencing rules at specific time intervals.
2. dynamic switching, to activate the alternative complementary rule as it is required for the conditions of the control measures.

Chapter IV

SWITCHING METHODOLOGY

In order to resolve the questions raised in Chapter III, the following major steps were undertaken:

- establishment of the conceptual model to control the shop.
- illustration of the problems to be addressed when creating a job shop control system.
- construction of a simulation model.
- creation of the control mechanism using the complementary sequencing rules.
- development of the objective function to represent the goals and determination of the upper and lower bounds for the control measures.

4.1 CONCEPTUAL MODEL

The use and the logic of the switching mechanism will be better understood through the following schematic of a job shop control system, Figure 2. An analogy for the conceptual model is a conventional feedback control system.

The transfer function consists of two components:

- the scheduler or the automatic controller of the system which defines the sequencing rule and the due date policy to be used.

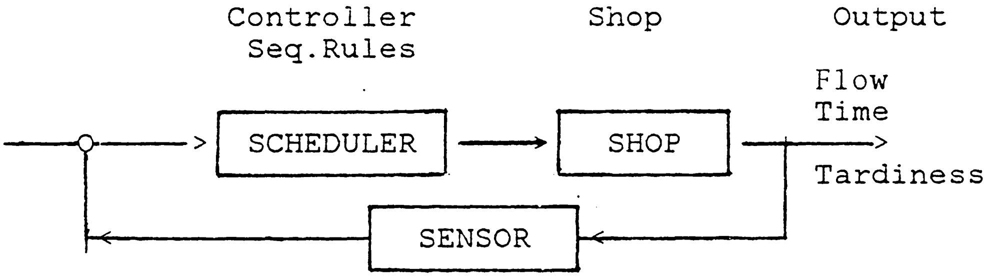


Figure 2: Scheduling Control System

- the job shop which has an effect on the performance measures to be monitored.

The sensor measures and monitors the output to further adjust the control parameters according to the target or plan. The plan reflects the scheduler's goals as expressed in the control parameters. The evaluator uses those parameters to induce corrective actions by the controller when needed. However in a DSS-IS, the corrective action is not necessarily needed; but instead, the scheduler is warned of further problems if no action is taken.

To better illustrate the control function when using a switching process, it is necessary to present the steps to follow in a general approach:

1. Determine the mean flow time and the mean tardiness using sequencing rule one. Study and establish the tendency of that rule.
2. Determine the mean flow time and the mean tardiness using a complementary sequencing rule of rule one. Study and establish the tendency of the second rule.
3. Confirm the complementarity of the rules.
4. Fix the desired trade-off point between the rules used in steps 1 and 2. Also, fix the control parameters or control plans to reflect the scheduler's goals.

5. Pick the adequate switching mechanism.
6. Monitor the control measure, transduce the output variable to the same format as the control measure.
7. Compare control parameter values coming from the sensor and/or the evaluator with the parameters which represent the target (plan). Determine the error with the expected plan.
8. If needed, take corrective actions based upon the error from the original plan.

4.2 PROBLEMS IN DESIGNING A JOB SHOP CONTROL SYSTEM

In order to structure a job shop control system by switching sequencing rules, the questions below should be addressed.

4.2.1 Problems Related to Both Control and Performance Measures

The questions presented herein are necessary to define the WHAT, WHEN, and HOW to collect or monitor both the control and/or the performance measures.

1. - WHEN TO MEASURE?
    1. At events.
    2. At a specific time (cycle).
    3. At a specific time, given by a control procedure.

2. - WHAT TO MEASURE?
    1. Historical data, based on jobs leaving the system.
    2. Current data, based on jobs currently in the system.
    3. A combination of Historical and Current data.
3. - HOW TO MEASURE?

    Erroneous or nonapplicable conclusions could be reached if the variability of the system is not considered. Therefore, some smoothing technique is suggested.

4.2.2 Problems Related to Switching Actions

This subsection presents the questions arising from the activation of the switching procedure to be applied.

1. - WHEN TO SWITCH?
    1. Based on critical tendency or error factor.
    2. Based on time assignation.
2. - HOW LONG SHOULD THE CORRECTIVE ACTION BE IMPOSED?
    1. Based upon the current new tendencies.
    2. Based upon time.
3. - HOW LONG IS IT GOING TO TAKE TO ACTIVATE THE CORRECTIVE ACTION?
    1. Based upon the current new tendencies.

2. Based upon time.

Before proceeding further, it is necessary to explain and justify the options taken in this research.

4.3 BASIC DECISIONS FOR THE DESIGN OF A JOB SHOP CONTROL SYSTEM

This section presents a brief justification of the decisions taken to respond to the questions that were raised in Section 4.2. These decisions will not be fully addressed and justified because the thrust of this research is to show the merit of using a switching control sequencing rule. In addition it was necessary to limit the research to a reasonable scope.

4.3.1 Control Measures Related

In reference to 4.2.1, WHEN TO MEASURE seems to be the easiest question to resolve. As it was established in the introduction, this study compares the application of a static control technique against pure SOT, pure SLACK and a dynamic control technique. As it has already been stated, the plan is to alternate complementary rules over the time frame of the simulation run. This switching action should balance the effect of the sequencing rules in use on the O Therefore, the decisions were:

1. For the static case, the control and the action measure is time.
2. For the dynamic case, because of the dynamic environment, the control measures are taken any time an event occurs.

The second question, WHAT TO MEASURE, is the most relevant. It only applies to the dynamic case because the static case is only time dependent. Even though it is not known whether tendencies can really be determined better using historical data, current data or a combination of both, the decision adopted in this research was to use current data. The decision was based on two considerations:

- current data expresses the actual status of the system.
- the variability of the current measures is lower than the historical data because of continuous updating.

Therefore, in the dynamic case, the decision is to switch based upon the current tendencies of the control variables.

The third question, HOW TO MEASURE?, will be treated in the "tendencies evaluation" discussion in Section 4.4.

4.3.2 Performance Measures Related

The answers to the question raised in Section 4.2.1 are:

- WHEN TO MEASURE? At the end of the simulation run, with an aggregate measure.
- WHAT TO MEASURE? Only historical data because they represent the results of the process.
- HOW TO MEASURE? By taking the statistical mean of the measures at the end of every run.

The performance measures are only taken to compare one method against the other. In consequence, they should be taken only once and this should be made at the end of the simulated period. In addition, all the comparisons among all variables should be performed under identical conditions.

4.3.3 Switching Action Related

The answer to question number one, WHEN TO SWITCH?, defines and creates the different approaches. The first option is the dynamic, and the second option is the static approach. Both approaches are tested in this research.

The answer to question two, HOW LONG SHOULD THE CORRECTIVE ACTION BE IMPOSED? creates a variation of the approaches just mentioned. Again, to switch back the corrective action could be considered as static and dynamic. In this, research for switching back, both static and dynamic approaches were used with the static and dynamic procedures respectively. See Section 4.4.3.

The last question, HOW LONG IS IT GOING TO TAKE TO ACTIVATE THE CORRECTIVE ACTION?, will not be considered in this research. Instead, it is assumed that the system could respond instantaneously.

4.4 SWITCHING AND PERFORMANCE MEASURES PRESENTATION

The following subsections present the variables to be used in the activation and the evaluation of the switching procedures. The steps are as follows:

- switching control measures definition, this section presents the variables whose behavior permit the scheduler to know when it is necessary to switch.
- switching measures synthesis, this process is intended to smooth the response of the variables involved in the switching mechanism.
- performance measure definition, this section presents the measures included in the Ø which permit the scheduler to compare solutions in the result of different scenarios.

4.4.1 Switching Measures

The switching mechanism could use two types of variables:

- historical measures which include flow time, lateness and tardiness of the jobs leaving the system.
- current measures which include allowance and work content remaining.

This research studies the application of the ALL/WKR (COE) ratio in a dynamic control system in order to switch the sequencing rules.

4.4.2 Monitoring Measure Synthesis

Due to the inherent variability of the control and switching measures, a smoothing technique was applied to reflect the real tendency of the rules in an improved manner. The improvement is reflected by a small variance in the switching measures. This step is only needed by dynamic approaches, to avoid switching due to noise in the control variable. The smoothing technique used was moving averages.

The intention of the control system is to produce corrective actions based upon the assumption that the cause and effect relationship in the job shop is consistent and constant. It is not necessary to know the internal processes governing the behavior of the shop but rather the effects of a given sequencing rule. Therefore, it is basically necessary to get a pattern of the output being monitored. If such a pattern exits, the global mean or an individual measure cannot be used as a basis for switching the sequencing rules. Thus, any other smoothing method would be more accurate than both variables named above.

One simple approach of monitoring the data is to collect a constant number of points to produce a series of means or moving averages. The set of points included in the calculation of the average defines the sample size (window). Every average, once collected is used as the control measure to determine if switching is needed.

The formula used in the dynamic switching approach is:

$$\mathrm{COE} = \mathrm{COE}_i/N$$

where,

N is the size or the number of jobs coming out of the shop.

COEi is the $\mathrm{ALL}_*/\mathrm{WKR}$ ratio at the time that job i is coming out of the system.

Computation of moving averages is a clear and easy way to smooth the data obtained from the shop.

4.4.3 Control Mechanism

When the control system was discussed, it was shown that there were two main approaches to activate the alternative complementary sequencing rule and another two to deactivate them.

Approaches to activate the complementary sequencing rule:

- activate the complementary sequencing rule when the control measure passes a limiting value.
- activate the complementary sequencing rule when the control measure passes a time value.

Approaches to deactivate the complementary sequencing rule:

- deactivate the complementary rule in use and go to the original sequencing rule when the control measure passes a limiting value.
- deactivate the complementary rule in use and go to the original sequencing rule when the control measure passes a point in time.

The limiting value can be called limiting bounds for the variable. In this research, control alternatives include only one bound to produce the switching. It may be possible to have an upper and a lower bound for activating or deactivating the complementary rule.

4.4.4 The Performance Measures

The selected measures were mean flow time and mean job tardiness. Flow time was selected because it reflects the ability of the shop to process the jobs. Mean tardiness represents the ability of the scheduler to have jobs completed by the due date. Also, the objective of the scheduler and of this research is to balance these two measures. Therefore, mean flow time and mean job tardiness are included in the objective function.

4.5 THE SWITCHING JOB CONTROL OBJECTIVE FUNCTION

The main purpose of the objective function is to reflect the goal of the control mechanism and to have a single value for comparing the different procedures. This single value, Ø, includes the variables that the scheduler wants to balance. Balancing of the variables in the Ø will minimize its value.

In this particular research, the objective function should express:

- the same performance and normalized Ø value when using pure SOT or SLACK sequencing rules.
- the goal of gathering the best properties of pure SOT and pure SLACK as an optimum.

The mathematical expression illustrating the indifference between SOT and SLACK is given in the equality value of the objective function as shown below:

$$\phi_{SOT} = \phi_{SLACK} = 1 \qquad (1)$$

the ϕ value equal to one was selected to normalize the weighting factors of the component in the objective function. This implies that the scheduler gets no difference when using SOT or SLACK even though they have very different behaviors.

The second property states that the optimal value of ϕ, should employ the F and T values coming from the application of the pure SOT and the pure SLACK. Therefore, the optimun to look for is a result of the best of SOT and SLACK. The expression of this idea is given now by:

$$\phi = \frac{F - F_{SOT}}{K1} + \frac{T - T_{SLACK}}{K2} \qquad (2)$$

This expression should approach zero as it gets closer to the desired results. The K1 and K2 factors, used in equation (2), are employed to normalize and equalize both terms of the equation.

When SOT is used exclusively, the objective function reduces to :

$$\frac{F_{SOT} - F_{SOT}}{K1} + \frac{T_{SOT} - T_{SLACK}}{K2} = 1$$

Therefore, the left portion of the equation goes to zero and then:

$$K2 = (T_{SOT} - T_{SLACK})$$

Proceeding in the same fashion to obtain the K1 value:

$$K1 = (F_{SLACK} - F_{SOT})$$

Now, equation (2) can be written in the following manner:

$$\phi = \frac{(F - F_{SOT})}{F_{SLACK} - F_{SOT}} + \frac{(T - T_{SLACK})}{T_{SOT} - T_{SLACK}} \qquad (3)$$

where;

F_{SOT} is an estimation of true mean flow time value for the SOT sequencing rule.

T_{SLACK} is an estimation of the true mean tardiness for the SLACK sequencing rule.

4.5.1 Static Switching

The mathematical expression for this procedure is given by:

(a). While SOT is in use, then

Y1 = 1, if TNOW >= TNEXT (==> change rule)

0, otherwise (==> no change)

(b). While SLACK is in use, then

$$Y2 = \begin{cases} 1, & \text{if } TNOW >= TNEXT \quad (==> \text{ change rule}) \\ 0, & \text{otherwise} \quad (==> \text{ no change }) \end{cases}$$

where

$$TNEXT = TNOW + BLOCK * (X * Y2 + (1 - X) * Y1)$$

$$Y1 + Y2 = 1$$

$$1 >= X >= 0$$

BLOCK represent the scheduler's planning time frame.

X represents the percentage of time during which the first rule is used (SOT).

(1-X) represents the percentage of time in which the complementary sequencing rule is used.

These steps define the static switching procedure used.

4.5.2 Dynamic Switching Equations

In the dynamic case, the rules are switched depending on the current status of the system. In fact, it is not only the variance of the arrival distribution that generates different shop loads, but also it is the interactions in the shop, such as: job types, queue size, dispatching rules, job routings and so forth. Because of the latter facts, because of the different behavioral patterns of SLACK and SOT, and because of jobs leaving the system and the remaining jobs in the system, it is necessary to control the situation dynamicaly. This means that the control system should work using measures that represent the current status of the system. This also implies the identification of some upper and lower bounds in those measures. The upper and lower bounds allow the scheduler to define the switching rule point to control the job shop system.

In the specific case of this research, a ratio of the allowance to the work content remaining was created. This ratio (COE), represents the number of free hours left to do one hour of work. The mathematical equations to represent this dynamic method are the followings:

(a). While SOT is in use, then

Y1 = 1, if COE <= LB (==> change to SLACK)

0, otherwise, (no change)

(b). While SLACK is in use, then

Y2 = 1, if COE >= UB (==> change to SOT)

0, otherwise, (no change)

This procedure switches sequencing rules any time the complementary one is needed.

Chapter V

EXPERIMENT DESCRIPTION

This chapter presents experiments illustrating the behavior of switching procedures between two sequencing rules. The experiments are separated into two categories which describe the static and dynamic switching of the sequencing rules (SOT and SLACK). The steps followed in this chapter were:

- significance test of the difference of flow time and tardiness given by both sequencing rules.
- determination of the estimators for the true flow time and tardiness for both sequencing rules which are to be used with the objective function.
- determination of K1 and K2.
- presentation of the experiment using the static switching procedure.
- presentation of the experiment using the dynamic switching procedure.

The intention of these experiments is to illustrate that switching is a viable alternative and to compare the choices of controlling the job shop using either a static switching procedure or a dynamic switching procedure. The experiments performed are schematically presented in table 1.

Switching Approach	Block Size	Upper Bound	Lower Bound	Exp.Set Number
STATIC	1300	XX	XX	1
	30	XX	XX	2
DYNAMIC	XX	3.5-7.5	7.5	3

TABLE 1

Experiments in Switching

5.1 SOT/SLACK COMPLEMENTARITY AND SIGNIFICANCE TEST

Before the execution of any experiment, it was necessary to show that SOT and SLACK behaved significantly different from each other for the mean flow time and tardiness. Five replications, using the individual rules, were performed. The results were the following:

	Pure SOT	Pure SLACK
Mean Flow Time	26.30	36.40
Mean Tardiness	7.58	2.31

SOT produced a better mean flow time, but a poor mean tardiness, while SLACK caused the results to be reversed. Using these values, a t-test was performed to determine if the ($F_{SOT} - F_{SLACK}$) and ($T_{SLACK} - T_{SOT}$) were significantly different at the five percent level of significance. The results indicated that the differences were significant. The development of the test can be found in Appendix C. Also, the difference in flow time and tardiness values between the use of pure SOT and pure SLACK can be observed in Figure 4. This particular figure was produced using seed number 5.

5.2 F(SOT) AND T(SLACK) ESTIMATION FOR K1 AND K2 EVALUATION

Given the fact that the factors K1 and K2 represent the true difference from SOT and SLACK for the mean flow time and tardiness; it was necessary to find a way to evaluate them. The evaluation was done using five replications:

$$F(x) = F(x)_{*} / N$$

where:

x is SOT or SLACK.

* represents the summation with j running from one to N where j is the number of the replication.

N is the total number of replications

The procedure was used for obtaining both T_{SLACK} and T_{SOT}

These estimated values are to be used in equation (3), Chapter IV. Therefore, 10.19 and 5.27 are the values obtained for K1 and K2 respectively.

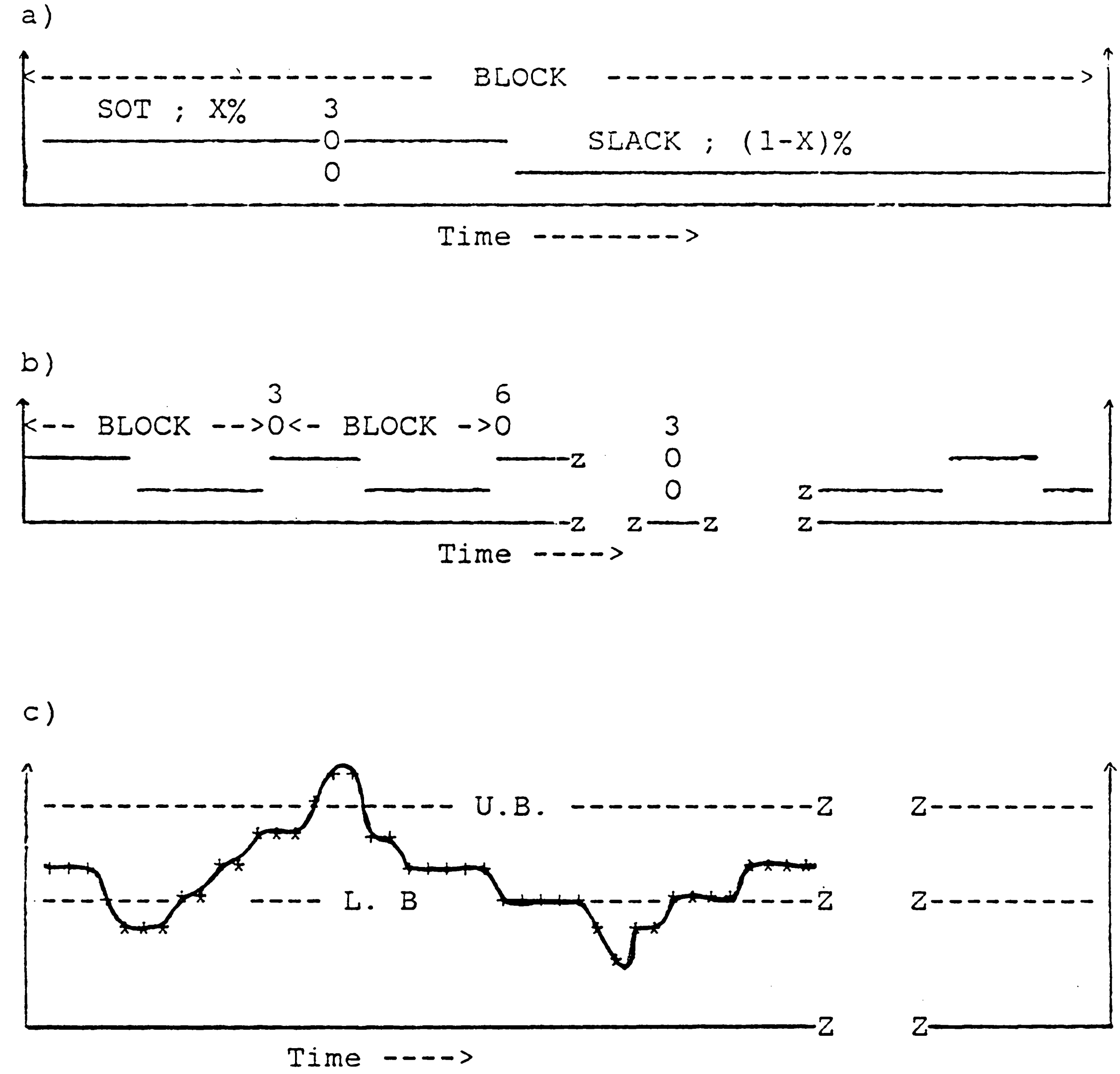
5.3 EXPERIMENT DESCRIPTION STATIC CASE

Two experiments were developed under the static approach. The description of these is as follows:

- Experiment one: the block size of the experiment was defined as 1300 units of time. (Figure 4 and 5). The complementary sequencing rule was used once since the job shop was empty.
- Experiment two: the block size was defined as 30 units of time. This was a value approximately equal to the mean of the mean flow times produced by SOT and SLACK together. The alternative sequencing rule was used once for each block. (Figure 6 and 7).

The statistics were collected starting after 300 units of time which is needed to load the shop for all the experiments. Figure 3-a) and Figure 3-b) displays the switching timing for the static experiments while Figure 3-c) does the same for the dynamic switching.

A block is the planning time in which one switching is scheduled to happen. Therefore, each block is divided in two complementary pieces. The first piece represented an X percentage of the total block size in which the SOT rule is to be used. In the remaining portion of the block, the SLACK rule is to be used. There were five replications for each alternative. Each alternative was created by varying X by 10 % at a time, starting from zero (no SOT used).



+ : Represents the SOT sequencing rule
* : Represents the SLACK sequencing rule
a) and b) are static switching experiment
c) is a dynamic switching experiment

Figure 3: Experiment 1, 2 and 3, General Description

The results of experiment number one can be seen in Figure 5, the values used to create Figure 5 are shown in Appendices D and G. Figure 4 is also an example of the Experiment No. 1 (specifically when seed 5 was used).

A regression analysis was performed over the curves in Figure 5 because the curves' shape seem to be very linear. The results were the following:

$$F = 26.09 + 9.92*(\%SLACK) \text{ and } R = +.9924$$

$$T = 9.49 - 6.92*(\%SLACK) \text{ and } R = -.9415$$

Figure 7 presents the results for experiment number two (See Appendices E and H). The regression analysis, performed over the data which produced Figure 7, gave the following results:

$$F = 27.14 + 9.14*(\%SLACK) \text{ and } R = +.9933$$

$$T = 8.00 - 5.85*(\%SLACK) \text{ and } R = -.9934$$

This analysis were done to test the same assumption as in Figure 5. Finally, Figure 6 presents a particular result for experiment number two.

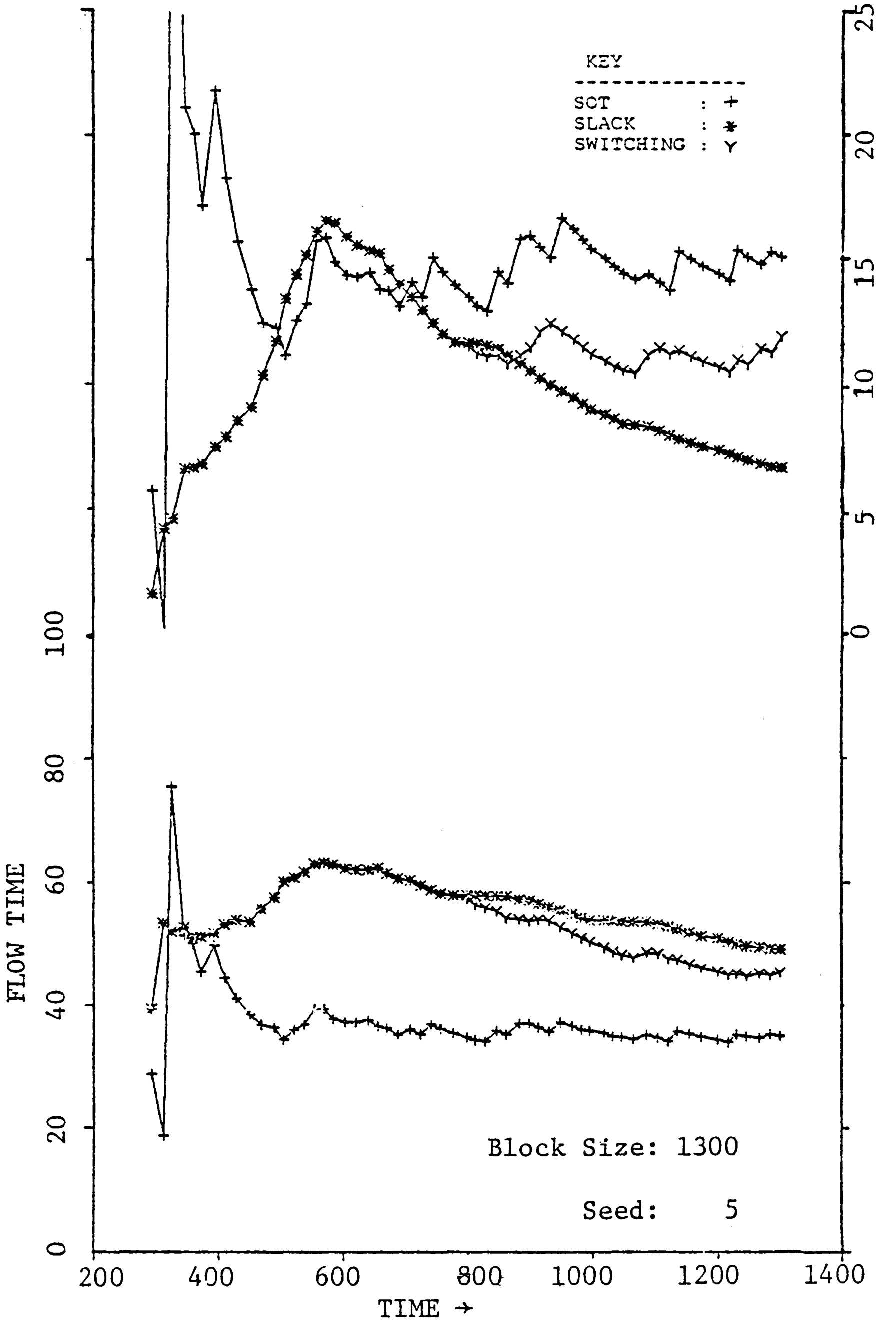


Figure No 4. Experiment No 1, Flow Time and Tardiness Comparison

Rules: SOT, SLACK, and Static Switching

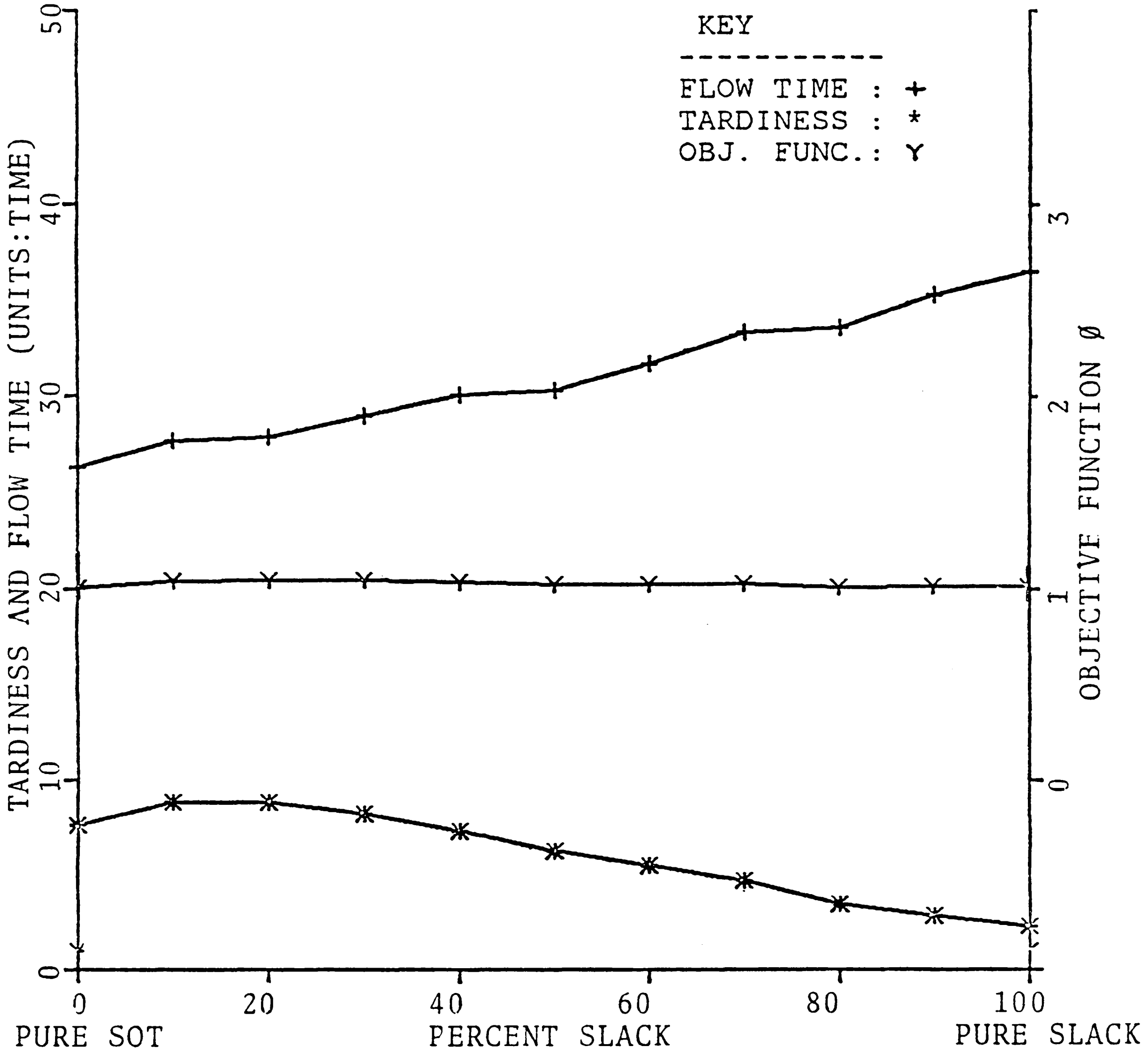


Figure No 5, Experiment No 1, Summary: Flow Time, Tardiness, and ∅ (Static Switching)

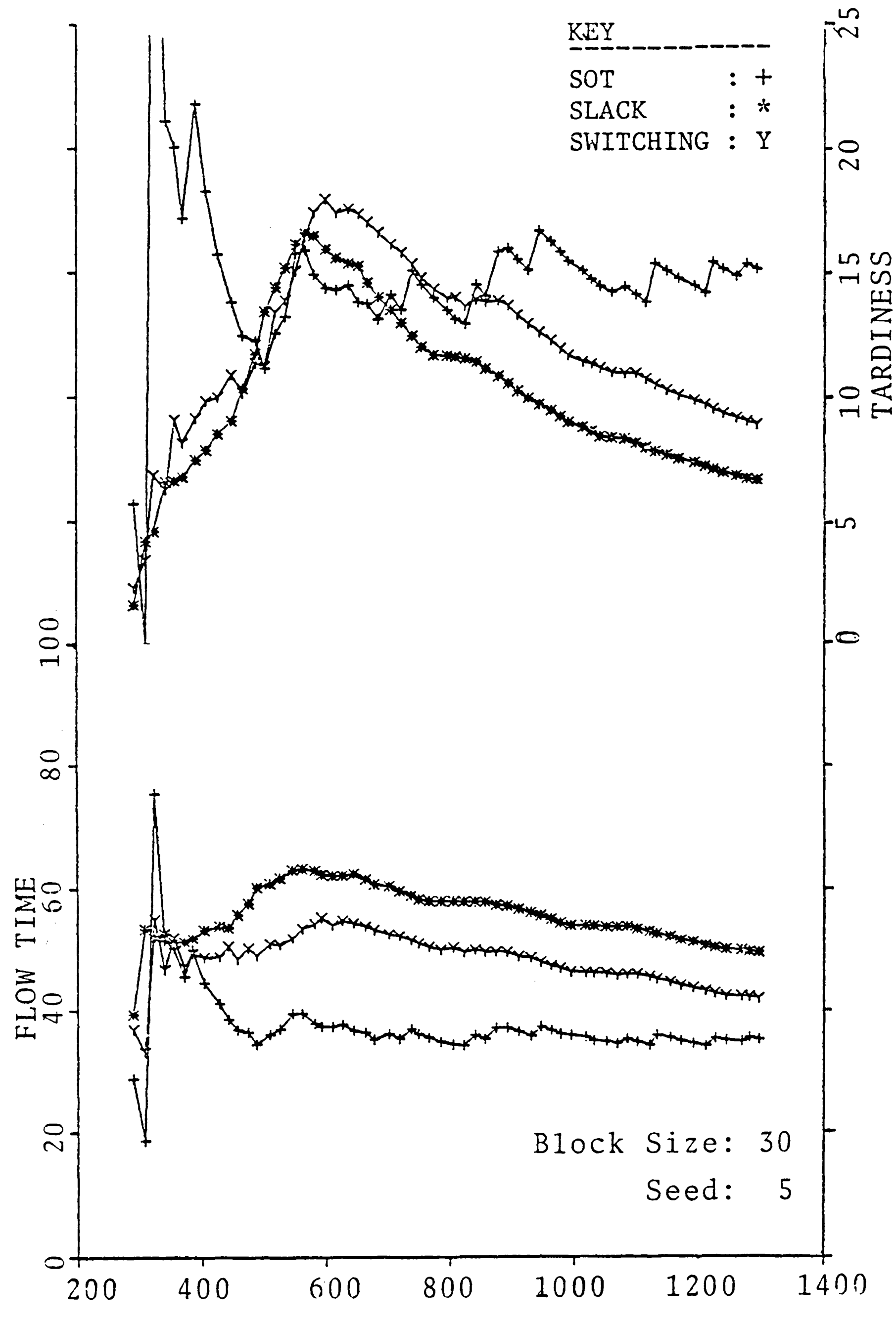


Figure No 6. Experiment No 2, Flow Time and Tardiness

Comparison Rules: SDS, SLACK, and Static Switching

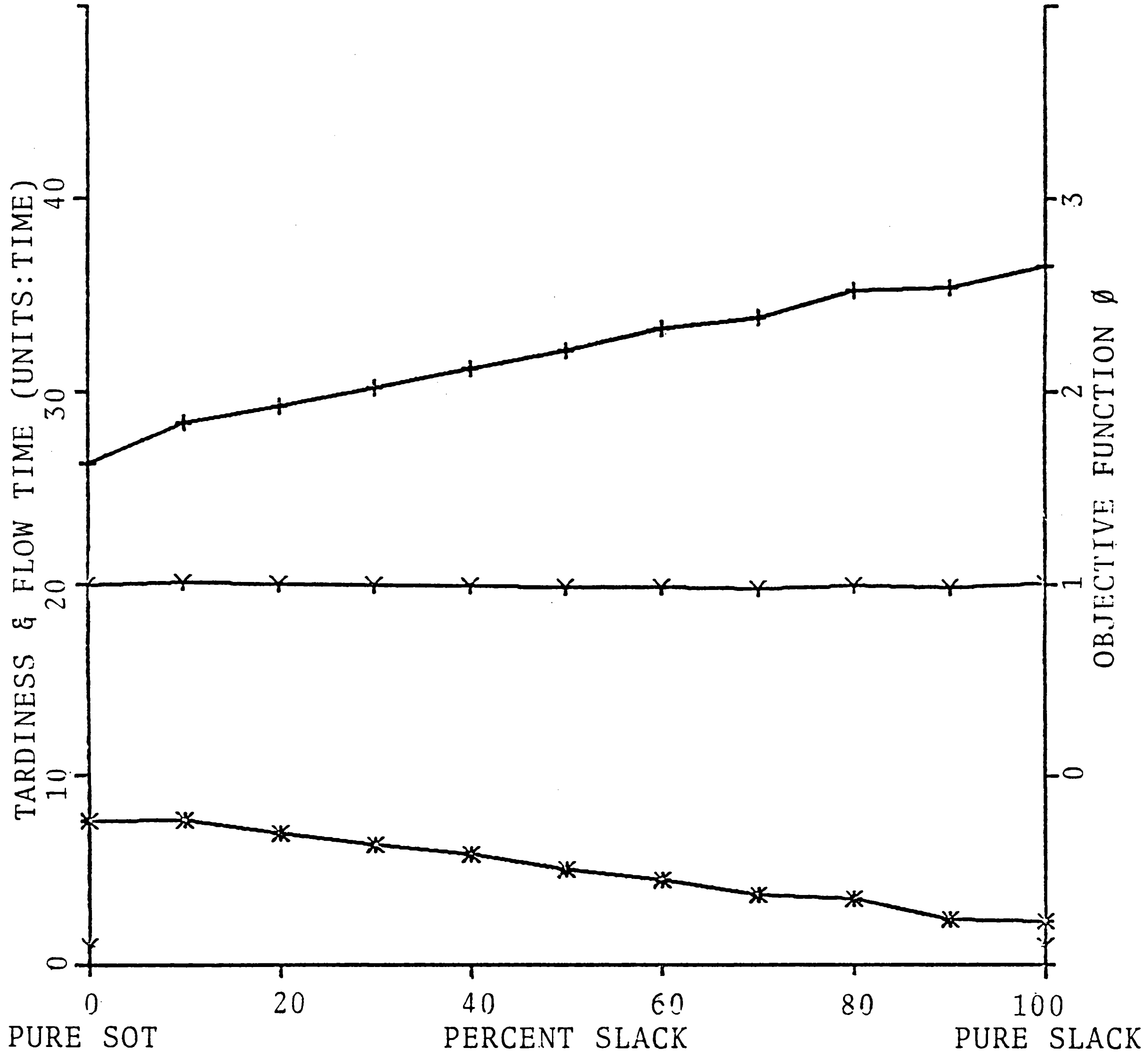


Figure No-7, Experiment No 2, Summary: Flow Time, Tardiness, and Ø (Static Switching)

5.4 DYNAMIC CASE

The first step of this experimention is to obtain an initial feasible upper and lower bound for the control measure to be used. The second step is to search for the best values for the upper and lower bound through a series of experiments.

5.4.1 Upper and Lower Limits Determination

The initial determination of the upper and lower limits was made by considering four main factors. The first factor was to determine the expected slack time of the jobs. This is defined by the due date assignment. In this case, every job was given a total of seven times its normal processing time as its available time to be processed. So, if the scheduler's objective is to minimize the tardiness, it will be necessary to process the job before its due date. Therefore, the maximum allowance and WKR for a job are six and one respectively. This gives a COE value of six which is the initial upper and lower bound of this study.

The second factor is based upon the fact that the SOT rule makes the COE ratio go down over time. This situation holds if the shop load remains constant. This is due to the fact that SOT keeps some jobs for a long time, thus producing a negative allowance while keeping the work content remaining very stable.

The third factor is based on the fact that SLACK produced an allowance that is fairly stable while the work content remaining increases very slowly with the time.

The fourth, and the most important, factor is based upon quantitative considerations. This means that one should plot the COE ratio for SOT and SLACK and look for the most stables zones which produce a balance in the flow time and tardiness measures. The balance should produce a better value for the ϕ.

5.4.2 Dynamic Switching Experiments

Having determined the starting point, the next step was to move the upper and lower bounds by one unit in each direction. This procedure was used to search for a better value of the objective function, ϕ.

Figure 8 presents an example of dynamic switching. The summarized results of this experiment are shown in Figure 9.

In addition to the plots already presented, three other cases are plotted to illustrate:

- the effect of reducing the lower bound value to control the use of the SOT rule. Observe Figure 10.
- the effect of increasing the upper bound value to control the use of the SLACK rule. Observe Figure 11.
- the behavior of the control parameter when using SOT or SLACK exclusively, and the dynamic switching of

SOT and SLACK. Observe Figure 12.

Finally, as in the static case, the dynamic case was replicated five times (See Appendix F). The ϕ values for the dynamic approaches are presented in Figure 9 which were obtained from values in Appendix I. In appendix J, it is developed a t-TEST, to determine the significance between pure SOT, SLACK, and of the dynamic switching. The result shows not to be significant. This meant that some more replication are needed to confirm that the dynamic switching is better than SOT and/or SLACK.

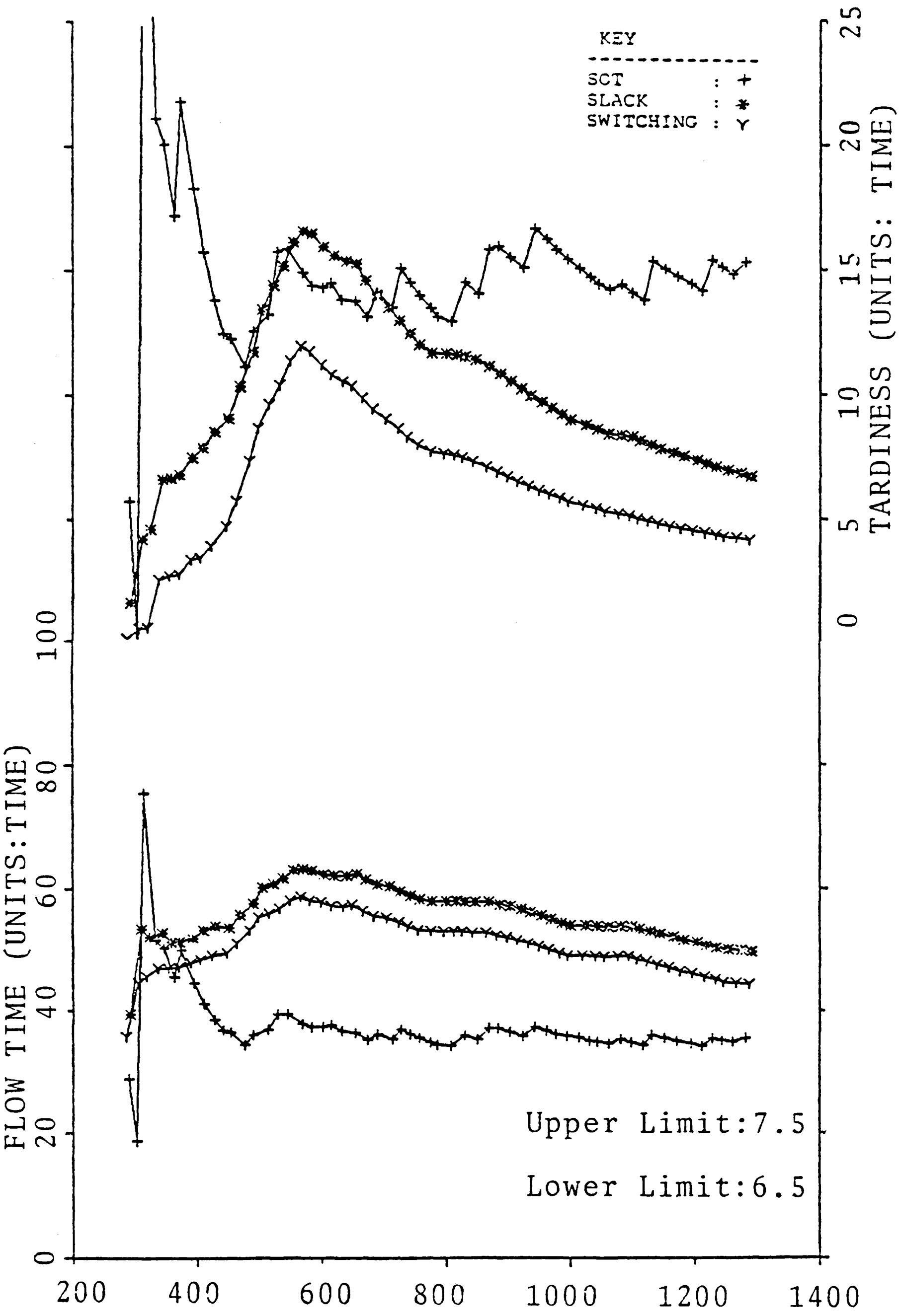


Figure No 8, Experiment No 3, Flow Time and Tardiness Comparison Rules: SOT, SLACK, and Dynamic Switching (6.5,7.5)

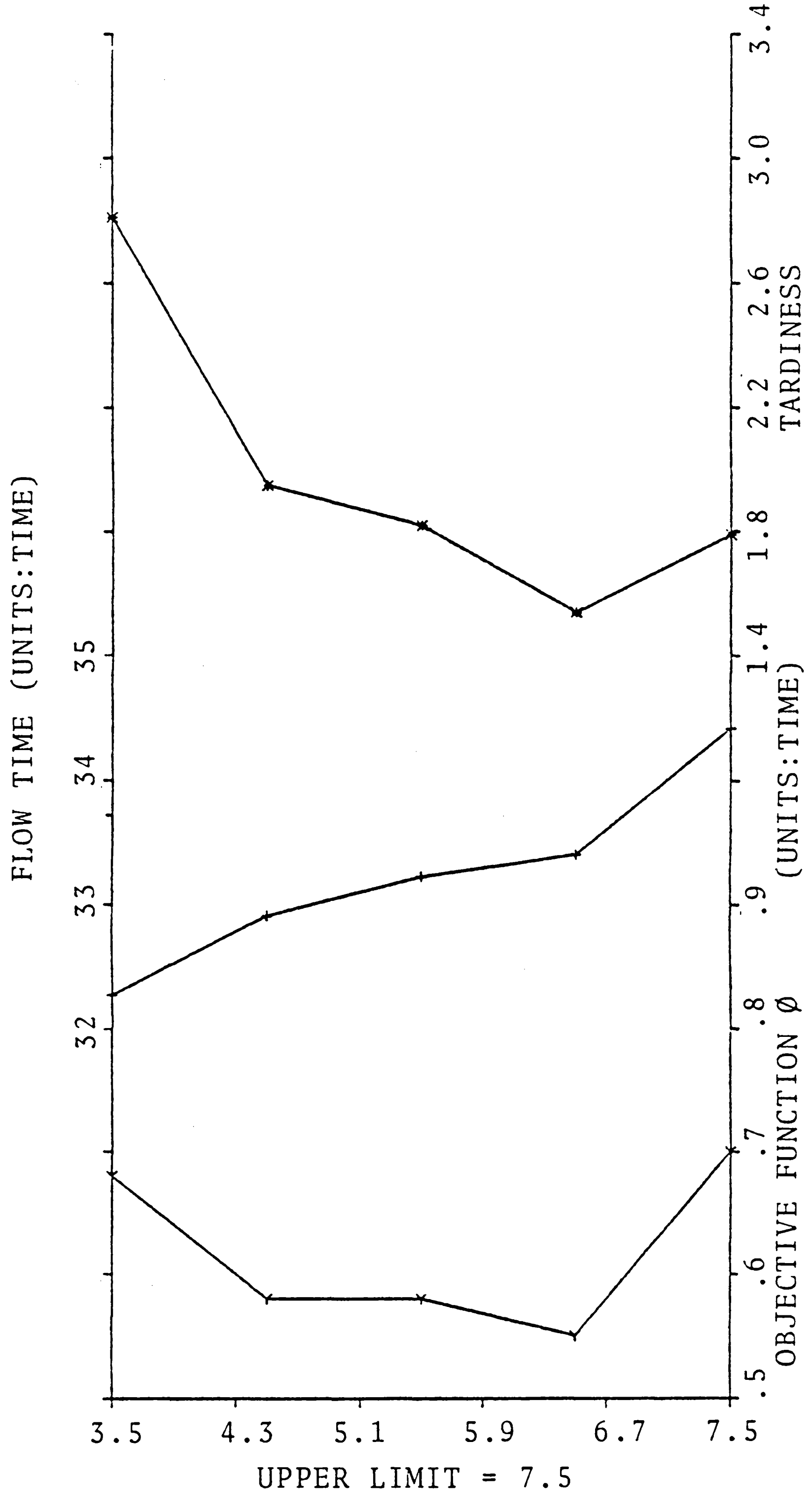


Figure No 9. Experiment No 3, Summary: Flow Time, Tardiness, and Ø (Dynamic Switching)

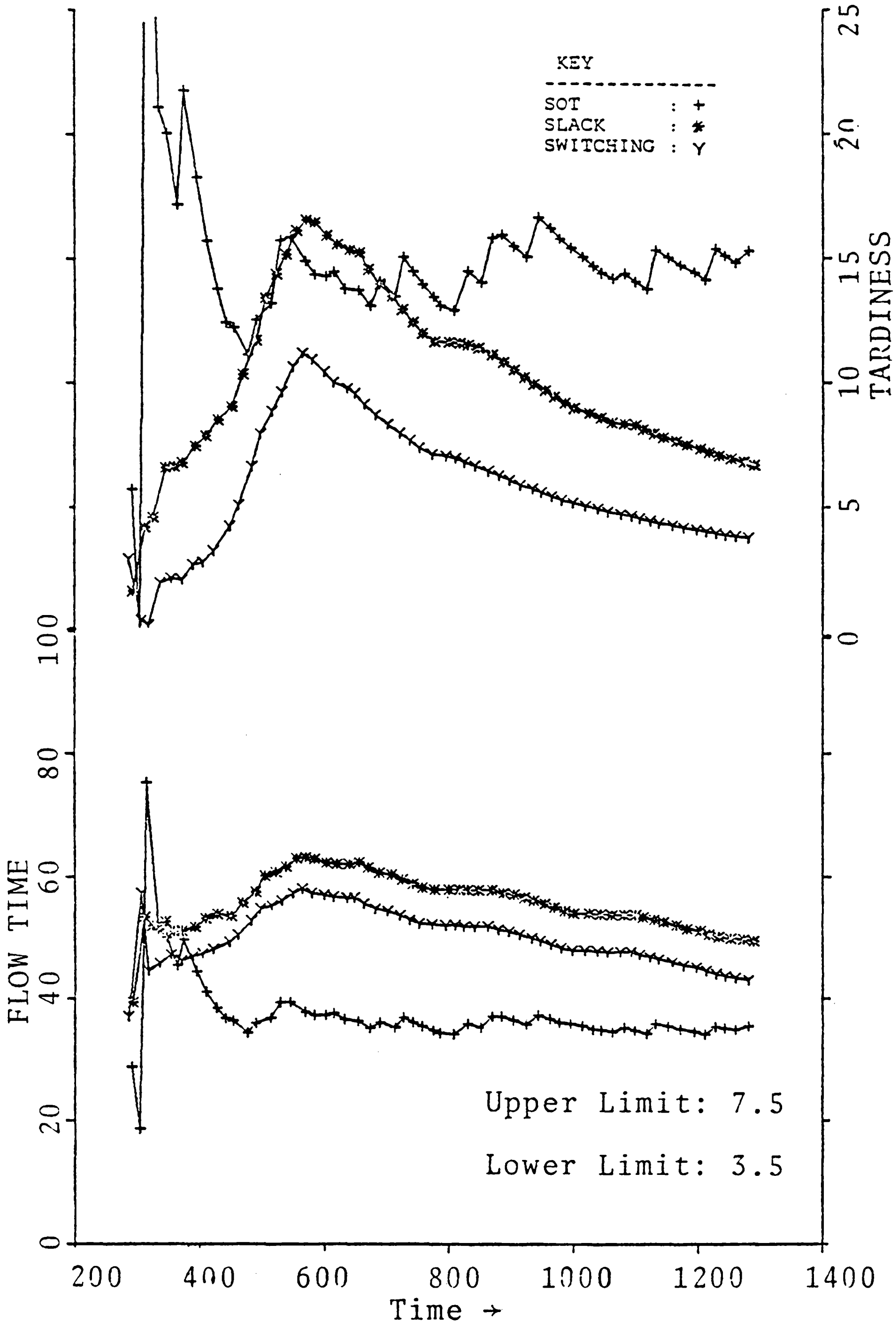


Figure No 10. Experiment No 3: Flow Time and Tardiness

Rules: SOT, SLACK, and Dynamic Switching (3.5, 7.5)

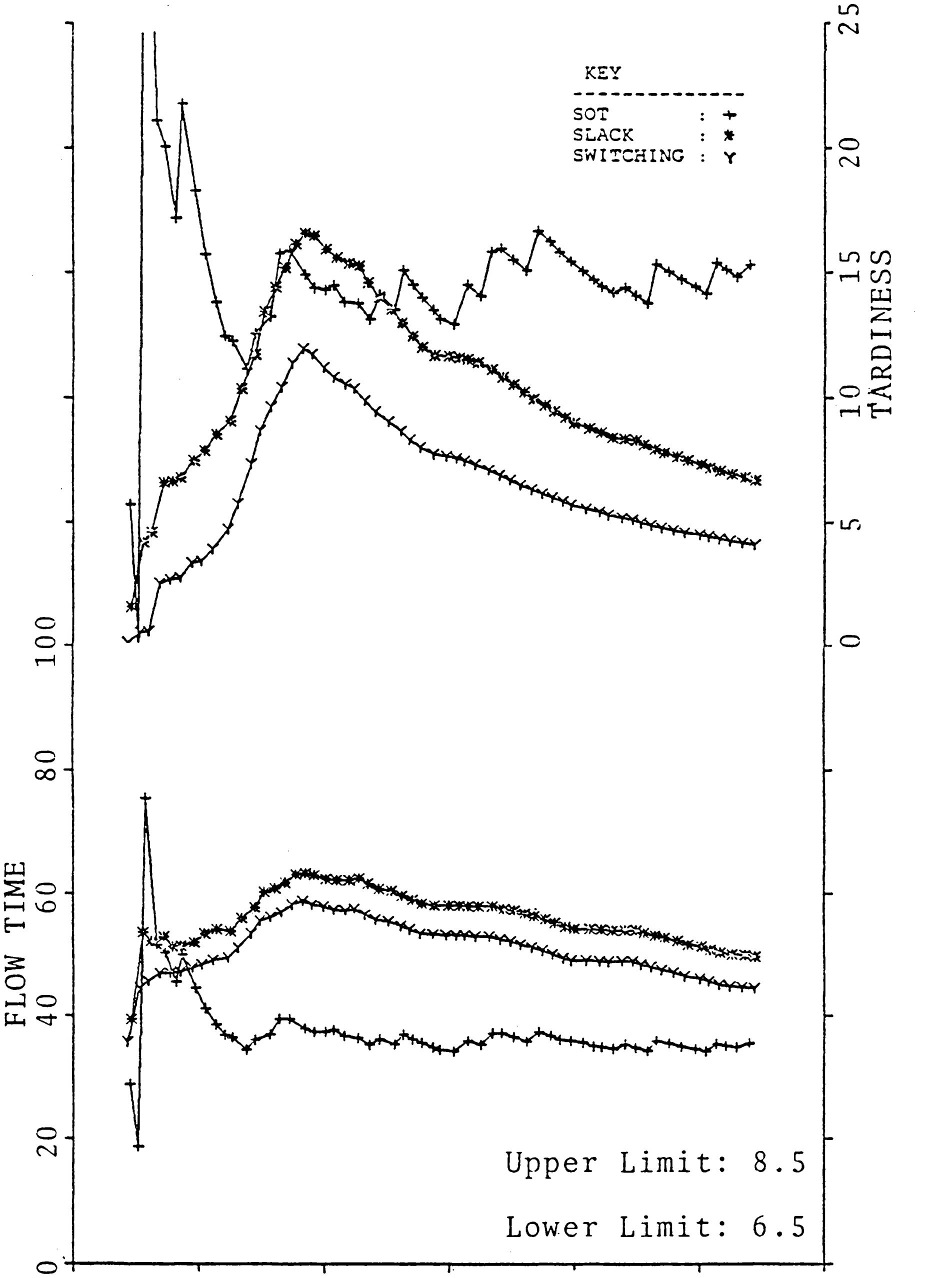


Figure No 11. Experiment No 3, Flow Time and Tardiness

Rules: SOT, SLACK, and Dynamic Switching (6.5, 9.5)

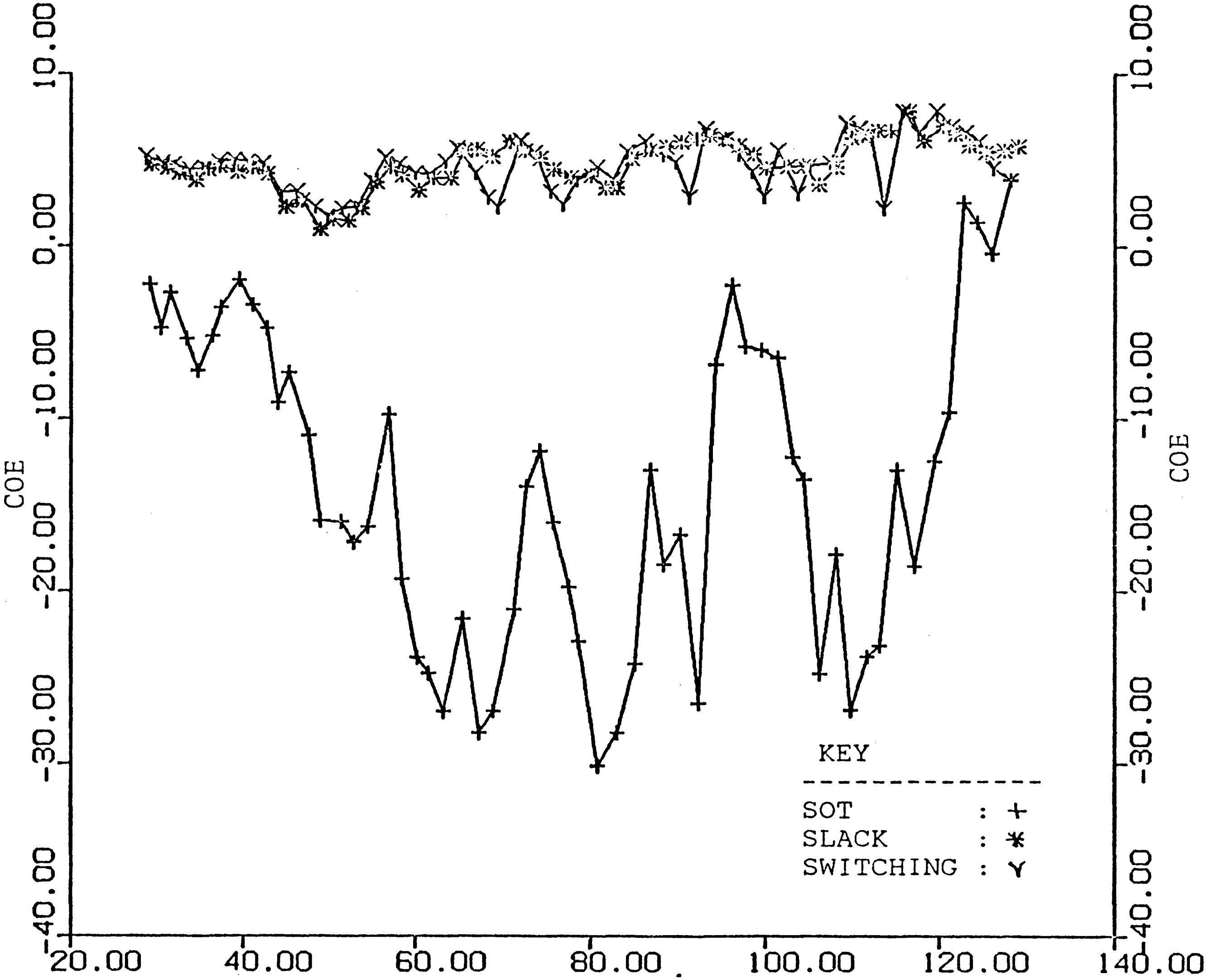


Figure 12: COE Ratio Comparison, SOT, SLACK, and Dynamic Switching

Chapter VI

RESULT ANALYSIS AND CONCLUSIONS

In this chapter, the results of the static and dynamic switching rule procedures are analyzed and discussed. Also, at the end, some recomendations are drawn as a result of this research.

6.1 STATIC EXPERIMENT ANALYSIS

Studying the static experiment results and observing the figures in the previous chapter, the main conclusions derived are:

1. While varying the percentage of SOT and SLACK, flow time and tardiness for the jobs completed showed a negative correlation. This can be observed in Figure 6 and Figure 9. For example, tardiness was 7.58 when using pure SOT and tardiness decreased to 2.56 when using pure SLACK. In other words, tardiness increases while flow time decreases, each time the SOT percentage of utilization increases.
2. Observing the plot in Figure 6 and Figure 9, it is easy to conclude that the flow time and tardiness curves are well represented by linear equations. This is also assured by their respective correlation coeficients.

3. Flow time and tardiness are linear so, Ø that is a linear combination of them is also linear.
4. The amount of switching increases the linearity of flow time and tardiness as it can be observed comparing Figure 5 and 7, and their respective correlation coeficients.
5. The performance measure Ø neither increases nor decreases when using the static switching procedure. This result is produced considering a tardiness weighting factor of 1.9 times the flow time. Therefore, an increase of the weighting factor will force the scheduler to use SLACK and a reduction of the weighting factor to use SOT.

The results were very much unexpected because a linear behavior, between and for flow time and tardiness, was never thought to exist. Therefore, there is no minimun value for the objective function, instead, the trade off between SOT and SLACK create an indifferent linear curve. The equation obtained for the experiment number one and two are the following:

$$\emptyset = \frac{(F-26.09)}{9.92} + \frac{(T-2.57)}{6.92}$$

$$\emptyset = \frac{(F-27.14)}{9.14} + \frac{(T-2.15)}{5.85}$$

6.2 DYNAMIC EXPERIMENT RESULT ANALYSIS

The dynamic switching procedure determined a much better result, in comparison with the previous methodology. The objective function went down from Ø = 1. to Ø = .55 (Figure 9). This means that the method captured part of the best characteristics of each individual pure rule. Figure 10 and Figure 11 show clearly that the tardiness of the dynamic switching procedure should be better than the tardiness produced either by the pure SOT or by the pure SLACK. In addition to the conclusion just presented, there are three other conclusions to consider:

1. Using the dynamic switching procedure, it was possible to have some type of control over the individual components of Ø. It is known that SLACK tends to finish all the jobs on time (regardless of their processing times), a fact that is reflected in an increase in the COE value. This factor alone permits one to reduce the tardiness in the Ø. That specific situation happens when the upper bound for the SLACK rule is reduced. On the other hand, SOT normally decreases the value of COE. Therefore, if the lower bound for SOT is decreased, the flow time improves.
2. There is a very strong indication that as COE increases the flow time value increases and tardiness

decreases. The opposite happens when COE decreases. This result can be observed, particularly in Figure 12.

3. The upper bound for SLACK, or the lower bound for SOT, produce a corrective effect over flow time or tardiness until some specific point beyond which there is no effect. This effect, on the tardiness measure, could be observed comparing Figure 8 and Figure 10.

The latter premise is due to the intrinsic characteristic of the shop and the due date assignment. Particularly, in this reasearch the COE value rarely went over ten.

As an illustrative example, Figure 8 and Figure 11 show the effect of the moving up and down of the upper bound.

The same is illustrated by Figure 8 and Figure 10, but showing the effect of moving up or down of the lower bound.

Even though, it may be true that the switching procedure gives some control over the flow time and tardiness values, the relation for the flow time and tardiness trade-off is not clear, up to now.

6.3 GENERAL CONCLUSIONS

The static and dynamic switching approaches gave two clear and distinct results. Also, both methodologies are very easy and inexpensive to apply when computer time is considered.

The static case only establishes the next new event that will point the time position for the switching of the sequencing rule being applied. The dynamic case needs to add the processing time to the WKR variable and its slack time to the ALL variable whenever a job arrives to the system, and to substract the elapsed time whenever a new event happens.

Referring back to the lower and upper bound determinations, it could be said that the most practical solution is to plot the variables involved in the switching procedure. Next, it is necessary to look for those values representing a very stable zone. Finally, they should be reinforced by simulations runs.

6.4 ISS, IS-DSS AND AUTOMATIC SYSTEM IMPLICATIONS

The static case gives an alternative to the scheduler that produces indifferent results. This allows the scheduler to use a percentage of one sequencing rule over time that will generate a good mean flow time, but a poor tardiness, which may be required by his needs. The converse could also be applied.

Also, if a specific trade-off is required (for example in a DSS-IS), this methodology could give some known solutions. This is due to the fact that the trade-off between SOT and SLACK is known to be linear.

The impact for the automatic case is also important, because once the behavior and the flow time and tardiness values for the individual pure rules in the shop are known it will be easy to look for the required values using the regression line associated with them.

For the dynamic case, the upper and lower limit will tell the scheduler that the trend of the control measure is going out of the required specifications. So, the scheduler can resort to some alternative complementary rule according to his wishes. This means that the ISS actually will have a way of interrupting the run of the program and asking for an intelligent decision from the scheduler.

The use of the dynamic switching procedure in a DSS-IS does not seem to be reasonable yet. First,more research is necessary to get the adecuate insight for the unknown behaviour and the trade off of the rules to be applied.

For the automatic case, this procedure will permit to minimize the proposed 0., while balancing the processing times of the jobs within the system.

6.5 AREAS FOR FURTHER RESEARCH

There are clear points that could be further investigated.

- Identification of other complementary rules with respect to SOT and SLACK. These goals can also be broader and could be studied as a way of classifying the complementary rule for many other rules. Not only SOT and SLACK.
- The use of the switching procedures in IS and DSS-IS.
- The integration of a lower bound for the SLACK rule.
- The relation between the shop load and the lower bound for the SOT rule.
- The use of a dynamic switching procedure including dynamic lower and upper bound, related with the shop load.

Finally, it would be usefull to study other different static and dynamic switching procedures and find other practical methodologies for real applications. This will also create a better background for further implementation of DSS-IS systems.

Appendix A

MEAN OPERATION TIMES AND SHOP LOAD CALCULATION

job type	exp.ope.time	(Pi*) fra.
1	6.00	1/6
2	10.00	1/6
3	6.50	1/6
4	8.00	1/6
5	5.50	1/6
6	7.50	1/6
	43.50	(P**)

The expected Work Content is,

$$WK = fr*Pi*=7.17$$

where:

X%	O
.80	1.79

Appendix B

JOB ROUTINGS

job type	routing
1	4-->2-->5
2	1-->2-->4-->3
3	3-->2
4	4-->2-->1
5	1-->4-->5
6	3-->1-->2--5

Job Type	Machine Number 1	2	3	4	5	Tot.Op. per job
1		x		x	x	3
2	x	x	x	x		4
3		x	x			2
4	x	x		x		3
5	x			x	x	3
6	x	x	x		x	4
Tot.Num. job/Mch.	4	5	3	4	3	5

Appendix C

SOT AND SLACK SIGNIFICANCE TEST, T TEST

A t-Test could be applied assuming that the mean flow times are normally distributed. The degree of freedom is given by $n_1 + n_2 - 2$ (Five replication each). First, the significance of the difference between the means produced by the SOT and SLACK sequencing rules alone were tested.

SOT: $F = 26.30$ $s_F = 5.59$
SLACK: $F = 36.49$ $s_F = 8.06$

Question: Is the difference between the mean flow times of these two sequencing rules significant at the .05 level of significance?

The statistic will be:

$$t_c = \frac{(F_{SOT} - F_{SLACK}) - (s(F_{SOT}) - s(F_{SLACK})}{s(F_{SOT} - F_{SLACK})}$$

Where:

s_Y is the variance of Y.

The hypotheses are:

H_o : $F_{SOT} - F_{SLACK} = 0$
H_1 : $F_{SOT} - F_{SLACK} > 0$

The calculation of t_c gives 2.32

Now, $t_{8,.95} = 1.86$ and $t_{8,.975} = 2.31$

Therefore, the decision is: reject Ho if $t_c > 1.86$

Since $t_c = 2.32 > 1.86$, H_1 is accepted and it is concluded that the difference between the means of the two sequencing rules is significant. The test is significant at the .025 level of significance.

Secondly and following the same steps, the t-test is performed for tardiness $_T$ using:

SOT: $T = 7.58$ $s_T = 4.60$
SLACK: $T = 2.31$ $s_T = 2.58$

Question: Is the difference between the mean tardiness of these two sequencing rules significant at the .05 level of significance?

The hypotheses are:

H_o : $T_{SLACK} - T_{SOT} = 0$
H_1 : $T_{SLACK} - T_{SOT} > 0$

The calculation of t_c gives 2.23
As before, $t_{8,.95} = 1.86$

Therefore, H_o is rejected and H_1 is accepted at the .05 level of significance.

Appendix D

REPLICATIONS: EXPERIMENT 1, FLOW TIME AND TARDINESS

Static Switching: Experiment 1.

%SLACK			Flow Times				Sta.	
(1-X)	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi	O
100.	34.25	38.51	29.39	30.84	49.46	36.49	8.06	1.00
90.	31.88	38.06	28.13	29.57	48.78	35.28	8.44	.98
80.	30.83	38.09	23.65	27.81	47.55	33.59	9.42	.93
70.	30.70	37.49	23.61	27.54	47.41	33.34	9.36	1.15
60.	25.09	36.55	23.75	27.54	45.68	31.72	9.26	1.14
50.	23.10	34.30	22.49	27.38	44.28	30.31	9.12	1.14
40.	23.35	33.29	22.91	27.29	43.39	30.05	7.64	1.32
30.	21.83	31.22	22.39	26.55	42.77	28.95	8.60	1.38
20.	21.06	30.06	22.61	25.21	40.24	27.84	7.73	1.38
10.	20.83	30.01	22.84	24.64	39.91	27.65	7.66	1.37
0.	20.83	27.78	22.85	24.84	35.19	26.30	5.59	1.00

%SLACK			Tardiness				Sta
(1-X)	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi
100.	1.69	2.45	.10	.68	6.64	2.31	2.58
90.	1.79	2.56	.98	2.03	6.97	2.85	2.33
80.	3.31	2.64	.47	2.85	7.86	3.43	2.71
70.	6.27	3.24	.57	3.10	10.43	4.72	3.78
60.	4.21	6.09	2.27	3.10	11.90	5.51	3.85
50.	3.71	7.23	2.79	3.24	14.32	6.26	4.84
40.	4.21	8.55	3.28	3.93	16.65	7.32	6.00
30.	3.58	9.39	3.41	5.67	19.02	8.21	6.50
20.	3.95	10.18	3.67	6.59	19.55	8.79	6.56
10.	3.88	10.51	3.94	6.68	19.09	8.82	6.35
0.	3.88	8.17	3.94	6.78	15.11	7.58	4.60

Appendix E

REPLICATIONS: EXPERIMENT 2, FLOW TIME AND TARDINESS

Static Switching: Experiment 2.

%SLACK			Flow Times				Sta.	
(1-X)	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi	ø
100.	34.25	38.51	29.39	30.84	49.46	36.49	8.06	1.00
90.	33.31	37.81	28.77	30.72	46.26	35.39	6.97	.91
80.	33.12	36.15	29.50	29.96	47.50	35.25	7.36	1.10
70.	30.06	36.81	29.25	29.11	43.98	33.84	6.51	1.01
60.	29.70	37.07	28.44	29.33	41.95	33.30	5.95	1.10
50.	28.87	34.36	28.12	28.47	40.81	32.13	5.49	1.10
40.	27.83	33.36	28.11	27.51	39.17	31.20	5.07	1.16
30.	26.69	32.78	26.25	26.77	38.62	30.22	5.41	1.15
20.	25.87	31.60	26.70	25.56	36.59	29.26	4.77	1.15
10.	25.03	29.70	25.57	24.77	36.81	28.38	5.12	1.22
0.	20.83	27.78	22.85	24.84	35.19	26.30	5.59	1.00

%SLACK			Tardiness				Sta.
(1-X)	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi
100.	1.69	2.45	.10	.68	6.64	2.31	2.58
90.	1.83	2.69	.22	1.20	6.24	2.39	2.31
80.	3.21	2.87	.82	1.88	8.68	3.49	3.05
70.	2.78	4.00	1.34	2.21	8.20	3.71	2.69
60.	2.99	5.24	1.89	3.40	8.88	4.48	2.74
50.	3.69	4.78	2.69	4.31	9.87	5.07	2.80
40.	4.56	5.93	4.01	4.61	10.23	5.87	2.54
30.	4.69	6.92	3.87	5.40	10.87	6.35	2.76
20.	5.68	7.25	4.28	5.50	11.99	6.94	3.01
10.	5.91	8.29	4.70	5.50	13.80	7.64	3.69
0.	3.88	8.17	3.94	6.78	15.11	7.58	4.60

Appendix F

REPLICATIONS: EXPERIMENT 3, FLOW TIME AND TARDINESS

Dynamic Switching: Experiment 3.

U.B=7.5			Flow Times				Sta.	
L.B	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi	Ø
3.5	27.52	33.74	28.90	28.58	42.62	32.27	6.26	.68
4.5	27.85	34.74	29.02	29.31	43.63	32.91	6.56	.58
5.5	27.98	35.75	29.45	29.34	46.63	33.23	6.55	.58
6.5	28.80	35.61	29.41	29.51	43.74	33.41	6.40	.55
7.5	29.30	35.29	29.64	29.66	48.23	34.42	8.11	.70

U.B=7.5			Tardiness				Sta.
L.B	Seed1	Seed2	Seed3	Seed4	Seed5	Mean	Devi
3.5	2.12	3.41	1.88	2.72	3.91	2.80	.85
4.5	1.59	2.28	.72	.97	4.17	1.94	1.38
5.5	1.40	2.18	.54	.90	4.06	1.82	1.40
6.5	.79	1.85	.33	.75	4.00	1.54	1.48
7.5	.59	1.71	.09	.59	5.96	1.79	2.41

Appendix G

SUMMARY: EXPERIMENT 1, FLOW TIME AND TARDINESS

Static Switching: Experiment 1.

%SLACK	Measures		
(1-X)	Flow time	Tardiness	Ø
100.	36.49	2.31	1.00
90.	35.28	2.85	.98
80.	33.59	3.43	.93
70.	33.34	4.72	1.14
60.	31.72	5.51	1.14
50.	30.31	6.26	1.14
40.	30.05	7.32	1.32
30.	28.95	8.21	1.38
20.	27.84	8.79	1.38
10.	27.65	8.82	1.37
0.	26.30	7.58	1.00

Appendix H

SUMMARY: EXPERIMENT 2, F, AND T

Static Switching: Experiment 2.

%SLACK	Measures		
(1-X)	Flow time	Tardiness	Ø
100.	36.49	2.31	1.00
90.	35.39	2.39	.91
80.	35.25	3.49	1.10
70.	33.84	3.71	1.01
60.	33.30	4.48	1.10
50.	32.13	5.05	1.09
40.	31.20	5.87	1.16
30.	30.22	6.35	1.15
20.	29.26	6.94	1.17
10.	28.38	7.64	1.21
0.	26.30	7.58	1.00

Appendix I

EXPERIMENT 3, DYNAMIC SWITCHING

Dynamic Switching: Experiment 3. Upper Bound : 7.5

Lower	Measures		
Bound	Flow Time	Tardiness	Ø
3.5	32.27	2.81	.68
4.5	32.91	1.95	.58
5.5	33.23	1.82	.58
6.5	33.41	1.54	.55
7.5	34.42	1.79	.70

Appendix J

SOT, SLACK AND DYNAMIC SWITCHING SIGNIFICANCE T-TEST

A t-Test could be applied assuming that the objective function values ($\emptyset$) are normally distributed. The degree of freedom is given by $n_1 + n_2 - 2$ (Five replication each).

First, the significance of the difference between the means produced by SOT and dynamic switching sequencing rules were tested.

SOT: $\emptyset = 1.00$ $s_{\emptyset} = 1.41$

Dyn. Swit.: $\emptyset = .55$ $s_{\emptyset} = .90$

Question: Is the difference between the $\emptyset$ of these two sequencing rules significant at the .05 level of significance?

The statistic will be:

$$t_c = \frac{(\emptyset_{SOT} - \emptyset_{Dy.Sw}) - (s(\emptyset_{SOT}) - s(\emptyset_{Dy.Sw})}{s(\emptyset_{SOT} - \emptyset_{Dy.Sw})}$$

Where:

s_Y is the variance of Y.

The hypotheses are:

H_o : $\emptyset_{SOT} - \emptyset_{Dy.Sw} = 0$

H_1 : $\emptyset_{SOT} - \emptyset_{Dy.Sw} > 0$

The calculation of t_c gives 0.60

Now, $t_{8,.95} = 1.86$ and $t_{8,.975} = 2.31$

Therefore, the decision is: reject Ho if $t_c > 1.86$

Since $t_c = 0.60 < 1.86$, H_0 is accepted and it is concluded that the difference between the means of the two sequencing rules is not significant.

Second, the same steps are followed to test the significance of the difference between the ϕ means produced by SLACK and Dynamic Switching:

SLACK: $\phi = 1.00$ $s_{\phi} = 1.27$
Dy.Sw: $\phi = .55$ $s_{\phi} = .90$

Question: Is the difference between the mean 0 of these two sequencing rules significant at the .05 level of significance?

The hypotheses are:

H_o : $\phi_{Dy.Sw} - \phi_{SOT} = 0$
H_1 : $\phi_{Dy.Sw} - \phi_{SOT} > 0$

The calculation of t_c gives .71
As before, $t_{8,.95} = 1.86$

Therefore, H_0 is accepted and the differences are not significant.

BIBLIOGRAPHY

1. Alter, S., "Why is Man-Computer Interaction Important for Decision Support Systems?", *Interfaces*, Vol. 7,No. 2, February, 1977.

2. Baker, C.T., "A Comparative Study of Flow-shop Algorithms", *Operation Research*, Vol. 23, No. 1, Jan.-Feb., 1975, pp. 62-78.

3. Baker, C.T., "An Elimination Method for the Flow-shop Problem". *Operation Research*, Vol. 23, No 1, Jan.-Feb., 1975, pp. 159-62.

4. Baker, C.T., and Dzielinski, B.P., "Simulation of a Simplified Job Shop", *Management Science*, Vol. 6, 1960.

5. Blackstone J., Phillips D.I., and Heinsterberg R.J., "A State-of-Art Survey on Dispatching Rules for Manufacturing Job Shop Operations", *Report GEMS-4-77 NSF/GRANT*, Apr. 76-22610, Texas A&M Research Project RF-3539, December 1, 1977.

6. Bratley, P., Florian, M., and Robillard, P., "Scheduling with Earliest Start and Due Date Constraints", *Naval Research Logistic Quaterly*, Vol. 18, 1971, pp. 511-17.

7. Burns,F., "Scheduling to Minimize the Weighted Sum of Completion Times with Secondary Criteria", *Naval Research Logistic Quaterly*, Vol. 23, No. 1, March 1976, pp. 125-29.

8. Chan, A.W., and Graefe,P.W.V., "An Interactive Sequencing Aid for Printing Presses", *Computer and Industrial Engineering*, Vol. 3, No. 4, 1979, pp. 321-5.

9. Cliffe, R.W., and Mac Manus, B.R., "An Approach to Optimization With Heuristic Methods of Scheduling", *International Production Research* (*GB*), Vol. 18, No. 4, July-Aug., 1980, pp. 479-90.

10. Conner, J.L., "Interactive Manufacturing Scheduling and Control System", *Proceedings of the APICS International Technical Conference*, October 10-12, 1973, pp. 66-74.

11. Connors, M.M., "Operation Research in a Conversational Environment", AFIPS, Proceedings of the Fall Joint Computer Conference, 1968, pp. 417-24.

12. Conway, R.W., "Priority Dispatching and Job Lateness in a Job Shop", Journal of Industrial Engineering, Vol. 16, 1965.

13. Conway, R.W., "Priority Dispatching and Work-In-Process Inventory in a Job Shop", Journal of Industrial Engineering, Vol. 16, 1965.

14. Conway, R.W. and Maxwell, W.L. "Network Dispatching by Shortest Operation Discipline", Operation Research, Vol. 10, (1962).

15. Conway, R.W.,Maxwell, W.L., and Miller,L.W., Theory of Scheduling, Addison-Wesley Publishing Company, 1967.

16. Day,J.E., and Hottenstein,M.P. "Review of Sequencing Research", Naval Research Logistics Quarterly, Vol. 17, 1970.

17. Eilon, S., and Cotterill, D.J., "A Modified SI Rule in Job Shop Sequencing", International Journal of Production Research, Vol. 7, 1968.

18. Eilon, S., and Chowdhury, I.G., "Due Dates in Job Shop Scheduling", International Journal Production Research. Vol. 14, No. 2, 1976, pp. 223-237.

19. Elmaghraby,S.E., "The Sequencing of Related Jobs", Naval Research Logistics Quaterly, Vol. 15, Mar. 1968, pp. 23-32.

20. Elvers, D.E., "The Sensitivity of the Relative Effectiveness of Job Shop Dispatching Rules with respect to Various Arrival Distributions", AIIE Transactions, Vol. 6, 1974.

21. Gere, W.S.Jr., "Heuristics in Job Shop Scheduling", Management Science, Vol. 13, 1966.

22. Giffler,B., "Detail Scheduling Models and Systems", 86th Symposium on the Theory of Scheduling and Its Applications, Edited by M.Bechman, Providence, G.Goos, Karlsruke, and H.P. Kunzi, Zurich 1973.

23. Godin,V.B., "Interactive Scheduling:Historical Survey and State of the Art", *AIIE Transactions*, Vol. 10, No. 3, Sept. 1978, pp. 331-7.

24. Gupta, J.N.D., "Analysis of a Combinatorial Approach for Flow Shop Scheduling Problems", *Operation Research Quaterly* (*GBS*), Vol. 26, No. 2, July 1975, pp. 431-40.

25. Haider, S.W., Buck, J.R., and Moodie, C.L., "Man Computer versus Automatic Scheduling", *Proceedings of the Human Factors Society 21st*, Santa Monica, California, USA: Human Factors Society, Oct, 17-20, 1977, p. 100-4.

26. Haider, S.W.,Moodie, and Colin L., "An Investigation of the Use of an Interactive Computer Model for Balancing Paced Assembly Lines", *Computer and Industrial Engineering*, Vol. 2, 1978, pp.83-89.

27. Hershauer, J.C., and Ebert, J., "Search and Simulation Selection of a Job Shop Scheduling Rule", *Management Science*, Vol. 21, No. 7, March 1974, pp. 833-43.

28. Hurrion, R.D., "An Investigation of Visual Interactive Simulation Methods Using the Job-Shop Scheduling Problem", *Journal of Operation Research Society* (*G*.*B*.), Vol. XXIX, No. 11, November 1978, pp. 1085-1093.

29. Hurrion, R.D., "Visual Interactive (Computer) Solutions for the Travelling Salesman Problem", *Journal of Operation Research Society* (*G*.*B*.), Vol. XXXI, Perg. Press, 1980, pp. 537-539.

30. Jackson, J.R.,"Networks of Waiting Lines", *Operation Research*, Vol. 5, August 1967.

31. Jain, Suresh K., "A Simulation-Based Scheduling and Management Information System for a Machine Shop", *Interfaces*, Vol. 6, No. 1, Part 2, November 1975, pp. 81-96.

32. Keen,P.G., and Wagner,G.R., "DSS: An Executive Mind-Support System", *Datamation*, Nov. 1979, pp. 117-122.

33. Lageweg,B.J., Lenstra,J.K., and Rinnooy Kan,H.G., "Job-Shop Scheduling by Implicit Enumeration", *Management Science*, Vol. 24, No. 4, Dec., 1977, pp. 441-450.

34. Lambrecht, M.R., and Vandervehen H., "Production Scheduling and Sequencing for Multi-stage Production Systems", ORSpektrum (Ger), Vol. 1, No. 2, 1979, pp. 103-14.

35. Lankford, R.L.,"Scheduling the Job-Shop", APICS 1973, Conference Proceedings, 1973, pp. 46.

36. Licklider,J.C.R., "Man Computer Symbiosis", IRE Transactions in Human Factors in Electronics HFE-I,1,4-11 March 1960.

37. Mc Mahon, F., "On Scheduling with Ready Times and Due Dates to Minimize Maximun Lateness", Operation Research, Vol. 23, pp. 475-482.

38. Moore,J.H., and Chang,M.G., "Design of Decision Support Systems", Data Base, Vol. 1, No. 45, Sep/Nov. 1980.

39. Oral,M., and Malouin,J.L., "Evaluation of the Shortest Processing Time Scheduling Rule With Truncation Process", AIIE Transaction, Vol. 31, 1973.

40. Panwalkar, S.S., "An Improved Branch and Bound Procedure for n x m Flow Shop Problems", Naval Research Logistic Quarterly (USA), Vol.22, No.4, Dec., 1975, pp. 787-90.

41. Panwalkar, S.S. and Iskander, W. "A Survey of Scheduling Rules", Operations Research, Vol. 25, 1977.

42. Phillips, D.T., Handwerker,M., Hogg, G.L.,"GEMS: A Generalized Manufacturing Simulator", Computer and Industrial Engineering (G.B.), Vol. 3, No. 3, 1979, pp. 225-233.

43. Potts, C.N., "Analysis of A Heuristic for One Machine Sequencing with Release Dates and Delivery Times", Operation Research (USA), Vol. 28, No. 6, Nov-Dec. 1980, pp. 1436-41.

44. Pristker, A.B., Miller, L.W., and Zinkl, R.J., "Sequencing n Products Involving m Independent Jobs on m Machines", AIIE Transactions, Vol. 3, No. 1, March 1971, pp. 49-60.

45. Rochette, R., and Sadowski, R.P., "A Statistical Comparison of the Perfomance of Simple Dispatching Rules for a Particular Set of Job Shops", International Journal of Production Research, Vol. 14, Jan. 1976, pp. 63-75.

46. Rogers, S., Griffin, T., Ganote, D., and Davis, B., " Ongoing, Online Production Simulation", AIIE, Proceeding 1980 Spring Annual Conference, pp. 479-486.

47. Sanderson, I.W.,"An Interactive Production Planning System in the Chemical Industry", Journal of Operation Research Society, Vol. 29, Pergamon Press 1978 (G.B.), pp. 731-739.

48. Sartaj, S., "Preemptive Scheduling with Due Dates", Operation Research (USA), Vol. 27, No. 5, Sep./Dec., 1979, pp. 925-34.

49. Schuermann, C.A., Ellyson, L.E.," Automated Barchart Construction", Computer and Industrial Engineering, Vol. 1, Pergamon Press (G.B.), 1976, pp. 27-34.

50. Secker, R.J.R.,"Visual Interactive Simulation Using A Minicomputer", Journal of Operation Research Society, Vol. 30, Pergamon Press Ltd. 1979, (G.B.), pp. 379-381.

51. Shannon, R.E., "Simulation: A Survey with Research Suggestions", AIIE Transactions, Vol. 7, 1975.

52. Spearman, Mark L., "Dynamic Interactive System Simulation: An Inexpensive Approach to Solving Logistics Problems", Proceeding 1980 Spring Annual Conference.

53. Smith, L. Douglas, "The Application of an Interactive Algorithm to Develop Cyclical Rotational Schedules for Nursing Personnel", INFOR, Vol. 14, No.1, February 1976.

54. Smith, W.E., "Various Optimizers for Single-Stage Production", Naval Research Logistics Quaterly, Vol. 3, 1956, pp. 59-66.

55. Vazsonyi, Andrew., "Decision Support System: The New Technology of Decision Making", Interfaces, Vol. 9, No.1, November 1978.

56. Wiest,J.D., "Toward a Man-Machine Interactive System for Project Scheduling", *86th Symposium on the Theory of Scheduling and its Applications*, Edited by M.Bechman, Providence, G.Goos, Karlsruke, and H.P. Kunzi, Zurich 1973.

57. Yamamoto M., "An Approximate Solution of Machine Scheduling Problems by Decomposition Method", *International Journal of Production Research* (*GB*), Vol. 15, No. 6, Nov., 1977, pp. 599-608.

REFERENCES

1. Baker, C.T., "Sequencing with Due-Dates and Early Start Times to Minimize Maximum Tardiness", Naval Research Logistic Quarterly, Vol. 21, pp. 171-176.

2. Bratley, F., "Scheduling With Earliest Start and Due Date Constraints on Multiple Machines". Naval Research Logistic Quaterly, (USA) Vol. 22, No. 1, March 1975, pp. 165-73.

3. Crawley,J.E., "Simulation Studies of Interface Design, Interfaces with the Process Control Computer", IFAC Proceedings August 1971, Published by The International Federation of Automatic Control, Distributed by The Instrument Society of America, Pittsburg, 1971, pp. 129-137.

4. Dannenbring, D.G., "An Evaluation of Flow Shop Sequencing Heuristics", Management Science, Vol. 23, No 11, July 77, pp. 1174-82.

5. Deane, R.H., and Modie, C.L. "A Dispatching Methodology for Balancing Workload Assignments in a Job Shop Production Facility", AIIE Transactions, Vol. 4, 1972.

6. Eilon, S., and Hodgson, R.M., "Job Shops Scheduling with Due-Dates", International Journal Production Research, Vol. 6, No. 1, 1967, pp. 1-13.

7. Emmous, H., "One Machine Sequencing to Minimize Mean Flow Time with Minimun Number Tardy", Naval Research Logistics Quaterly, Vol. 22, No. 3, Sept., 1968, pp. 585-592.

8. Erschler, J., Roubellat, F., and Veruhes, J.P., "A Decision-making Process for the Real Time Control of a Production Unit", International Journal Production Research, (GB) Vol. 14, No. 2, July 1976, pp. 275-284.

9. Ferguson, R.L., Curtis, H.J., " A Computer Aided Decision System", Management Science, Vol. 15,No 10, June 1969, pp. 550-561.

10. Garey, M.R., "Performance Guarantees for Scheduling Algorithms", Operation Research, Vol. 26, pp. 3-21.

11. Godin, V.B., "The Interactive Shop Supervisor", Industrial Engineering, Vol. I, November 1969, pp.16-22.

12. Gupta, D., "Optimality Criteria for Flow-Shop Schedules", AIIE Transactions, Vol. 3, No 3., Sept. 1971, pp.199-205.

13. Gustafson, C.E., "Computer Assisted Interactive Resource Scheduling System", NASA Special Publication 326, November 7-8, 1972, pp. 143-146.

14. Hodgson, T.J., "On-line Scheduling in the Production Environment. I. An 'unsuccessfull' case history", Interfaces, Vol. X, No. 1, February 1980, pp. 77-80.

15. Hodgson, T.J., "On-line Scheduling in the Production Environment. II. A 'successful' case history", Interfaces, Vol. X, No. 2, April 1980.

16. House,W.C.,Editor "Interactive Decision Oriented Data Base Systems", Petrocelli/Chapter. New York 1977.

17. Jones, C.H., "A Comparative Study of Decision-Making from Computer Terminals", AFIPS Proceedings of the Spring Joint Computer Conference, 1970, pp. 559-605.

18. King, J.R. and Spachis, A.S. "Heuristics for Flow-Shop Scheduling", International Production Research, Vol. 18, No. 3, May-June 1980, pp. 345-352.

19. King, J.R. and Spachis, A.S. "Improving Computational Efficiency in Tree Search Methods for Scheduling: A Statistical Approach", Omega, Vol. 8, No. 6, Nov. 1980, pp. 655-660.

20. Lenstra, J.K., "Job-shop Scheduling by Implicit Enumeration", Management Science, Vol. 24, No.7 , Dec. 77, pp. 441-450.

21. Nelson, R.T., "Centralized Scheduling and Priority Implementation Heuristies for a Dynamic Job Shop Model", AIIE Transactions, Vol. 9, No. 1, March 1977, pp 95-102.

22. Nicholson, T.A.J., Pallen, R.D., "A Computer Terminal System for Managing Schedules Orders Through Plants, In Decision Design and the Computer", Institution of Chemical Engineers Symposium Series No. 35, ISBN 85295076 4, London: Institution of Chemical Engineers, 1972.

23. Panwalkar,S.S., Dudek,R.A., and Smith,M.L., "Sequencing Research and the Industrial Schedulin Problem", 86th Symposium on the Theory of Scheduling and its Applications, Edited by M.Bechman, Providence, G.Goos, Karlsruke, and H.P. Kunzi, Zurich 1973.

24. Sambadam, N., "Four Simple Heuristies for Scheduling a Flow Shop", International Journal of Production Research (GB), Vol. 16, No. 3, May 1978, pp. 221-231.

25. Smith, H.T., Crabtree, R.G., "Interactive Planning: A Study of Computer Aiding in the Execution of a Simulated Scheduling Task", International Journal of Man-Machine Studies, Vol. 7, 1975, pp. 213-271.

26. Smith, A.W., and Stafford, E.F.Jr., "A Comparison of Multiple Criteria Solutions of a Large-scale Flow Shop Scheduling Problems". Operation Research (USA), Vol. 28, No. 6, Nov-Dec. 1980, pp. 1436-1441.

27. Weeks, J.J., "A Simulation Study of Predictable Due-Dates", Management Science, Vol. 25, No. 4, April 1979, pp. 363-373.

28. Wilkerson, L.J., and Irwin, J.D., "An Improved Algorithm for Scheduling Independent Tasks", AIIE Transactions, Vol. 3, 1971.

29. Worrall B.M., and Mert B., "Application of Dynamic Scheduling Rules in Maintenance Planning and Scheduling", International Journal of Production Research, Vol. 18, No. 1, Jan-Feb. 1980, pp.57-71.

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APPLICATION OF TWO COMPLEMENTARY SEQUENCING RULES TO CONTROL THE JOB SHOP BY SWITCHING

by

RUBEN B. TELLEZ

(ABSTRACT)

This research presents two switching techniques using SOT and SLACK, as complementary sequencing rules, to show that they are practical procedures to control a job shop. These two approaches are:

- Static switching of the complementary rules.
- Dynamic switching of the complementary rules.

This study also presents questions which arise in creating different switching rules or procedures for an interactive scheduling system.

It is also developed a normalized objective function to measure the balance of the best properties produced by SOT (low flow time) and SLACK (low tardiness).

It should be noted that even though such a system could be viewed as complex and expensive,it is not. Computational requirement will be sligthly increased, but no more data is required than is expected for a typical scheduling procedure.

Finally, a procedure to calculate the upper and lower limits is presented for dynamic switching procedures.