DEVELOPMENT OF AN EMPIRICAL MODEL FOR JOBSHOP FLOW TIME AND DUE-DATE PREDICTION

BY

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CERTIFICATION

We, the undersigned hereby certify that this research thesis has been carried out by AKINNULI, OLUFEMI BASIL for the partial fulfillment of the requirements for the award of Master of Engineering (M.Eng.) in Production Engineering, Federal University of Technology, Akure, and to the best of our knowledge that the work has not been submitted elsewhere for the award of a degree.

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DEDICATION

Dedicated to God who filled man with his spirit, wisdom, and in understanding, and in knowledge, and in all manner of workmanship.

Exodus 31:3.

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NOMENCLATURE

SYMBOL	
F_i	Expected flowtime for any randomly selected job
$E(n)$	Expected number of operations in any random job
λY	Arrival rate of jobs to the shop
μ_n	Mean number of operations per job
μ_p	Mean operations processing time
m	Number of machines in the shop
ρ	Steady state shop utilisation
ρ_t	Short term utilisation estimate at a time t
W_t	Work remaining in the shop at time t
J_t	Jobs remaining in the shop at time t
A_t	Allowance remaining for work in the shop at time t
P_{ij}	Processing time for operation j of job i
n_i	Number of operations in job i
a_j	Arrival rate from outside system to facility j
λ_i	Arrival rate from other facilities (other than j) into j
P_{ij}	The transaction probability from facility i to j
W_{ij}	Waiting time of job i on machine j
W_i	The mean of waiting times on individual machines
σ^2	Variance
D_{ij}	Departure time of job i on machine j
ψ_{ij}	In-process delay

DD_i	Due-date
O_i	Arrival date for job i
W_i	Worst scenario waiting time
W_i	Best scenario waiting time
K	Multiple factor = 3 used with Shewart's Control Limits
σ	Standard Deviation
SCON	Static Constant Flowtime
DCON	Dynamic Constant Flowtime
SPPW	Static Processing Plus Waiting Time
DPPW	Dynamic Processing Plus Waiting Time
DFM	Dynamic Forecasting Model
JFM	Job in-system Feedback Model
WFM	Work In-Process Feedback Model
IDD_i	Internal Due Date
XDD_i	External Due Date
SPT	Shortest Processing Time
FCFS	First Come First Served
OLV	Operation Lateness Variance
K_{ppw}	Static "tightness" Parameter
α	Exponential Smoothing Constant
IL_i	Internal Lateness
XL_i	External Lateness

ABSTRACT

A computer software was developed and tested for validation for jobshop flowtime and due date prediction.

The software utilises data from shop floor which are analysed to predict expected waiting time on each individual machine on a periodic bases.

Projection of these waiting times are made for future flow time prediction by using moving averages.

The methodology employed implicitly accommodates job characteristics, shop status, system characteristic as well as delaying factors external to the shop.

This software is capable of prescribing a range of due-dates to reflect the best, most likely and worst case possible scenarios with their times.

When the total theoretical time of a job was 570 minutes, with the arrival date and time 24/08/98 and 8:00 hours respectively the software was able to predict the due-dates for best case scenario, most likely scenario and worst case scenario thus:

Best case Scenario due-date: 24/08/98 Time: 12:08 hours

Most likely Scenario due-date: 25/08/98 Time: 12:08 hours

Worst case Scenario due-date: 26/08/98 Time: 13:08 hours.

This range will greatly assist management in negotiations with prospective customers. Improving performance of job shops and their ability to execute jobs within due-dates.

CHAPTER ONE

INTRODUCTION

The significance of assigning accurate due dates to job in a production system is well recognised by researchers and practising managers. Due to advances in manufacturing systems e.g. Flexible Manufacturing System (FMS), Computer Aided Manufacturing etc (CAM) and introduction of the ideal concept of inventory control system, due dates based research has received considerable attention in the last decade and a wealth of literature has been reported in this area.

Therefore a new job shop's ability to attract new jobs depends in part on its perceived performance in the timely execution of previous jobs awarded to it. This timely execution of jobs is usually assessed through the shop's ability to execute job within due dates which more often than not have been mutually agreed by customers and the shop management.

The due date management problem is of great practical significance to an organisation for many vital planning functions such as planning order release and resource requirement planning. Karmaker (1987) presents a rather extensive discussion of the role of due date assignment in the context of master production scheduling. An industrial survey of U.S companies using FMS indicates that meeting promised delivery dates or due date, is the most desirable objective which, management wants to achieve Smith et al (1986). Completion of jobs ahead of the due date would result in storage costs, on the other hand, if the jobs are complete after due dates there will be tangible (penalty) costs (e.g. electrical work, plant overtime) as well as intangible cost (e.g loss of good will, dwindled customer satisfaction etc). Management therefore desires both predictability (i.e to set due date correctly) and controllability (i.e to meet the set due dates).

In negotiating due dates, the job-shop manager must be in a position to effectively predict the completion time of a new job. This completion is often known as flow time.Flow time depends in large measure on the processing times of the various operations and the delay or waiting times associated with the operations. The delay can be external or internal. External delays arise as a result of factors outside the control of the job-shop.

They include shortage of power supply (electricity) inability to secure raw materials promptly, inadequate finance for working capital, labour problem and other miscellaneous factors arising from the socio-economic environment amongst others. These external delays tend to have limiting effects on the overall capacity utilisation of the job-shop on an aggregate basis. On the other hand, internal delays arise as a result of jobs being executed or waiting to be executed on the machines or other non-machine workstations. The internal delay times are not only dependent on the shop load but also on the scheduling methods adopted by the shop management.

In predicting job-shop flow times, provision must be made for both external and internal delay as well as the particular job's operational characteristics. This study has reviewed previous models for predicting job-shop flow times especially in relation to their applicability in job-shop problems of developing economies. This study has developed a software which accounts for external factors as well as avoiding most of the limiting assumptions and constraints of previous models.

The software also prescribed an effective data-base system through which the present software could be effectively implemented.

After due date assignment,negotiation with customers on the quoted due date is usually necessary. If the quoted due date is accepted, the job is assigned to the production system joining the set of unreleased jobs ready to be scheduled.

CHAPTER TWO

2.00 LITERATURE REVIEW

2.01 DESCRIPTION OF JOB SHOP

Job shop is a process technology suitable for variety of custom-designed products in small volumes. It requires it's own unique set of processing steps, or routing through the production process e.g job done by a printing shop. Each product uses only a small portion of the shop is human resources and general purpose equipment. With large numbers of diverse jobs elaborate job-tracking and control systems are used. Much time is spent waiting for access to equipment, some equipment is overloaded while other equipment is idle, depending upon the mix of jobs at hand.

2.02 FACTORS THAT INFLUENCE DUE-DATE PRODUCTION

In order to align with just in time (JIT) production approach, deviation of job completion times from their due date must be minimized. If the due dates are set internally by the scheduler then the task is to estimate the flow time of each job and to assign its due date exactly equal to its predicted completion time (Conway, et al (1967)). Although Little (1961) has proved that, in a queuing process, "the mean, flow time of a job" is equal to the expected number of jobs in the system "times" the mean time between the arrivals of two consequtive jobs"; in a dynamic job shop, where jobs of various types enter and leave the production system continually in a random manner, flow time and completion time of a specific job may be influenced by many factors and are very difficult to predict accurately.

Various methods proposed by early research are related to the prediction of job completion times and the setting of due dates. Weeks (1979) assigns the due date of an arriving job equal to the time of arrival plus total processing time and an estimated queuing time, which depends on the numbers of jobs in the system when the job arrives. Weeks concludes that this rule provide better (attainable) due dates than rules based solely on job characteristics. Miyazaki (1981), uses a flow time based rule to assign due dates. He estimates the flow time of a job based on total processing time for the job, number of operations and standard deviation of queuing time per operation. He concludes that his scheduling approach, which combines this due-dates assignment method and job sequencing procedures, performs better than the conventional scheduling system. Ragatz and Mabert (1984) also utilize flows time based rules to assign due dates. Various factors of job characteristics and/or shop status information are used to estimate job flows time. They conclude that: resulting rules are dependent on the dispatching rule used to sequence work: information about work centre congestion along a job's routing is more useful than general shop conditions; and use of more detailed information in predicting flow time provides only marginal improvement in performance over other rules that use more aggregate information. Chang (1988e) assigns the flow time of an arriving job equal to the sum of total processing time and an expected sequencing time, which depends on the job processing time and the number of job in those machines on the jobs route when it enters the shop.

As indicated by the discussion above, completion time of a job in a dynamic job shop can be affected by many different factors related to job characteristics and shop status and is very difficult to predict accurately. Also, the level of influence of each factor on the completion time of a job can depend on other characteristics of the production system, such as the dispatching rule used and shop utilization rate.

To assign a due date for job; in a dynamic job shop, most methods include one or more of the following factors:

1. Total processing time of the job (p_i)
2. Number of operations of the job (N_i)
3. Number of jobs in workcentre queues on job is routing when it is released to shop (JIQ_i)
4. Total processing time of all jobs in workcentre queues on job i is routing when it is released to the shop (WIQ_i)
5. Number of jobs in the system when job i is released to the shop (JIS_i)
6. Mean flow time in the system (MF)
7. Standard deviation of flow time in the system (SF)
8. Mean queuing time in the system (MQ)
9. Standard deviation of queuing time in the system (SQ).
10. Mean queuing time per operation (M_q)
11. Standard deviation of queuing time per operation (S_q)
12. Means numbers of jobs in the system (M_j)
13. Standard deviation of number of jobs in the system. (S_j)

For example Week's (1979) rule includes factors 1,8,9,12 and 13; Miyazaki's (1981) rule includes factors 1,2,10, and 11; Ragatz and Maberts' (1984) rule response mapping rule (RMR) for the first - come - serve dispatching rules includes factors 1,2,3,4 and 5.

Among these factors, P_i and N_i are related to job characteristics, JIQ_i, WIQ_i, and JS_i are related to shop status; MF, SF, MQ, SQ, M_q, S_q, M_j, S_j, are related to system characteristics which include number of workcentres in the shop, dispatching rule used, and shop utilization rate.

2.03 JOB CHARACTERISTICS

The jobs have three important characteristics

(a) **The flow pattern:** The flow pattern in certain situations, all job follows the same pattern of flow through the system in other cases, each job follows its own (specified) pattern.The first situation is termed a flow shop and its exemplified by wood work, in which the flow might be sawing, followed by sanding, followed by finishing. In a flow shop, routing is not typically a problem. The second situation is termed a randomly routed job shop.

The randomly routed job shop is a more difficult shop to analyse than the flowshop. Furthermore, it requires more information to be maintained, that is, the likelihood of going from process i to process j must be known.

(b) **Machine usage time:** In job shop scheduling it is assumed that the length of time each jobshop requires for each process is known before hand. Infact, the scheduling is based on machine usage time. Further more, if machine usage times are not known then essentially the problem is treated not as a job shop scheduling problem but as queueing problem. In most queueinng models,the service times are unknown! (Averages are utilised).

(c) **Due dates:** In many situations. "Due dates" are given for each job. We have the form in quotation because its meaning can vary. That is, the meaning of "due dates" could by anything from a promise to a contractual obligation.

In some contracts, the due dates is fixed. In others it is specified as a target, with penalties stated for late delivery and incentive payments offered for early delivery.

If r_i, p_i, q_i,and f_i denote the arrival time, total processing time, queuing time in the system, and completion time of job,respectively then

$$f_i = r_i + p_i + q_i \quad \text{---------------- eqn (2.01)}$$

Because r_i and p_i are known constant after the arrival of job, q_i, is the only variable that needs to estimated to predict f_i, for each experiment, which has a specific combination of dispatching rule and shop utilization rate, information is collected on the queuing times and values of interested factors for some randomly selected jobs. Then a single factor analysis of variance (ANOVA) method with fixed factor levels is used to analyse the simulation results and to identify factors that have significant effects on queueing times (and completion times) of the jobs.

For each of those significant factors identified, a simple due date assignment rule based on that factor is constructed.

Conway (1965) demonstrated in his study that due date assignment methods based on job characteristics, such as processing time and number of operations lead to poorer performance than external due date assignment methods which are not related to job characteristics. In their study, Eilon and Chowdhury (1976) indicated that due date procedures that take into account the shop congestion information produce less mean tardiness than procedures based only on job content. They also concluded that due date priority rules may perform better than non-due-date priority rules in terms of missed due dates.

Chang (1994)[25] stated due-date assignment rules in his research work for each of the significant factors identified in every experiment a simple due-date assignment rule based on that factor is constructed to study its relative effect on due-date predictability and other related performance measures. The rules are as follows:

1. For factor p_i, d_i, $= r_i + P_i + k * P_i$ ----- Eqn (2.02)
2. For factor N, d_i $= r_i + P_i + k * N_i$ ----- Eqn (2.03)
3. For factor JIQ, d_i $= r_i + P_i + k * JIQ_i$----- Eqn (2.04)
4. For factor JIS, d_i $= r_i + P_i + k * JIS_i$----- Eqn (2.05)

where d_i denotes the assigned due date for job i and k is the parameter that reflects the expected queueing time that job will experience in the system. The k values are estimated based on the following regression models.

1. For factor pi, $q_i = k * P_i$ -------------- Eqn (2.06)
2. For factor Ni, $q_i = k * N_i$ -------------- Eqn (2.07)
3. For factor JIQ, $q_i = k * JIQ$ -------------- Eqn (2.08)
4. For factor JIS, $q_i = k * JIS$ -------------- Eqn (2.09)

and the results shown in Table 2.1.

For the purpose of bench marking, the following rule based only on the mean queueing time in the system as also constructed.

$$d_i = r_i + P_i + MQ \quad \text{--------------- Eqn (2.10)}$$

where MQ is the mean queueing time in the system.

Table 2.1

Effects of Four Factors on Queuing Times in the System Under Various Production System Conditions

Dispatching Rule	Shop Utilization Rate	Queueing Time Mean	Queueing Time Standard Deviation	Factor	Mean Factor Value	F-value	Rank[1]	K[2]
FCFS	0.50	44.39	43.17	*P*	49.06	177.37*	4	0.77
				N	4.93	431.57*	2	8.98
				JIQ	5.76	1150.01*	1	7.53
				JIS	10.10	286.92*	3	4.32
SPT	0.50	32.36	34.86	*P*	49.04	299.63*	3	0.60
				N	4.93	377.50*	2	6.58
				JIQ	5.20	503.58*	1	5.83
				JIS	8.91	132.26*	4	3.49
S/OPN	0.50	40.45	38.42	*P*	49.06	520.18*	3	0.77
				N	4.93	594.55*	2	8.31
				JIQ	5.60	881.66*	1	6.92
				JIS	9.72	272.52*	4	4.08
FCFS	0.90	372.14	216.68	*P*	49.99	598.56*	3	6.32
				N	4.99	1628.62*	2	74.53
				JIQ	39.19	2996.90*	1	9.23
				JIS	77.21	154.19*	4	4.78
SPT	0.90	147.84	255.49	*P*	50.01	449.94*	1	3.23
				N	4.99	149.40*	3	30.06
				JIQ	18.61	160.68*	2	7.78
				JIS	36.09	21.68*	4	4.04
S/OPN	0.90	354.35	212.57	*P*	49.97	878.00*	3	6.18
				N	4.99	1808.18*	2	71.65
				JIQ	37.54	2191.74*	1	9.06
				JIS	73.53	155.50*	4	4.79

*Significant beyond 0.001 level

[1] Based on *F*-value, higher rank for larger value

[2] Least-square estimator of *K* in regression model "Queueing Time = *K* * Factor Value"

CHANG F.R (1994)

Chang (1994) also discussed the performance measures used to evaluate the relative effectiveness of the due date assignment rules and associated factors. These performance measures he stated thus:

1. Mean Absolute Missed Due Date (MAMD)

$$MAMD = \{ \sum_{i=1}^{n} [\max(0,d_i-f_i) + \max(0,f_i-d_i)]\}/n \text{---------} \quad \text{Eqn (2.11)}$$

2. Mean Earliness (ME)

$$ME = [\sum_{i=1}^{n} \max(0,d_i-f_i)]/n \text{-----------------------} \quad \text{Eqn (2.12)}$$

3. Mean Tardiness (MT)

$$MT = [\sum_{i=1}^{n} \max(0,f_i-d_i)]/n \text{----} \quad \text{Eqn (2.13)}$$

4. Mean Assigned Flow Time (MAFT)

$$MAFT = [\sum_{i=1}^{n} (d_i-r_i)]/n \text{ ----} \quad \text{Eqn (2.14)}$$

where n is the sample size.

Mean absolute missed due date (MAMD) which measures the average absolute differences between actual completion date and promised due dates of the jobs, is used in this study as the primary performance measure. A smaller MAMD values implies better due date production capability. MAMD is always equal to the sum of mean earliness (ME) and mean tardiness (MT). Mean assigned flow time (MAFT) is average expected flow times of the jobs.

A smaller MAFT value is better because it means shorter quoted delivery dates for the orders.

2.04 SHOP STATUS

Effective management of loading and work flow is becoming increasingly important in manufacturing. However, research has not addressed the associated dynamic interval performance issue as effectively as possible.

Increasingly, the management of work-in-process inventory is seen as an indicator of overall manufacturing performance. Emphasis has been placed on determining production policies which reduce lead times and improve delivery performance, while maintaining required through puts. Too much work-in-process inventory leads to excessive lead times, poor delivery performance, excessive material handling and a breakdown in the proper selection of priorities. Too little work-in-process inventory may result in insufficient throughput. These are important issues. In addition to aggregate work-in-process inventory, the balance of work-in-process inventory must be considered. The distribution of work-in-process inventory at any given time as well as well through time determines the stability of resources requirements. Improvement of internal performance requires a better understanding of leaching effect and work flow behaviour. This inturn requires greater emphasis on internal performances measures.

The basic due date setting model has been developed and tested in previous research (Enns 1995). New extensions for input control, work load balancing and buffer size adjustment mechanisms are described.

The use of input control has long been advocated Weight (1970) and Bett (1976). Among the recognized benefits are stabilized queue lengths, reduced shop floor congestion and work-in-process inventory investment, faster and more predictable work flow and simplified control of priorities. Generally, input control leads to reduced loads and improved load balancing as well. Some researchers, such as Shimoyashiro et al (1984) and Ragatz and Mabert (1988), also indicated that the use of input control reduces importance of the dispatch rule as an indicator of performance. However, for a given level of delivery performance, input control does not result in decreased lead times. This has been pointed out in a number of studies including Melnyk and Ragatz (1989) and Melnyk et al (1991).

Studies involving input control generally utilize work load and balance measures along with delivery performance measures, such as mean tardiness or percentage tardy jobs. Work load is commonly measured in terms of the mean number of jobs on the shop floor or the mean amount of work-in-process inventory. Work-in-process inventory may be stated in terms of either the total processing time required of the completed processing time associated with jobs currently on the shop floor. Using shop load balance as a performance measure was advocated by Deane and Moodie (1972). They suggested using the variance of work in queue, as expressed by processing time requirements, as an appropriate measure. This measure is machine specific. Other shopload balance measures, such as the variance of total work-in-process inventory (Melnyk et al 1991) or the mean of the variance of work in queue, of each machine (Melnyk and Ragatz 1989), have also been used. A problem with performance measurement in studies attempting to justify input control is that the benefits due to reduced work-in-process inventory and better load balance must be simultaneously considered along with lead time requirement and delivery performance. This type of analysis requires conversion of all measures to a common value such as cost. Studies that have used this approach include Onur and Fabrycky (1987) and Ragatz and Mabert (1988).

The methods of input release found in the research literature is diverse. Aggregate work loads have been used to trigger job release in a number of ways. Ragatz and Mabert (1988) used the number of jobs in the shop as one of their trigger mechanisms. The order of the input buffer given release priority was the one of requiring the way machine of the shortest queue. Melnyk et al (1991) used aggregate remaining uncompleted processes time for jobs currently in the shop as a trigger to maintain constant work-in-process load levels, where work-in-process is defined to be the sum of total processing time requirements for jobs currently in the shop. This release mechanism has been referred to as Constant Work-In-Process (CONWIP) by Spearman et al (1990). Constant Work-in-process (CONWIP) is similar to other work load trigger if it is assumed that there is always some work in the input buffer. Other methods tested include releasing work at a fixed rate equal to the desired rate of throughput (Roderick et al (1997). This approach advocated by Wight, assumed constant throughput is desirable.

Local work load triggers have also been used, Ragatz and Mabert (1988) used the number of operations in the job and length of queue along the routing to determine job specific release dates. Melyk and Rgatz (1989) used a work centre load trigger that released jobs whenever the work load at a gateway machine fall below a certain level. This can help in avoiding work 'starvation' and may be particularly appropriate if used to regulate work feeding toward bottleneck machines. A related approach was used by Roderick et al (1992). Jobs competing to enter the same gateway machine buffer were selected on the basis of earliest due date. Finally, Ragatz and Mabert (1988) used finite loading to dictate what jobs could be released. This approach simultaneously addresses both the aggregate work load and the load balance issues.

Ragatz and Mabert (1988) suggest that both job characteristic and shop congestion information should be used in determining the timing of job releases. In many studies, due dates are set on the basis of job characteristics and input release is then based on the current shop floor load. Seldom does the release mechanism take current throughput requirements into current account. A mechanism which attempts to maintain stable shop floor loads works well when throughput requirements are fairly steady. However, this may not be the situation under which input control is most beneficial. When throughput requirements vary through time, as in most job shops, the release mechanism should take the relationship between shop floor loading and throughput requirements into account. In other words, input control should not only dampen the effects of fluctuating order types and inter arrival times but should also adjust to longer term changes in throughput requirements. It is well known that higher shop floor loads, as expressed by work-in-process inventory, allow throughput to be increased. Throughput requirements can be estimated from completed work in the system, including the input buffer, and the remaining flow allowance for this work. However, the nonlinear relationship between throughput and work-in-process inventory is hard to deal with and may be one reason few studies have taken fluctuating throughput requirements into account.

Input control is closely related to allocated machine buffer space. In the extreme, maintaining finite machine buffers on the shop floor result in blocking which acts as a form of input control. Blocking is defined as a restriction on the movement of a job to its next stage caused by downstream machine buffers being full. Blocking occurs whenever new orders are prevented from being released onto the shop floor or when jobs on the shop floor are prevented from advancing due to machine buffer restrictions. Kanban production control systems may be viewed in this way. The number of Kanban cards dictates buffer sizes at individual machines, while input release is also controlled by using select cards to pull new jobs into the system. Research on machine buffer space allocation in more general serial production systems is reviewed by Conway et al (1988). As pointed out by these authors the problem of buffer space requires much further investigation.

Work balance on the shop floor is influenced by dispatching in addition to the job release mechanism used. Putman et al (1971) recognized that buffer requirements may be different at various machines and it may be beneficial to take this into account during dispatching. Berry and Finlay (1976) modified critical Ratio and Slack dispatch rules to take historical queue time information into account. They found work-in-process inventory did not decrease with the use of queue time information. Deane and Moodie (1972) sought to balance work loads at each machine around average loading for that machine. They advocated replacing the use of simple dispatch rules with a work load projection mechanism that would provide machine under loading forecasts. This information could then be used to give priority to jobs that would be fed toward potentially 'starved' machines. Beclite (1988) developed a model in which a desired work load at each machine is established and jobs are released on the basis of maintaining these work loads through time. A simple forecasting procedure was used to anticipate how much current upstream work would arrive at each machine in each future period. Beclite also showed that by maintaining stable work loads, the flowtime of jobs through the shop can be predicted more accurately. This allows valid flow allowances to be established.

2.05 WORK LOAD ANALYSIS

Before analysing the workload pattern of a typical job shop, a brief discussion of some commonly used assignment rules determining flow allowances to set due-dates is important.

(1) Total Work in shop (TWK) - flow allowances assigned to jobs are proportional to the total work in the shop;

(2) Equal amount of waiting Slack (SLK)-flow allowance is assigned to job to allow for equal amounts of waiting slack

Several studies have identified the following as some of the most efficient heuristic dispatching rules:

(1) Shortest processing time (SPT)-giving priority to the jobs with shortest processing time; and

(2) Earlier due dates (EDD)-giving priority to jobs with the earlier due-dates.

It is logical that flow allowances should reflect work load conditions since the work-load of the shop is a natural indicator of its state. If L_j denotes the workload in the system at time r_j (not including the processing time of the arriving job itself, and if jobs are sequenced in the arrival order as presented by the earliest release date (ERD) priority rule, then the waiting time for job j is measured by L_j and the flow time is measured by :

$$F_j = L_j + P_j \text{ ------------ (i)}$$

Where P_j denotes processing time. If flow allowance a_j are set according to this equation

$$a_j = L_j + P_j \text{ ------------- (ii)}$$

then each job would be completed precisely at it's due date. It implies that workload information can be used to devise a perfect assignment rule in the sense that it guarantees a mean tardiness of Zero. The disadvantage of this assignment rule, however, is that there is no way the tightness of the due-dates can be controlled. Moreover, the rule can only reveal an allowance factor at which tardiness is avoidable.

There are a number of ways in which workload information can be captured, including proportional workload function (PWF) adjustment, which was employed by Baker and Bertrand (1981). With this techqniue, the tightness parameter is adjusted proportionally to the actual workload. For example the basic scheduling rule, the CON (constant) jobs are assigned constant flow allowances-rule can be modified so that

$$a_i \quad = \quad (kl_i/\bar{L})P_i \text{ ------------- (iii)}$$

where k is the allowance (tightness) factor and $\bar{L}$ is a scaling factor which ensures that $\bar{a} = K\phi$.

The quantities $\bar{a}$ and ϕ denote the means of allowance factors and the distribution of processing times respectively. In particular, $\bar{L}$ is the mean system workload with the following equation, for which Baker and Bertrand gave the derivation

$$\bar{L} \quad = \quad \lambda(\phi^2 \quad + \quad \delta^2) \;/\; 2(1 - \lambda\phi) \text{ -------(iv)}$$

in which δ denotes the standard deviation of the distribution of processing times and λ the arrival rate of the jobs. With $\bar{L}$ defined this way, the mean value of $L_i/\bar{L} = I$, yields $\bar{a} = k\phi$. The CON rule is not investigated in this study because several studies have shown it to be less effective than the TWK or SLK rule. For the SLK rule, a PWF adjustment led to the form:

$$a_i \quad = \quad P_i \quad + \quad \phi(k\text{-}I)L_i/\bar{L} \text{ ----------------(v)}$$

This definition seems to make sense because $\phi(k\text{-}I)L_i/\bar{L}$ plays the role of a waiting time allowance. For the TWK rule, a PWF adjustment of the tightness parameter leads to the form:

$$a_i \quad = \quad (kL_i/\bar{L})P_i \text{ ---------------------------(vi)}$$

The likely flaw in the TWK rule is that if the shop is empty when a job arrives, then $L_i = 0$, resulting in a flow allowance of zero. It becomes preferable in this case to include the processing time of the arriving job when defining "workload". Doing so leads to the form:

$a_i = KP_i(L_i + P_i) / \bar{L}$ --------- (vii)

An alternative way of capturing workload information, as suggested by Baker and Bertrand (1981), is to include workload as accumulative distribution function (CDF), in which the constraint

$\bar{a} = K\phi$ is preserved in the form

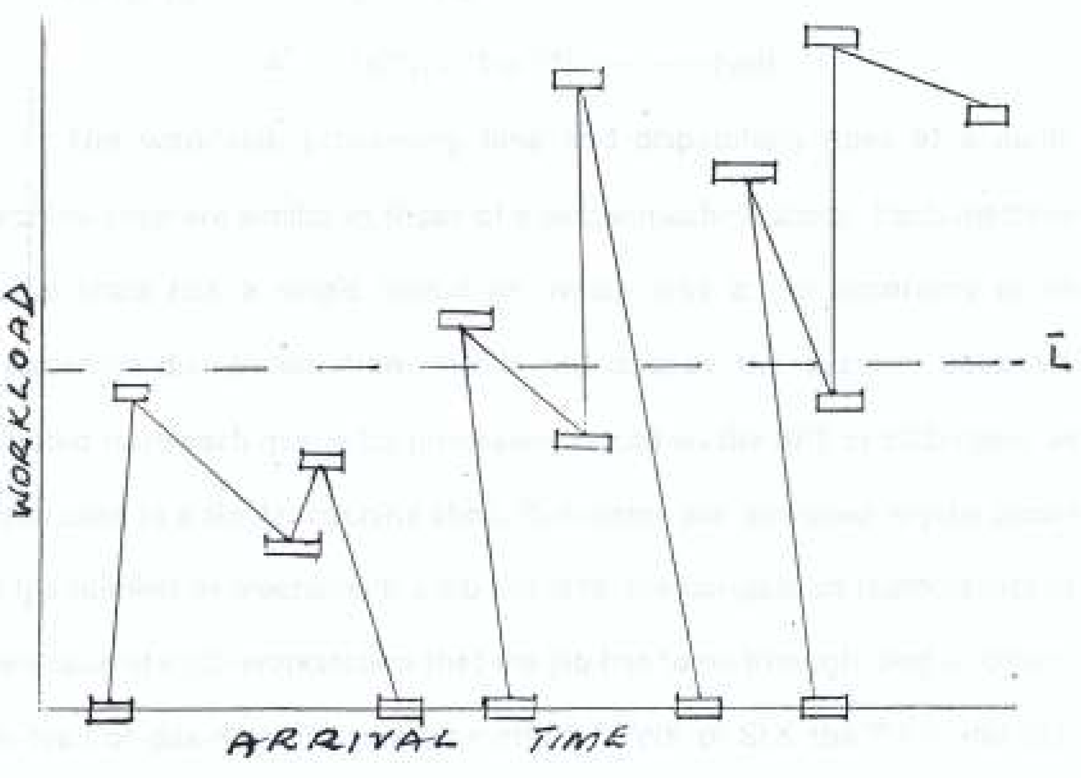
$a_i = 2KF((L_j)P_j$, in the case of TWK and

$a_i = P_i + 2P(k-1)F(L_j)$, in the case of SLK..

This form is justified by the fact that the mean value of cumulative function, $F(L_j)$, will always be one-half and that L_i and P_i are independent.

The behaviour of the actual workload with the CDF adjustment can be illustrated with a "saw tooth" graph as shown in the figure below. As illustrated, the expected or long-term mean of the workload is given as

$L_j/2$ (i.e. $(L_j + 0)/2$).



Workload Pattern for Job Shops.

GODWIN J. UDO (1994)

In some periods the shop is filled to capacity (i.e workload = L_j), but in other periods the shop is empty (workload = 0). If the workload varies over time in the pattern shown above, at the arrival of job j the workload will increase by P_j and decrease at a rate of -1 until the next arrival or until the system becomes empty, whichever occurs first. In this case, workload is independent of the priority rule as long as the machine is not permitted to be idle when a job is in the system.

In the case of exponential processing times we know from queuing theory that $F(L_j)$ itself takes on the form of an exponential distribution with a mean of $\phi/(1-\lambda\phi)$ for example,

$$F(L_j) \quad = 1/\mu e^{-1}/\mu L_j \text{ for } L_j \geq 0$$

where

$1/\mu$ is a constant service time for the system.

$$F(\lambda \leq L_j) \quad = \quad \mu e^{-\mu l} dL_j$$

$$= \quad (e^{-\mu\lambda}) = 1 - e^{-1/\mu L j} \text{ ------------(viii)}$$

The workload, processing time and dispatching rules of a multi-machine shop are similar to those of a single-machine shop. Each machine in the shop has a single queue on which jobs arrive according to an exponential distribution from inside and outside the system. Jobs are selected from each queue for processing based on the SPT or EDD rules, as in the case in a single-machine shop. Due dates are assigned to jobs based on the number of machines the job requires, the congestion (cumulative) of the queue at each workstation that the job has to go through, and of course the type of due-date assignment method. TWK or SLK the TWK and SLK methods are adjusted for the F(Lj) function as already explained in the previous two paragraphs.

2.06 SYSTEM CHARACTERISTICS

These are characteristics which include number of work centers in the shop, dispatching rules used and shop utilization rate. Some other related factors are:

(i) mean flow time in the system (MF)

(ii) standard deviation of flow time in the system (SF)

(iii) mean queuing time in the system (MQ)

(vi) standard deviation of queuing time in the system (SQ)

(v) mean queuing time per operation (M_q)

(vi) standard deviation of queuing time for operation (S_q)

(vii) mean number of jobs in the system ((M_s)

(viii) standard deviation of number of jobs in the system (S_j)

The facility or process of interest is usually called a system, and in order to study it scientifically we often have to make a set of assumptions about how it works. These assumptions which usually take the form of mathematical or logical relationships, constitute a model that is used to try to gain some understanding of how the corresponding system behaves.

If the relationships that compose the model are simple enough, it may be possible to use mathematical methods (such as algebra, calculus, or probability theory) to obtain exact information on questions of interest; this is called an analytic solution. However, most real-world systems are too complex to allow realistic models to be evaluated analytically, and these models must be studied by means of simulations. In simulation we use a computer to evaluate a model numerically, the data are gathered in order to estimate the desired true characteristics of the model.

A system is defined to be a collection of entities e.g people or machines that act and interact together toward the accomplishment of some logical end. (this definition was proposed by Schnudt and Taylor (1970)). In practice, what is meant by "the system" depends on the objectives of a particular study. The collection of entities that compose a system for one study might be only a sub-set of the overall system for another. Fishman (1978). We define the state of a system to be that collection of variables necessary to describe a system at a particular time, relative to the objectives of a study (system characteristics).

We categorise system to be of two types, discrete and continuous. A discrete system is one for which the state variables change instantaneously at separate points in time. While continuous is one for which the state variables change continuously with respect to time. For system in practice are wholly discrete or wholly continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous.

At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered. Figure 2.02 maps out different ways in which a system might be studied.

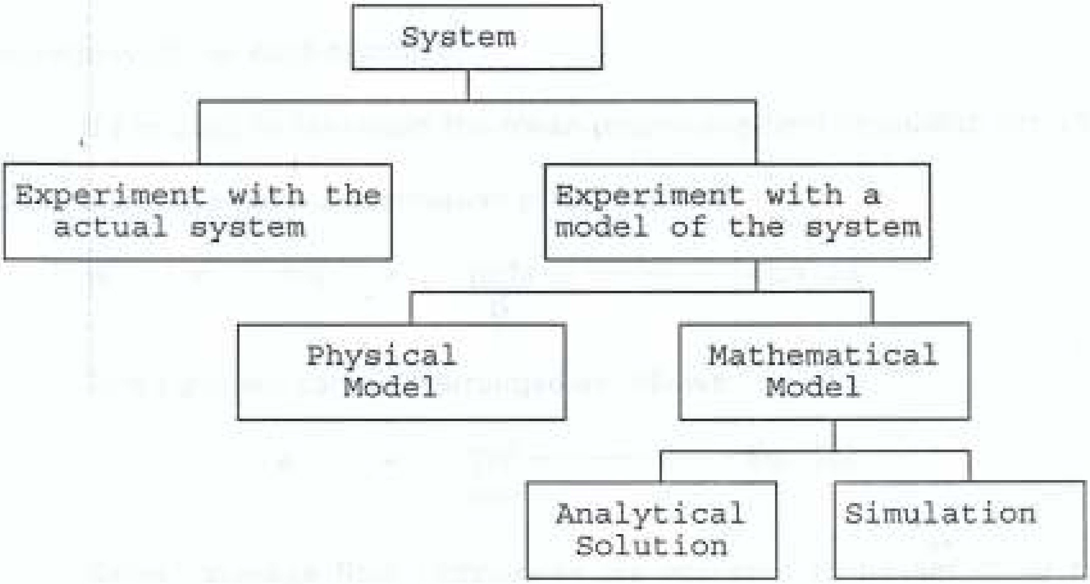


Fig 2.02: Ways To Study a System
Averil and Kelton (1972).

Since shop loading is highly auto correlated (Adam et al 1978), the best estimate of short-term utilization is the current utilization level. When the expected utilization at each machine is the same, the level of current utilization can be estimated from the current shop load by using Little's result (Little 1961).

$$\phi = f\lambda = \frac{f\rho}{p} \text{ ---------------------- Eqn (1)}$$

where

ϕ = mean number of jobs at each machine

f = mean flowtime per operation at each machine

ρ = Steady-State utilization

λ = mean arrival rate of jobs at each machine

p = mean operation processing time.

The average total work remaining in the shop, W, equals the sum of average work at each machine.

If r is used to represent the mean processing time remaining per job in the shop, the following equation may be stated

$$W = mr\phi = \frac{mrf\rho}{p} \text{ ------------------ Eqn (2)}$$

This equation can be rearranged as follows:

$$\rho = \frac{WP}{mrf} \text{ ------------------- Eqn (3)}$$

Since average flow allowances are assumed to be set equal to predicted flowtimes, the average flowtime per job can stated in terms of the average remaining flowtime allowance for all jobs in shop, A, and the average number of jobs in the shop, j

$$\frac{rf}{p} = \frac{A}{J} \text{ -----------------Eqn (4)}$$

Substitution of equation (4) into (3) leads to the following equation.

$$\rho = \frac{WJ}{Am} \text{ ----------- Eqn (5)}$$

A short time utilization estimate, at the time of job release, can therefore be obtained using the following equation:

$$P_t = \frac{W_t V_t}{A_t m} \text{ ----------- Eqn (6)}$$

Where

P_t	=	short time utilization estimate at time t
W_t	=	work remaining in shop at time t
J_t	=	jobs remaining in the shop at time t
A_t	=	allowance remaining for work in shop at time t

m = number of machines in the shop.

This equation illustrates shop load and leadtime relationships. Suppose that utilization, ρ_t, and shop load are initially low. As the arrival rate of work increases, ρ_t will increase in approximately direct proportion to the number of jobs in the shop, J_t, The ratio of remaining work to remaining flow allowance, W_t/A_t, stays approximately the same. Thus, leadtime requirement for individual jobs are not affected much. However, as the rate of work arrival continues to increase, utilization will approach 1.0. The only way to constrain ρ_t to be less than 1.0 is to increase the total flow allowance, A_t, at a faster rate than total work remaining W_t, is increasing.

Therefore, loadtimes for individual jobs increase at an increasing rate as shop load continued too rise. This non linear relationship between shop loads and leadtime, requirements at high utilization rates suggests that there is a utilization level beyond which the benefits of increased resource utilization are offset by the cost associated with long lead times and high work-in-process inventory.

2.10 SCHEDULING INVOLVING DUE DATE

A general picture of the production planning scheduling relationship is presented in the figure below Fig. 2.1.

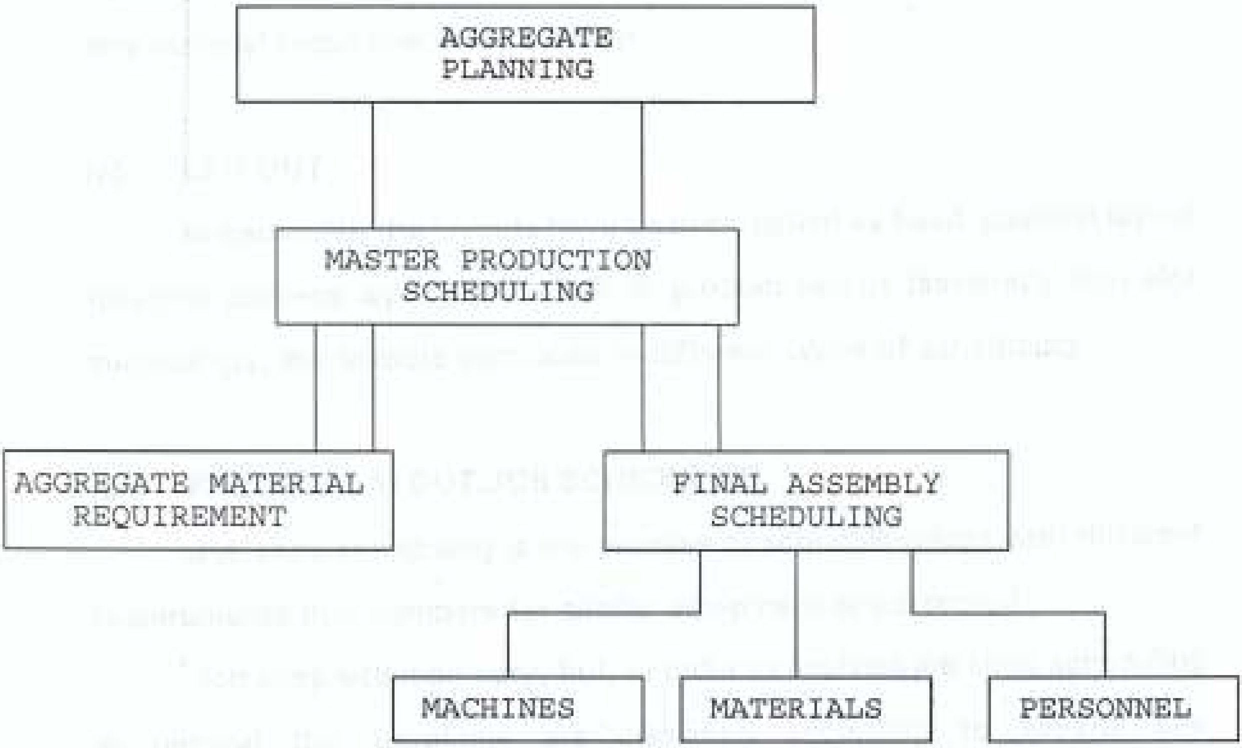


Fig. 2.1: Enns J.T. (1993)

Typically, the scheduling process is broken down into five categories

(i) Routing: determining where the work is to be done

(ii) Scheduling: determining when the work is to be done

(iii) Dispatching: issuing the order to begin work.

(iv) Control: monitoring the process to determine the operation are viewing according to plan

(v) Expediting: improving the completion of a job.

Of the functions of routing, scheduling, dispatching, control, and expediting, the two key functions are routing, scheduling

In combination these functions dictate which process is loaded (routing) and when (scheduling), which in turn dictates both the personnel and material requirement for the firm.

(a) **LAY OUT**

In particular, the layouts have been classified as fixed position layout (project) process layout (job shop) or product layout (assembly line) Not surprisingly, the layouts each lead to different types of scheduling

(b) **PROCESS LAYOUT/JOB SCHEDULING**

Job shop scheduling is the process of scheduling jobs with different requirements that compete for similar equipment or personnel.

Job shop situation vary, but, in order to analysis job shop scheduling in general the situations are classified according to several key characteristics.

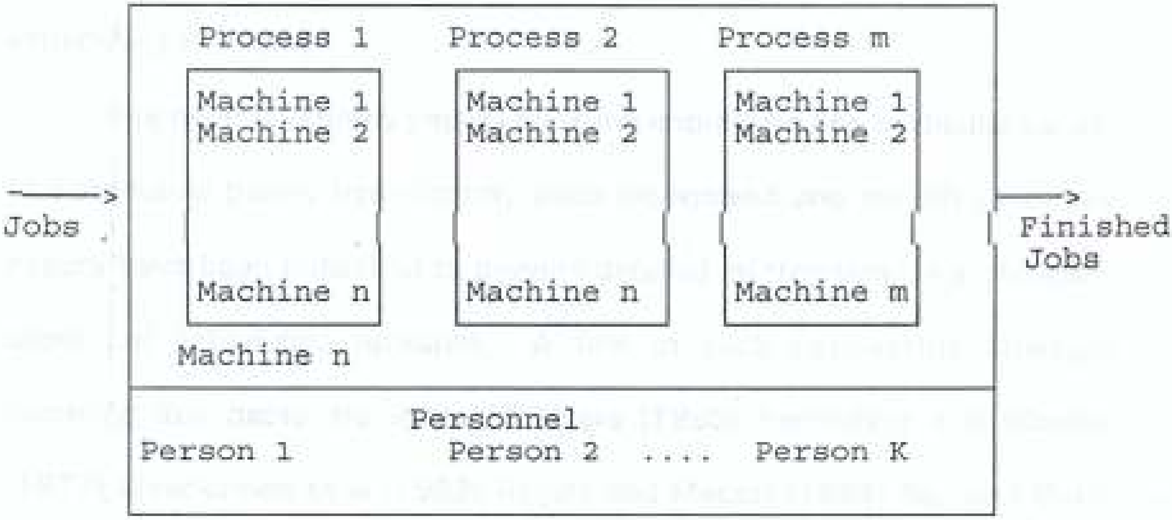


Fig. 2.2: Jackson J.R. (1963

The components of a job shop are detailed above. Jobs arrive at the shops needing to be transformed by one or more processes. There are several different types of processes and different number of machines within each type of process. Different employee are available to staff the different process one of the questions job shop scheduling must answer is which employee should be assigned to which process. But the major question to be addressed, though, is: when different jobs compete for the same process, which should be performed first?

A survey of due date based research reveals that due dates are usually treated as given information and taken as input to a scheduling problem. However, in actual practice, the due date can be a decision variable within the domain of the scheduling problem.

The former type of scheduling problems are reviewed in-depth by Sen and Gutta (1984) and Gutta and Kyparisis (1987). But no attempt has so far been made to review the theoretical developments of the latter type of scheduling problems.

The need for survey papers focusing entirely on one particular aspect of scheduling theory has recently been recognised and wealth of survey papers have been published to provide detailed information on a particular aspect of scheduling research. A few of such noteworthy attempts involving due dates are those of Elvers (1993) Panwalker and Islander (1977) Blasckstone et al (1982) Ragatz and Mabert (1984) Sen and Gutta (1984) Guppta and Kyparisis (1987) and Smith and Seidmann (1983). While the first three papers review, among others, the dispatching rules and their performance when the due date information is provided, the latter four are excellent attempts to provide a frame work for studying due date related scheduling problems. Sen and Gutta (1984) and Gutta and Kyparisis (1987) have concentrated their efforts to analyze the literature concerned with state and single-machine scheduling problems when due dates are given. However, no attempts so far has been made to analyse the literature dealing with due date assignment policy decisions. Ragatz and Mabert (1984) have provided a conceptual model of a due date management problem which, among other important variables, identifies a variety of due date assignment rules. They do recognise the need for further research using different due date assignment methods. Smith and Seidmann (1983) have presented a comprehensive classification of due date selection procedures from which three major categories are derived: direct procedures (rules), heuristic procedures and simulation.

2.11 CLASSIFICATION OF SCHEDULING PROBLEMS

Scheduling problems may be classified according to various schemes. According to Eilon (1978), the scheduling problem can be classified as static vs. dynamic, deterministic vs Stochastic, single product vs multiproduct, single-processor vs multiprocessor facilities and theory vs practice. This project surveys both static and dynamic scheduling problems with primary interest in the due date determination decision variable. This literature is categorised into single-machine and multi-machine cases.

This section defines the most relevant variables and concepts and proposes a classification scheme to analyse the literature.

A scheduling problem consists of a set of jobs:

J = [J/i = 1,2,3------ n] and a set of machines M

= $(M_j/j=1,2\text{-------},m)$.

Each job J_i is characterized by the processing time P_i, the release time r_i, and the due date d_i. The symbols C_i, T_i, E_i and F_i are usually used to denote the completion time, tardiness, earliness, and flow time of job j_i respectively.

In a job shop production system, each job on arrival is assigned a due date for delivery before it is actually released to the shop floor for processing. An analysis of the literature reveals that a variety of decision rules has been suggested to assign due dates. These due date assignment procedures can be discussed under the following categories and are displayed in the figure 2.3 below.

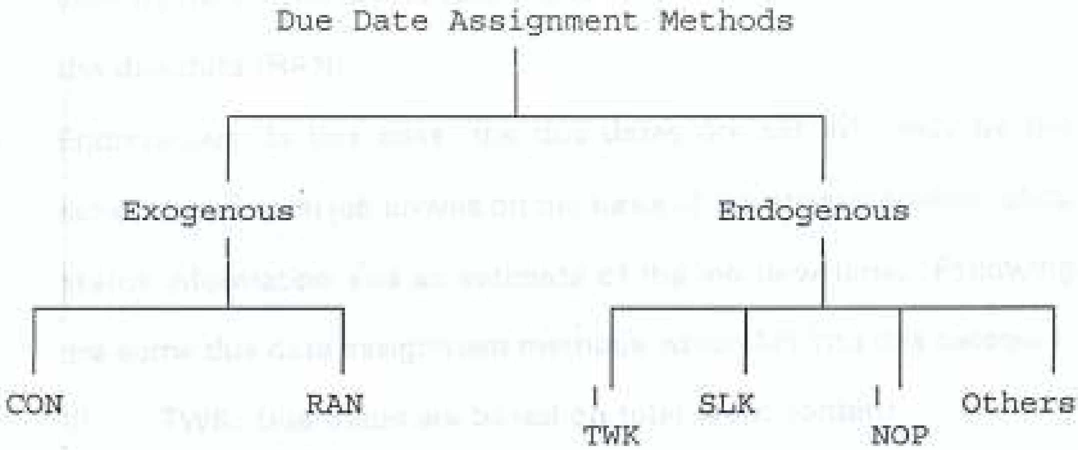


Fig. 2.3: Cheng and Gupta (1989)

(1) Exogenous: In this case, the due dates are set by some independent external agency and are announced upon arrival of the job. They are a fixed and given attribute of a job. Two types of due date assignment methods have been studied in this category:

(i) Constant (CON): All jobs are given exactly the same flow allowance.

(ii) Random (RAN): The flow allowance for a job is randomly assigned.

These two rules can be expressed in notational form as follows:

CON: $d_i = r_i + k$

RAN: $d_i = r_i + e_i$

Where k is a constant and e_i is a random number

Clearly, these two methods entirely ignore any information about the arriving job, jobs, already in the system , jobs or the structure of the shop itself. These due date methods are representatives of common practice where salesmen quote a uniform delivery date on all orders (CON) and where the customer establishes the due date (RAN).

(2) Endogenous: In this case, the due dates are set internally by the scheduler as each job arrives on the basis of job characteristics, shop status information and an estimate of the job flow time. Following are some due date assignment methods which fall into this category.

(i) TWK: Due dates are based on total work content

(ii) SLK: Jobs are given flow allowances that reflect equal waiting times or equal slacks

(iii) NOP: Due dates are determined on the basis of the number of operations to be performed on the job.

These methods can be written in notational form as follows:

TWK: $d_i = r_i + kp_i$

SLK: $d_i = r_i + p_i + k_i$

NOP: $d_i = r_i + p_i + kn_i,$

Where n_i,is number of operation of job i.

These due date assignment methods take into account job characteristics in one form or another when compared with exogenously established due dates, these methods are generally found to be superior, as observed by Conway (1965).

Recently, another class of due-date assignment methods has been proposed which considers shop status information, ie information about jobs already in the system see Blackstone et al. (1982) and Ragatz and Mabert (1985). Many researchers have claimed improved performance resulting from this type of methods, including

(i) JIQ: Due dates are determined based on current queue lengths in the system (Eilon and Chowdhury, 1976).

(ii) JIS: Due dates are determined based information on numbers of jobs in the system (Weeks 1979).

(iii) PPW: Due dates are determined based on information on waiting time in the system (Kanet 1982).

Notationally, these methods can be expressed as follows:

JIQ: $d_i = r_i + k_i p_i + k_2 Q_i$

JIS: $d_i = r_i + p_i + D + a(j_i)\sigma_D,$

PPW: $d_i = r_i + p_i + K_1 m_1$,

where k_1 and k_2 are constants: Q_i , is number of jobs in queue at machines job i will visit; D is the mean waiting time in the system σ_D is the standard deviation of waiting time in the system. J_i is the number of jobs in the system when job i arrives, and $a(j_i)$ is defined as

$$a(j_i) = \begin{cases} -1 \text{ if } j_i < \delta_j, \\ 0 \text{ if } j - \sigma_j < j_i < j + \sigma_j, \\ 1 \text{ if } j_i \geq j + \sigma_j; \end{cases}$$

where j and σ_j are the mean standard derivation of number of job in the system respectively and mi; as the number of operations of job i.

In addition, a number of papers have studied the effect of combining two or more due date assignment methods. For example, Ashour and Vaswani (1972) combined TWK with NOP by multiplying the processing time by number of operations. Also, Cheng (1983b) presents a study of such a combination of TWK and NOP in a dynamic job situation.

These different due date assignment methods have been considered in the scheduling literature for a variety of purposes, including :

(i) to access the performance of some dispatching rules,

(ii) to find the optimal due date and optimal sequence in the static job shop situation

(iii) to compare the performance of different due date assignment methods and

(iv) to find the optimal due date multiple, k, to process the jobs in dynamic environments.

2.12 STATIC JOB SHOP ENVIRONMENT

In static job shop model, all jobs are available for processing at one starting time so the main objective is to find the optimal due date when any one of the due date methods is given and to find the corresponding optimal sequence optimizing one or more performance criteria. A survey of the excusing literature reveals that the most commonly used performance criteria are:

(i) mean absolute lateness (MAL)

(ii) squared lateness (L^2),

(iii) sum total of earliness and tardiness ($\Sigma t(E_i + T_i)$; and

(iv) total aggregate cost function ($f(\sigma,d)$).

One of the earliest works in minimizing MAL is by Kanet(1981) Among others, Kalra and Bagga (1983), Sundararaghavan and Ahmed (1984), Bagchi et al. (1986), Ragavachari (1986)) and Bector et al (1987, 1988), have considered special versions of due date determination problem with this performance measure. The CON due date method is used but the due date is constrained to be greater than or equal to the makespan (MS), the sum total of all processing times of all jobs (ie d MS). However, Chang (1987a) shows that this constraint can be somewhat relaxed without affecting the validity of Kanet's efficient algorithm to find the optimal schedule.

Kanet (1981) proposes an algorithm to determine the optimal schedule S which is obtained by the concatenation of partial job-set B to job-set A. His algorithm requires three necessary and sufficient conditions to be fulfilled:

(i) Jobs in set B are sequenced by longest processing time first (LPT), while jobs in set A are sequenced by shortest processing time first (SPT)

(ii) If n is even, /B/ = /A/, otherwise /B/ = /A/ + 1.

(iii) There is a one to - one mapping of jobs in A into jobs in B such that

$K \ A \dashrightarrow j \ B \implies P_k \leq P_i$

However, Kalra and Bagga (1983) present a counter example and state that the three conditions are necessary but not sufficient. They offer an alternative algorithm to determine the optimal schedule on the basis of a lemmia which states that the longest job must be processed before d in any optimal sequence. The conjecture made by Kanet (1981) about the shape of the optimal schedule was proved by Ragavachari (1986). He proved that an optimal schedule for any common due date will be V-shaped, meaning that in the optimal schedule the jobs are processed in decreasing order of processing times until the shortest job is completed after which the jobs are scheduled in increasing order of processing times. Eilon and Chowdhury (1977) have proved the V-Shapedness of the optimal schedule for a class of related single-machine sequencing problems which has lately attracted much research attention, see Hall (1986) and Bagchi et al (1987a, 1987b). It is also noted that the algorithm proposed by Kanet (1981) is similar to one of the algorithm suggested in Eilon and Chowdhury (1977).

Sundararaghavan and Ahmed (1984) further extend the results to the multi-machine problem. They provide an algorithm to determine the optimal schedule as well as optimal due date constrained by the makespan on each machine. Recently, Bacihi et al. (1986, 1987a) presented an algorithm for determining multiple optimal schedules under the restrictive assumption about the due date. It stated that the number of optimal schedules, assuming all P_i are different, is $2^{n/2}$ if n is even and $2^{(n-1)/2}$ if n is odd. However, for [2] each optimal schedule, the corresponding optimal due date d is different. A close examination of the results leads to the conjecture that 'half of the number of optimal schedules are just the antitheses of the other half'. Antithesis schedule implies that the objective function value for the schedule 1,2,3 -------------- n-1, n is the same as the objective function value for the schedule 1,n, n-1, ---------- 3,2, ie the order of the last n-1 jobs can be reversed without affecting the objective function value.

Chang (1985a, 1986f) suggests a duality approach to determining the optimal due date that minimizes the weighted sum of absolute values of job lateness. By manipulating the duality property of linear programming (LP), Chang proves that the optimal due date must coincide with the completion time of one of the jobs. Quaddus (1987a, 1987b) extends Chang's result to derive the optimal job sequence under the assumption that all jobs have equal weights. Similar optimal results for different versions of the problem, using different approaches are also obtained Panwalker et al (1982) and Bagchi et al (1987a). In a recent paper, Chang (1988e) discusses an alternative proof of his optimal result using Kuhn - Tucker's optimality conditions.

Panwalker et al. (1982) consider a total aggregate penalty function to be minimized. They provide the algorithm following two lemmas to determine an optimal sequence and the corresponding optimal due date. Their penalty function is based on the per unit time cost of due date, earliness or tardiness the job represented by P1, P2 and P3 respectively. They prove that for any specified sequence σ, there exists an optimal due date equal to C_{1k1}, where k is the smallest integral value greater than or equal to $n(P_3 - P_1)/(P_2 + P_3)$.

Recently, Chang (1986a) proved the same result using the duality theorem of LP for this type of performance measures. Seidmann et al, (1981) also consider the same type of objective function with a slight variation to find the optimal due date for each job and the corresponding optimal sequence. In this case P_1 is the per unit lead time penalty. This shows that;

if $P_1 \leq P_3$, $\quad d_i = t_i \quad i=1,2$ -------n;

otherwise $\quad d_i = \min(A.\Sigma ti)$

$i = 1,2,$---------------n.

Where A represents the lead time that customers consider to be reasonable and expected. They also prove that the SPT sequence will be optimal for this type of problems. Chang (1987c) considers the problem of finding the optimal common due date and the optimal job sequence of minimize the maximum deviation of the job completion time about the common due date. It is shown that the problem can be converted to an equivalent LP minimization problem. Based on the strong duality property of LP, Chang derives a closed form optimal solution. Using a similar approach. Chang (1988b) obtains a closed form optimal solution to the constant flow allowance problem and shows that the optimal solution is independent of job sequence. In another study, Chang (1988c) considers the problem of assigning optimal common due dates with limited completion time deviations.

It appears that Chang (1984) is the only paper in this category which attempts to find an optimal due date using the TWK due-date assignment method. The objective is to minimize squared lateness. Cheng shows that the optimal value of the common processing time multiply can be obtained by differential calculus and the optimal sequence as STP. Cheng (1986e, 1987d, 1988a) continues his study and generalizes the results to problems with TWK - power due date and random processing times.

2.13 DYNAMIC JOB SHOP SITUATION

In a dynamic job model the number of jobs available for processing varies overtime. Jobs continually enter and leave the production system in a random manner governed by some probabilistic laws. Incorporating this dynamic and stochastic behavior of the job arrival in the theoretical model renders the result thus obtained more applicable in realistic situations. Analysis of the dynamic model is usually so complicated and difficult that a feasible analytical solution procedure can hardly be found and computer simulation becomes the only feasible method of analysis.

The research effort in a dynamic job shop may best be discussed by classifying the literature into two categories as follows.

In the first category we will analyse the important results relating to due date assignment methods which have been studied to test their performance as well as the performance of various dispatching rules. Conway (1965) studied the effect of due date assignment method on the performance of various dispatching rules.

He considered the: (i) COW (ii) TWK (iii) SLK and (iv) RAN due date methods and found that the NOP is the most effective method of assigning due dates with respect to the criterion of meeting due dates at high level of job utilization. He explains that it is due to a large proportion of job's flow time is spent in waiting for service and the waiting time is proportional to the number of operation of a job.

Eilon and Chowdhury (1976) compared two approaches of assigning due dates:

(i) the assigned due date is a function of job characteristics only (e.g TWK, SLK, NOP) and

(ii) the assigned due date is a function of job characteristic and current shop status (e.g JIS, JIQ)).

Their results show that the latter method of assigning due dates, when used in conjunction with due date oriented dispatching rules, performs better than the former one. Similar results are reported by Ragatz and Mabert (1985).

Baker and Bertrand (1982) perform and experimental study of the effects of due date tightness on shops performance i.e. it is shown that in the situation where due dates is extremely tight the choice of due date assignment method is relatively unimportant and the use of a flow time oriented sequencing rule is preferable. On the other hand, in the situation where due date is extremely loose the choice of sequencing rule is relatively unimportant but a due-date assignment method which assigns due date in proportion to the workload of the production system could result in better performance.

Baker and Bertrand (1981) compare: (i) CON, (ii) SLK, and (iii) TWK due date assignment methods, and show that a rule for determining the flow allowance of a job should be based upon the job's length. Two work load Scenarios: random workload pattern and controlled workload pattern are examined and it is concluded that in complex production control system it might be desirable to have a strategy for due date selection that depends on the strategy for order release, since the latter will affect the workload behavior.

Baker, and Bertrand (1981b) further continue their investigation and introduce a modified due dated selection rule which functions effectively in the conjunction with internally-set deadliness and which may be adapted to both tight and loose conditions in the due dates.

Kanet (1982) compares NOP,PPW and TWK due date rule He finds that TWK is superior in terms of mean tardiness performance: Bertrand (1983) uses PPW as a Frame work in studying the effects on infinite Vs finite loading in setting due dates. He finds it desirable to modify PPW by recognizing planning workload in calculating a job's flow allowance Recently, Baker (1984) surveys the tactical rules and methods of assigning due dates.

Among other results, it is shown that TWK is typically the best of the five due date rules studied, which indicates that due dates should reflect work content. Baker also finds that NOP may also yield efficient due dates for avoiding tardiness completely. Ragatz and Marbet (1985) provide an excellent simulation analysis of due date assignment rules. They conclude that the dispatching rules used to sequence jobs at work centres influence shop performance; information about work centre congestion along a job's routing is more useful than information regarding generally shop conditions; and the use of more detailed information in predicting flow time provides only marginal improvement in performance over other rules that use more aggregate information.

In the second category we will discuss research work related to the due date determination problem in a dynamic job shop. The scheduling literature concerning the due date assignment can be further classified according to the method of solution employed as: computer simulation approach and analytical approach.

2.14 STATIC VS DYNAMIC JOB SHOP ENVIRONMENT

The literature is classified into static job shop situations and dynamic job shop situations. The main difference between these two situations is that jobs are simultaneously available in the former case while in the latter case one or more of the job characteristics are unknown but determined by probability laws. Therefore, in the static job shop, the problem of interest is to find the optimal due date and the corresponding optimal sequence whereas in the dynamic situation the problem is to find the due dates only.

The literature in the static job shop is analysed from two perspectives. First the due date is constrained to be greater than or equal MS; second, the optimal due date and optimal sequence are to be determined when the due date assignment method is specified.

The literature on dynamic job shops is also reviewed under two broad cases. In the first class, all the literature concerned with comparative and investigative studies to identify the best due assignment method: was discussed. It is noted that different due date assignment methods perform differently under different scheduling environment and with different dispatching rules. In the second class dealing with determination of optimal due date values was discussed. Two types of approaches have been used in the literature to study this class of problems: computer simulation approach analytical approach.

2.20 BASIC ANALYTIC MODELS

An obvious draw back of simulation and similar approaches relying on trial an error to determine the due date multiple factor is that to obtain reasonably accurate estimates of the parameters, a great number of simulation run is usually required. It is, therefore desirable to contrive some analytical approaches to establishing the optimal due date multiple factor in the dynamic job shop environment.

One of the earliest works is by Reinitz (1963). He views the shop operations as a Markov process and uses dynamic programming to assign optimal due date in machine constrained shops. Heard (1970) also used dynamic programming to assign optimal due dates. He considers determination of optimal due dates as sequential control problem. Since dynamic programming is always limited by the computational complexities of the problems considered, one needs to search for other more efficient, analytical approaches to determining optimal due dates.

Seidman and Smith (1981) present an analytical formulation of a dynamic single-machine scheduling problem with CON due dates and obtained the optimal lead time that minimized the expected aggregate cost per job. A similar problem is studied by Chang (1985b) in which the TWK due date assignment method is used. In a related study, Miyazaki (1981) proposed a total scheduling system approach which combines the due dates assignment and job sequencing procedures to reduce job tardiness in a job shop. On the basis of two formulae derived to give the mean and the standard deviation of job flow times, a method of due date assignment which contains a due date adjustment factor is proposed. The assignment method is combined with the sequencing procedure to construct a total scheduling system for reducing job tardiness. The experimental results show that the efficiency of the proposed system is better than that of the conventional scheduling system.

Cheng (1983b) suggests an analytical model to determine the optimal processing time and number of operations multiple for the TWK and TWK-NOP due date assignment methods in a dynamic job shop, subject to restrictive assumptions on queue discipline and processing time distribution. The analytical results are compared with the experimental results obtained from the simulation of a hypothetical job shop under various shop conditions. The close agreement of these results reveals the validity of the analytical model. In addition, the results show that the TWK-NOP method is more effective in minimizing missed due date costs in a job shop. The cost model considered in this research is very general since no specific contributions for the underlying random process are assumed. Thus it argued that the result can be applied to actual practice and the derivation of the optimal due date assignment policy becomes a simple process that can be easily implemented to help improve shop performance Cheng (1986(b)) also proposes a method of assigning due dates in a single-machine shop employing the SPT dispatching a rule. A heuristic approach to determining the optimal due date which minimize the average amount of missed due dates is also suggested. The effectiveness of the method is evaluated by computer simulation of a hypothetical job shop having different processing characteristics and under various shop conditions. It is shown that, despite its simplicity the heuristic method is able to assign accurate dates effectively.

The analytical approach has rarely been applied to dynamic job problems and a literature search reveals that much more work can be done in this area.

As is evident from the literature search, that there is paucity of applied papers, thus future research efforts should be directed to apply the analytical models proposed for different scheduling problems in practical situations. Cheng (1983a, 1983b) proposed two models to study due date determination and scheduling in the dynamic job shop. The results obtained from the models are very general and establish the validity of the model. With the relaxation of the assumption on the processing time distribution, the model developed in Cheng (1983b) is still able to yield accurate results for moderately loaded shops. It is argued that the model could be applied to analyze a small fabrication shop in actual practice. It is thus a worthwhile study to test the applicability of the theoretical results of these and other analytical models in real production situations.

Previous work by Miyazaki (1981) and Cheng (1985, 1986) has lead to results which minimize mean squared derivations between due dates actual completion times when certain single parameter rules are used. The due dates specified by these rules may be viewed in terms of predicted job completion times. Enns (1993) extended the work of Miyazaki and Cheng by considering the distribution of prediction error. If the distribution of errors associated with completion time predictions can also be determined, then, statistical analysis can be used to determined expected delivery performance at due dates other than those set equal to expected completion times. In other words, a due date setting model which allows management to control expected delivery performance can be developed. Another objective of Enns was to evaluate the impact of using dynamic shop load information in making flow time predictions. If flowtime predictions can be significantly improved through use of such information, costs related to deviation between actual completion times and promised delivery dates can be reduced. These costs, reflected in various earliness and tardiness related measures are considered a key indicator of performance in most job studies.

Sufficient conditions under which the Jackson decomposition principle may be applied are as follows:

(1) Jobs arrivals are randomly generated by a poisson process with a stationary mean.

(2) Operation processing times are independent and all generated from negative exponential distributions with the same mean.

(3) The routing of jobs is specified by probabilities in a fixed transaction matrix.

(4) Jobs in queue at each machine are processed on a first come first served. (FCFS) basis.

Under these conditions the job shop system may be analysed in terms of a network of independent queues. Such a network is presently referred to as a Jackson queuing network. It is important to note that flowtimes are independent of due date setting in these case .

Analytical results to determine parameters which minimize mean squared differences between due dates and actual completion time for several due dates setting rules have been derived. These are based on assumption constant with the Jackson decomposition principle plus assumption of equal steady state utilization at each machine. Three single parameter rules for which such result have been derived are the constant (CON), total work constant (TWK) and processing plus waiting time (PPW) rules. These rules may be stated as follows:

$$DD_i = O_i + \overset{j=1}{K_{CON}} \quad \text{----(1)}$$

$$DD_{iTWK} = O_i + \sum_{j=1}^{n_i} P_{i,j} K_{TWK} \quad \text{----(2)}$$

$$DD_{iPPW} = O_i + \sum^{n_i} P_{i,i} + n_1 K_{DDW} \quad \text{----(3)}$$

Where

DD_i due date for job i

K due date for rule tightness parameter

O_i arrival date for job i

n_i number of operations in job i

P_{ij} processing time for operation j of job i

Miyazaki (1981) derived an exact formula for the processing plus waiting (PPW) due date setting rule parameter that will minimize mean squared error. A method of approximating the flowtime variance associated with jobs having a specific number of operations was also developed. This variance can be viewed in terms of the lateness variance. Miyazaki suggested that an appropriate method of setting due dates was to set flowtime allowances equal to the expected flowtime plus a multiple of the standard derivation of lateness. Such an approach would allow control over expected tardiness.

Miyazaki tested his due date setting model against a total work content (TWK) due date setting model. Average flow allowances were set equal for both models. The due dates based on Miyazaki's steady-state flowtime prediction did result in better delivery performance.

Cheng (1985) was able to derive an exact formula for determining steady-state flowtime variance. Later he analytically determined due-date rule parameters that minimize mean squared error for the TWK due date setting rule and another two-parameter due date setting rule (Chang 1986) This second rule called TWK + NOP, had a parameter associated with both the total processing time and the number of operations. The fact that the parameter for TWK portion of the TWK+NOP rule turned out to be 1.0 making this rule equivalent to PPW, is consistent with what would be expected under the Jackson queuing network assumption and equal machine utilizations.

Baker and Kenet (1984) reviewed Miyazaki's study and presented evidence that TWK due-date settings resulted in lower tardiness than Miyazaki's rule when the due date dependent dispatch rule is used. Since the benefits of using due-date-dependent dispatch rules are well documented, Baker and Kanet questioned the value of Miyazaki's approach. There is, however, a different perspective which can be taken. Research involving due-date dependent dispatch rules has so far relied upon analysis of previously generated data to develop flowtime prediction relationships. Studies by Eilon and Chowdhury (1976), Weeks (1979), Ragatz and Marbet (1984) and Vig and Dooley (1991) are examples. None of these studies have examined the distribution of prediction errors. Therefore, no mechanism to set delivery due dates on the basis of performance targets has been developed.

Bertrand (1983) made a distinction between the due dates used for internal shop floor control and the due dates quoted to customers. The former were termed internal due dates (IDD) while the latter were termed extract due dates (XDD). This distinction is useful in developing a due-date-setting model based on flowtime prediction if IDD values are consistently set equal to predicted completion times. The difference between internal and external due dates can be viewed as a delivery strategy allowance. The size of this allowance should depend on the distribution of flowtime prediction errors and the desired level of delivery performance. The idea of distinguishing between internal and external due dates and using the estimated lateness distribution to control tardiness can be clarified by referring to Fig. 2.4. Lateness is defined to be the deviation of completion time from the due date and can also be either positive or negative. Internal lateness (IL) is thus the completion time deviation from the (IDD), while external lateness (XL) is the deviation from the XDD. For simplification, variation in the processing time and number of operations in each job are not represented in fig 2.4 shown below:

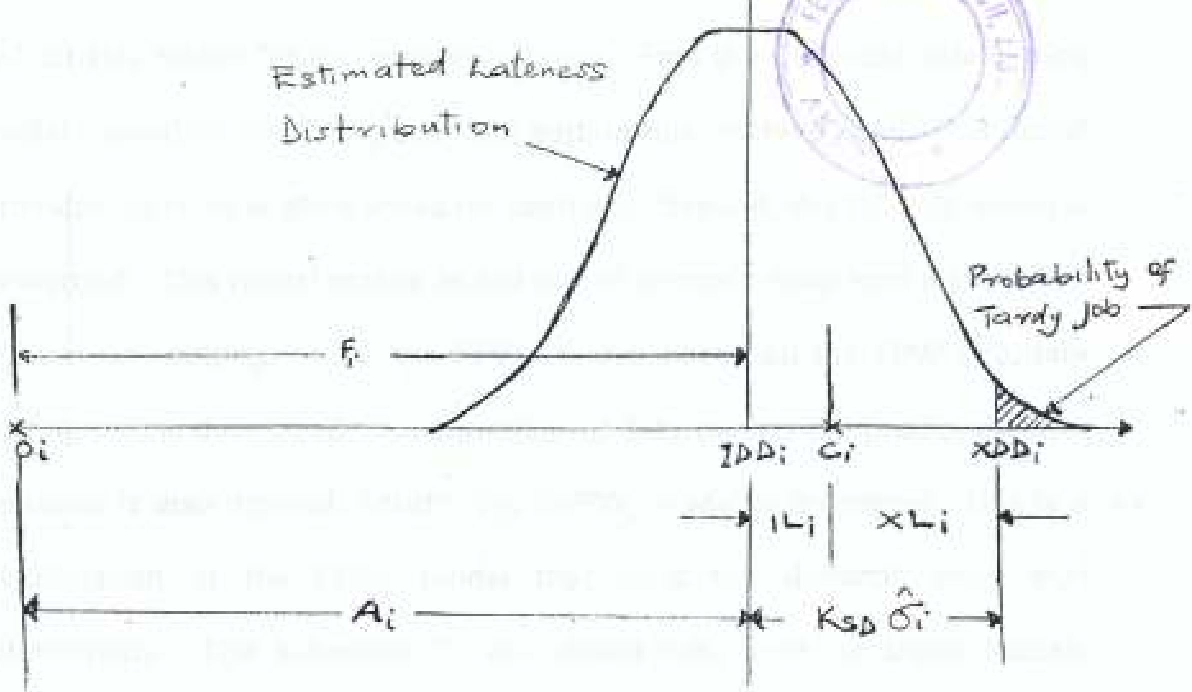


Fig 2.4: Time and state references for job flow
Enns J.T., 1993.

Where:

A_i	Job flowtime allowance
C_i	Job completion date
F_i	Actual job flow time
IDD_i	Internal (target) due date
IL_i	Internal lateness
K_{sD}	Safety allowance factor
O_i	Job order arrival date
XDD_i	External (delivery) due date
XL_i	External lateness
δ_i	Estimated standard deviation of lateness

Enns (1993) extends the work of Miyazaki and Cheng by comparing the prediction performance difference due-date setting models. The initial objective is to develop models which facilitate setting internal due dates that will closely match future completion times. First the CON due date setting model, based on the CON_p due date setting rule, is developed. This model provides equal flow allowances for each job. Second, the DCONp model is presented. This model makes added use of dynamic shop load information in due date setting. Third, the PPW_p model, based on the PPW due date setting rule,is developed. An equation for determining the prediction error variance is also derived. Fourth, the $DPPW_p$ model is presented. This is a modification of the PPW_p model that uses the dynamic shop load information. The subscript 'P' associated with each of these models indicates that the due date rule multipliers are being set to be consistent with predicted flowtimes.

These four basic analytical models are:

2.21 STATIC CONSTANT FLOWTIME PREDICTION MODELS SCON

Static constant flowtime prediction models, such as by Chang, where predicted flowtime is the same for all jobs and depends on a shop loading factor which is static. In this model, the expected flowtime and its variance are predicted using equations 1 and 2.

$$F_i = E(n)\,[\mu_p + (\pi\mu_n\mu_p^2/m(1-p))] \text{ ---- } (1)$$

$$\sigma^2 = (E(n^2) + E(n) - E(n^2))\,[\mu_p + (\pi\mu_n\mu_p^2/m(1-p))] \text{ ---- } (2)$$

where

F_i	=	expected flowtime for any randomly selected job
E(n)	=	expected number of operations in any random job.
λ	=	arrival rate of jobs to the shop
μ_n	=	mean number of operations per job
μ_p	=	mean operation processing time
m	=	number of machines in the shop
e	=	Steady state shop utilization.

2.22 DYNAMIC CONSTANT FLOWTIME PREDICTION MODELS DCON

These are basically similar to static models except that the shop load factor vary over times. In this model, the equations for SCON hold except that ρ is replaced with a dynamic value ρt whose value is given as:

$$\rho_t = W_t J_t / A_t M \text{ ----------- Eqn 3}$$

where

ρ_t = short term utilization estimate time t

W_t = work remaining in shop at time t

J_t = jobs remaining in the shops at time t

A_t = allowance remaining for work in shop at time t

M = number of machines in the shop

2.23 STATIC PROCESSING PLUS WAITING TIME PREDICTION MODELS SPPW

Static processing plus waiting time prediction models, such as by Miyazaki, where flowtime is a sum of individual processing time plus a product of number of job operations and a waiting time average which is predicted to be the same for all machines on an aggregate basis. With this model, the expected flowtime F_i and its variance σ^2 are expressed mathematically as:

$$F_i = \sum_j P_{ij} + n_i [\pi \mu_n \mu_p^2 / m_1 - \rho)] \quad ---- (4)$$

$$\sigma^2 = n_i [(\pi \mu_n \mu_p^2 / m(1-\rho)^2 + 2\pi \mu_n \mu_p^3 / m(1-\rho)] \quad ---- (5)$$

Where

P_{ij} = processing time for operation j of job i

n_i = number of operation in jobi

λ = arrival rate of jobs to the shop

μ_n = mean number of operation in any job

μ_p = mean operation processing time

m = number of machines in the shop

ρ = steady state shop utilization

2.24 DYNAMIC PROCESSING PLUS WAITING TIME PREDICTION MODELS DPPW

This is the same as the static processing plus waiting time prediction SPPW except that the shop loading factor ρ is replaced with a dynamic factor ρ_t which reflects short term utilization at a particular time t.

Enn's simulation revealed that the DPPW provides best results in terms of more accurately predicting job-shop flow times and can therefore be more reliably used in due-date setting. The major limitation of DPPW is that waiting times are treated on an aggregate basis which implies that each machine has the same expected utilization rate. This assumption is far from reality as DPPW may provide unrealistically high estimate for jobs with few operations on relatively free machines. A far more serious limitation on the four models discussed by Enn is that the data requirement are excessive and rather confusing. It does appear that these analytic models are introducing mathematical complexities which may render them inapplicable. On a more practical note, Vig and Dooley (1991) had tried to introduce elements of realism into the shop flowtime prediction process by formulating an empirical rule which estimates job flowtime based on sampling of recently competed jobs. There is also no known study that has accounted for external factors such as delays or waiting caused by electricity disruption, raw materials shortage, labor problems etc. These are factors that are far more critical to flowtime determination particularly in developing countries.

An ideal situation is one where waiting time can be predicted on each individual machine through periodic sampling. The Jackson's (1963) network, where the queue to a job-shop can be decomposed into different independent networks provides a realistic option for achieving this. Using Jackson's network, each facility can then be treated as an M/M/S queuing system. However,the major problem with this seemingly obvious solution is the determination of the job arrival rate for the individual machines. Hiller and Liebermann (1990) expressed this arrival rate λ_j in terms of stream of arrival rates from outside the shop and from within the shop(i.e from other machines) as shown in Equation 6.

$$\lambda = a_j + \Sigma p_{ij}\lambda_i \quad i \neq j \text{ -------- Eqn 6}$$

where

a_j = arrival rate from outside system to facility j

λ_i = arrival rate from other facilities (other than j) into j

P_{ij} = the transition probability from facility i to j

The determination of λ_j therefore depends on a cumbersome estimation of transition probabilities and a general solution by simultaneous equations. It is probably this problem that has prevented the effective use of the Jackson's decomposition principle.

2.25 COMPUTER SIMULATION APPROACH

Any queueing system that can be described and for which data on arrival and service times can be obtained, can be simulated. Because most queueing problems involve the determination of the number of facilities that must be made available, and because we generally can estimate fairly closely what the optimal number is, it is usually not necessary to simulate very many different numbers of facilities to find the optimum.

The availability of computers has greatly reduced the time required to solve large queueing problems by simulation. Running time is often very short. Programming, which once required a great deal of time, can now be reduced by use of such special simulation languages as SIMSCRIPT. Many smaller queueing system can be simulated by hand.

The use of simulation in the queueing problem is particularly useful when either the process never reaches stability (as when a service facility is open for only a short time) or the transient states are critical (as in the opening of a department store on the day of a big sale). It s usually very difficult to study non-steady states of queues by analytic procedures but it is quite easy to do so by the use of simulation.

Simulation modeling should be regarded as "the next best thing to observing a real system in operation. Indeed, the basic contribution of a simulation model is that it allows partinental observation about the system to be completed overtime. These observation are then used to calculate the desired measures of performance.

Simulation typically represents the system as a whole, rather than in a segmented fashion as in mathematical models. As a result, all the "cause and effect" relationships among different components of the model are accounted for all times. These "cause and effects" relationships are readily identifiable because all simulation really does is devise a model that imitates the behaviour of real system (as closely as possible). Collection of observations is then effected by monitoring the behavior of the different model components as a function of simulation time.

One of the earliest works is due to Eilon and Hodgson (1967) who employ simulation model of a machine constrained shop to find a multiple of the estimated job processing time to be used in the assigning due dates which minimize several lateness penalty functions for various shop loads and dispatching rules. Jones (1973) provides an economic evaluation of a machine constrained job shop to evaluate dispatching rules, the amount of work-in-process inventory and due date lengths. However, Weeks and Fryer (1976) present a methodology which is directly related to the due date determination problem. It estimates minimum cost, due-dates in a job shop production system. They suggest using regression analysis techniques to analyze the simulation results. Both multiple linear and nonlinear regression are used to estimate the relationship between the response measures (e.g mean job flow time costs, mean job lateness costs, mean earliness cost mean job due date cost etc) of shop performance and the value of k, the multiple of total processing time employed in assigning due dates. Weeks (1979) continues this simulation study assigning attainable or predictable due dates in hypothetical labour and machine constrained job settings of varying size and structure, several predictable due date assignment rules are developed and it is concluded that assigning due dates based on expected job flow time and shop congestion information may provide more attainable due dates. He also confirms that better due dates performance appears to be achieved when due date oriented dispatching rules are employed and when the shop system is not structurally complex. In a recent paper, Cheng (1988d) studies the effect of integrating priority despatching with due date assignment and concludes that such an interpretation can lead to significant improvement in performance of both the dispatching and due date assignment rules.

Computer simulation has been a viable tool to study the dynamic job shop and to provide considerable insights into the complex scheduling problems. Weeks (1979) concludes that the due date assignment procedures, dispatching rules and shop structure affect performance in terms of meeting due dates. While predictable due date assignment methods are suggested, it is desirable to develop more predictable due date assignment procedures which are possible and economical from a practical view point.

CHAPTER THREE

3.00 MODEL DEVELOPMENT

The area concerned under this development are: shop flow prediction; Empirical determination of waiting time; treatment of in-process delay as well as due date setting.

Enn's (1995), developed a model for completion time prediction. The assumption in his analysis are that routings are random and that the distribution of operation processing times at each machine is identical. This means utilization of each machine is also equal. Furthermore, both the mean operation processing time and the steady state utilisation are assumed to be known.

The average total work remaining in the shop, W, equals the sum of average remaining work at each machine.

$$W = mr\phi \text{ ------------------ Eqn (3.1)}$$

W = average total work remaining in the shop

m = number of machines in the shop.

r = average remaining processing time per job in the shop

ϕ = average number of jobs at each machine

Using Little's Result (1961), ϕ can be replaced by λf. Furthermore, recognizing the $\rho = \lambda p$ allows equation (3.1) to be rewritten as follows:

$$W = mrf\lambda = \frac{mrf\rho}{P} \text{ -------------- Eqn (3.2)}$$

f = average flow time per operation at each machine.

p = average operation processing time

λ = average arrival rate of jobs at each machine

ρ = steady state utilization

Average flowtime per apparition can then be stated as follows.

$$f = \frac{WP}{mr\rho} \text{ ------ } Eqn\,(3.3)$$

It can be argued that better operation flowtime predictions will result if current shop loads, Wt, rather than average shops loads are used. Since shop loading is highly autocorrelated, the best indicator of short term shop loading is the current load. A dynamic version of equation (3.3) can be stated as follows:

$$f_t = \frac{W_t P}{mr_t \rho_t} \text{ ----- } (3.4)$$

f_t = predicted flowtime per operation at time t

W_t = total work remaining in the shop at time t

r_t = average remaining processing time per job at time t

ρ_t = short term utilization estimate at time t

The difficulty with this equation is that it contains too many unknowns. The shop load W_t, can be dynamically measured and m and p are assumed known but r_t and ρ_t are more difficult to determine. Only under certain conditions can the relationship between f and ρ be determined. Miyazaki (1981) and Cheng (1985, 1986) for example examine the relationship under conditions where Jackson queueing network assumption hold. Bertrand (1983) realized that the relationship between work load, W_t and utilization, ρ_t, is nonlinear. At high utilization rates a large change in work load has only a small effect on utilization. Therefore, he reasoned that the steady state utilization, ρ, which is assumed to be known, could be substituted for ρ_t without greatly affecting results. Therefore, equation (3.4) can be written as follows.

$$F_t \quad = \quad \frac{W_t P}{m r_t \rho_t} \text{ --------------- Eqn (3.5)}$$

The problems with the average remaining processing time per job, r_t also being unknown can be approached in several ways. It should be recognized that this value is a function of the dispatch rule used. For example, r_t would be higher with shortest- processing - time (SPT) dispatch than with first-come-first-serve (FCFS) dispatch. The reason is that with SPT jobs with long operation processing times tend to get delayed longer waiting in queue because of their lower priority. Bertrand (1983) circumvented the problem by assuming r_t to be a constant. He then use prior information, based on earlier simulation runs, to set the state value of r. There is however, another approach which may be taken. This is to estimate the value of r_t dynamically. First, it must be recognized that, as long as no assembly operations are involved, the following relationship holds.

$$r_t \quad = \quad \frac{W_t}{j_t} \text{ -------------- Eqn (3.6)}$$

r_t = estimated remaining processing time per job at time t

W_t = estimated remaining total processing time at time t

j_t = uncompleted jobs in the shop at time t

Substituting equation (3.6) into (3.5) yields the following result.

$$F_t = \frac{J_t P}{m\rho} \text{ ----------------- Eqn (3.7)}$$

The estimated flowtime per operation, F_t, for a given job i can be determined at the time of release by setting f_i, equal to the current value of F_t. The expected waiting time per operation can then be estimated using the following:

$$W_i = f_i - P \text{ ----------------------- Eqn (3.8)}$$

W_i = predicted waiting time per operation in job i

f_i = predicted flowtime per operation in job i

This value of W_i, is the same as the parameter that one would use in the processing plus waiting (PPW) due-date rule if the parameter were being adjusted for each individual job and if the objective was to set the due date equal to the predicted completion time. Therefore, the due-date rule based on the above analysis will be called the dynamic processing plus waiting ($DPPW_p$) due date rule,where the subscript 'p' is used to indicate that due date are being set equal to predicted completion times. The $DPPW_p$ due date setting rule can be written in the following form:

$$IDD_i = O_i + \sum_{j=1}^{ni} P_{i,j} + n_i\left[\frac{J_t P}{m\rho} - P\right] \text{ ---- Eqn. (3.9)}$$

IDD_i = internal due date for job i

O_i = order arrival date for job i

P_{ij} = processing time for operation i of job i

n_i = number of operations in job i

Using this formula, the internal due date (IDD) can be calculated at the time of job arrival, when O_i and t are equal. Intuitively, the equation makes sense in that as the jobs in the shop, J_t increases, the expected waiting time at each machine increases. If jobs in the shop, J_t, decrease, the calculated operation waiting time will decrease. Although the estimated waiting time per operation can theoretically become negative with very few jobs in the shop, tests using simulation confirmed that as long as the required utilization level, ρ, is reasonably high the shop load seldom drops this low.

This equation (3.9) describes the dynamic forecasting model (DMF) under conditions where both internal and external due dates are being set equal to predicted completion time. A provision for setting appropriate delivery safety allowances if tardiness is to be controlled is still lacking.

A second model, called job-in-system feedback model, (JMF) using this approach was developed to compare against the DMF. The number of jobs currently in the shop was used as an indicator of shop load. The due date setting equation for the JMF model can be written as follows:

$$IDD_i = O_i + \sum_{j=1}^{n_i} P_{i,j} + n_i \left[\left(\frac{J_t}{J_{avg}} \right) K_{ppw} \right] \quad \text{---- Eqn. (3.10)}$$

J_t = number of jobs in the shop at time t

J_{avg} = average number of jobs in the shop

K_{ppw} = static "tightness" parameter.

In order to set due dates equal to predicted completion times, appropriate values of J_{avg} and K_{ppw} must be chosen. This requires prior information.

A third model, called the work-in-process feedback model (WFM), was also tested. This model was based on the approach Bertrand (1983) used in that a static value of r was used and remaining processing time, Wt, replaced Jt as the workload feedback measure. The due date setting equation for the WFM can be written as follows:

$$IDD_i = O_i + \sum_{j=1}^{n_i} P_{i,j} + n_i \left[\frac{W_t P}{m r \rho} - P\right] \quad \text{---- } Eqn.\ (3.11)$$

A set of simulation experiments was designed to obtain results from the DFM, JFM, and WFM that could be compared. The shop environment assumed was the same as that described by Baker (1984). The shop has four machines. The number of operations per job is uniformly distributed between two and six. Poisson job arrivals are negative exponentially distributed operation processing times, with mean of 1.0 are assumed.

Table 3.1: Comparison of DFM, JFM, and WFM prediction performance mean

Model	Utilization	PD rule	Flowtime	Lateness	MAE
DFM	0.89(0.03)	EDD	35.0(10.7)	-0.53(0.55)	7.2(2.6)
JFM	0.89(0.03)	EDD	34.2(10.8)	-1.33(1.09)	7.0(2.6)
WFM	0.89(0.03)	EDD	35.0(10.8)	-0.27(1.20)	7.3(3.1)

Enns (1995)

This comparison makes DFM look favourable since it alone requires only expected utilisation, ρ, and mean task processing time,p, assumptions. The JFM requires prior information on J_{avg} and the appropriate setting of K_{ppw}, while WFM requires prior information on r. In these experiments values were set using preliminary runs with the same model. Under less ideal conditions, one would expect the relative performance of JFM and WFM to deteriorate because of less appropriate parameter selection. Therefore, the DFM can be considered a superior forecasting model when compared with the JFM and WFM.

2. MODEL DEVELOPMENT FOR DELIVERY PERFORMANCE CONTROL

The expected deviation between actual and predicted completion time will be a function of the number of operations in the job only under certain conditions. These conditions occur when behavior at each queue in the system may be treated independently, as under the Jackson queueing network assumptions (Enns 1993). Since variances are addictive, the expected error will be a function of the number of operations in the jobs under these conditions. All assumptions are consistent with those of the Jackson queueing network when FCFS dispatch is used. Therefore one would expect that a good method of setting delivery safety allowances under FCFS dispatch should take the number of operation into account. Intuitively, the queueing behaviour at individual machines would also seem to be quite independent under SPT dispatch.

Enns developed two methods of estimating lateness variance: one for use with due date independent dispatch and one for use with due-date dependent dispatch.

The first method, known as operation lateness variance (OLV) estimation, assumes that lateness variance is a function of the number of operations in the job. Delivery safety allowances should be set proportional to the number of operations in the job under these conditions. The method is appropriate for use with FCFS and SPT dispatching on estimate of lateness variance per operation can be dynamically obtained using lateness feedback worked well. In the following formula, the mean square error per operation for jobs already completed is used to estimate forecast error variance per operation.

This form of equation is common to forecasting models where the variance of error is being estimated by exponential smoothing (see Smith 1989, pp 95, for example). If it is assumed that the lateness per operations unbiased and normally distributed, such an estimation is appropriate.

$$\sigma_{t}{}^{2}{}_{oLV} = (1-\alpha)\,\sigma_{t}{}^{2}{}_{,\,oLV} + \alpha\,\left(\frac{C_k - IDD_k}{n_k}\right)^2 \text{----} Eqn\,(3.12)$$

$\sigma^2_{t,oLV}$ = estimated variance of lateness per operation at time t

α = exponential smoothing constant

n_k = number of operation in last job, k, completed

c_k = completion date of the last job k, completed

IDD_k = internal due date for the last job, k, completion

The estimated variance of lateness per operation $\sigma^2_{i\,oLV}$, for a new job i is set equal to the current value of $\sigma^2_{i,\,oLV}$ at the time of release. Since variances are additive, the square root of $n_i\sigma^2_{i,\,oLV}$ becomes the estimated lateness standard derivation for the job. This lateness standard derivation can be multiplied by the number of standard deviations of safety allowance desired to obtain an appropriate delivery safety allowance. The equation for setting customer delivery dates (XDD) can be stated by adding the delivery safety allowance to the internal due date (IDD) given by equation (3.9).

$$XDD_i = O_i + \sum_{j=1}^{n_i} P_{i,j} + n_i \left[\frac{J_t P}{m_p} - P\right] + K_{SD}\sqrt{n_i \sigma_{i,\,oLV}} \text{----} Eqn\,(3.13)$$

. XDD_i = external (or delivery) due date for job i

K_{sp} = number of lateness standard deviations of safety allowance desired

$\sigma^2_{t,\,oLV}$ = estimated variance of operation waiting times at time job i is released.

The second method, named job lateness variance (JLV) estimation, assumes that the lateness variance is not a function of the job characteristics. The method is appropriate when a due-date dependent dispatch rule is being used, such as EDD or SCR. An exponentially smoothed value of mean square forecast error is calculated at the time of each job completion. This value is treated as estimated of the current lateness variance,

$$\sigma_t{}^2{}_{,\,jLV} = (1-\alpha)\,\sigma_t{}^2{}_{jLV} + \alpha\,(C_k - IDD_k)^2 \text{----} Eqn\,(3.14)$$

$\sigma^2_{t,\,jLV}$ = estimated variance of lateness at time t

The estimate of the job i lateness variance, $\sigma^2_{t,\,jLV}$ is set equal to the current value of $\sigma^2_{t,\,jLV}$ at the time of job release. The delivery due date setting equation using JLV can then be stated as follows;

$$XDD_i = O_i + \sum_{j=1}^{n_i} P_{i,j} + n_i \left[\frac{J_t P}{m_p} - P\right] + K_{SD}\,\sigma_{i,\,JLV} \text{----} Eqn\,(3.15)$$

$\sigma^2_{t,\,JLV}$ = estimated variance of job waiting time at time job i is released.

3.01 SHOP FLOW TIME PREDICTION

The predicted flowtime F_i of a job i can be expressed as follows:

$$F_i = \sum_j [P_{ij} + W_{ij}] \quad ----Eqn. (3.16)$$

Where

P_{ij} = processing time of job i on machine facility j

W_{ij} = waiting time of job i on machine j

Since W_{ij} is not known ahead of time, it can be predicted by an expected value.

W_j = $E[W_{ij}]$. The value of W_j is the mean of waiting times on individual machines which can be calculated on a periodic basis for a dynamic estimate. The mean W_j and the variance σ^2 are given in Equations (3.17) and (3.18).

$$W_j = \frac{\sum_i [W_{ij}]}{n_j} \quad ----Eqn. (3.17)$$

$$\sigma^2{}_j = \frac{\sum_i [W_{ij} - W_j]^2}{(n_j - 1)} \quad ----Eqn. (3.18)$$

where n_j = number of the jobs for the periods under observation.

It should be noted that this flowtime prediction is totally as a result of statistical sampling and does not make any assumptions on arrival and service distributions, or service disciplines.

To forecast this waiting time for future periods, an N- period moving average or exponential smoothing procedure can be employed. This is explained further in later sections.

3.02 EMPIRICAL DETERMINATION OF w_{ij}

The value of wij for any job can be determined using Equation (3.19) below.

$w_{ij} = D_{ij} - A_{ij} - P_{ij}$ -------------------- Eqn (3.19)

where

A_{ij} = arrival time of job i on machine j

D_{ij} = departure time of job i on machine j

A job card can therefore be created to record arrival, departure and processing times for all jobs on all processing machines. Every machine should also keep a machine load card to record the number of jobs n_j for every period of observation.

3.03 TREATMENT OF IN-PROCESS DELAYS

The time between the arrival of a job on a machine A_{ij} and its departure on the immediately preceding process D_{ij-1} is known as the in - process delay. This in-process delay ψ_{ij} is given in equation (3.20) as follows:

$\psi_{ij} = A_{ij} - D_{ij-1}$ ---------------------- Eqn (3.20)

Although in-process delay ψ_{ij} is as a result of a shop's materials handling capability, its value can be estimated against machine$_j$. In-process delay time can be either be calculated separately or included in the waiting time calculations. If the later option is adopted Equation (3.19) for waiting time will now read:

$w_{ij} = D_{ij} - D_{ij-1} - P_{ij}$ --------------- Eqn (3.21)

It is indeed computational easier to use Eqn (3.21) than Eqn (3.19) and (3.20) separately.

3.04 DUE DATE SETTING

Due date DD_i can in general be set as follows:

$DDi = O_i + F_i$ ---------------------- Eqn (3.22)

where O_i = arrival date for job i

and F_i = expected flowtime as previously defined.

This estimate is based on the mean of the individual machine's waiting times and can be regarded as a baseline due date setting. However, for management and negotiation purposes, other scenarios must be properly examined.

Worst case scenario: This is the case of high machine loading where the load distribution density is unaltered but waiting time is on the very high side on each and every machine on which the job is processed. Under this condition, the expected waiting time can be accommodated to include the highest possible variation within the normal shop load. The worst case scenario waiting time W_j, flowtime F_i and due date setting DDi are given in Equations (3.23), (3,24) and ((3.25) respectively. Ideally the worst case scenario for a new job is when the FCFS discipline is employed.

$$\overline{W}_j = W_j + K\sigma \text{ ------ } Eqn.\ (3.23)$$

where k is multiple which can be set to 3 in line with Shewhart's control limits.

$$F_i = \sum_j [P_{ij} + \overline{W}_j] \text{ ----- } Eqn.\ (3.24)$$

$$DD_i = O_i + F_i \text{ ----- } Eqn.\ (3.25)$$

Best case scenario: This is the case of low machine loading where the load distribution density is unaltered but waiting time is on the low side on each and every machine on which the job is processed. Similarly, for this scenario, the waiting time $\underline{W}_j$ is a shown in Eqn (3.26) while other parameters such as flowtime and due date assumes. the same forms as Equations (3.24) and (3.25) respectively. Ideally, the best scenario for a new job is when the PRIORITY service discipline is employed.

$$\underline{W}_j = W_j - K\sigma \text{ ----------------------------- Eqn (3.26)}$$

Waiting time estimation obtained through empirical methods not only reflects job characteristics, shop status, system characteristics but external factors as well.

3.05 FLOW CHARTS

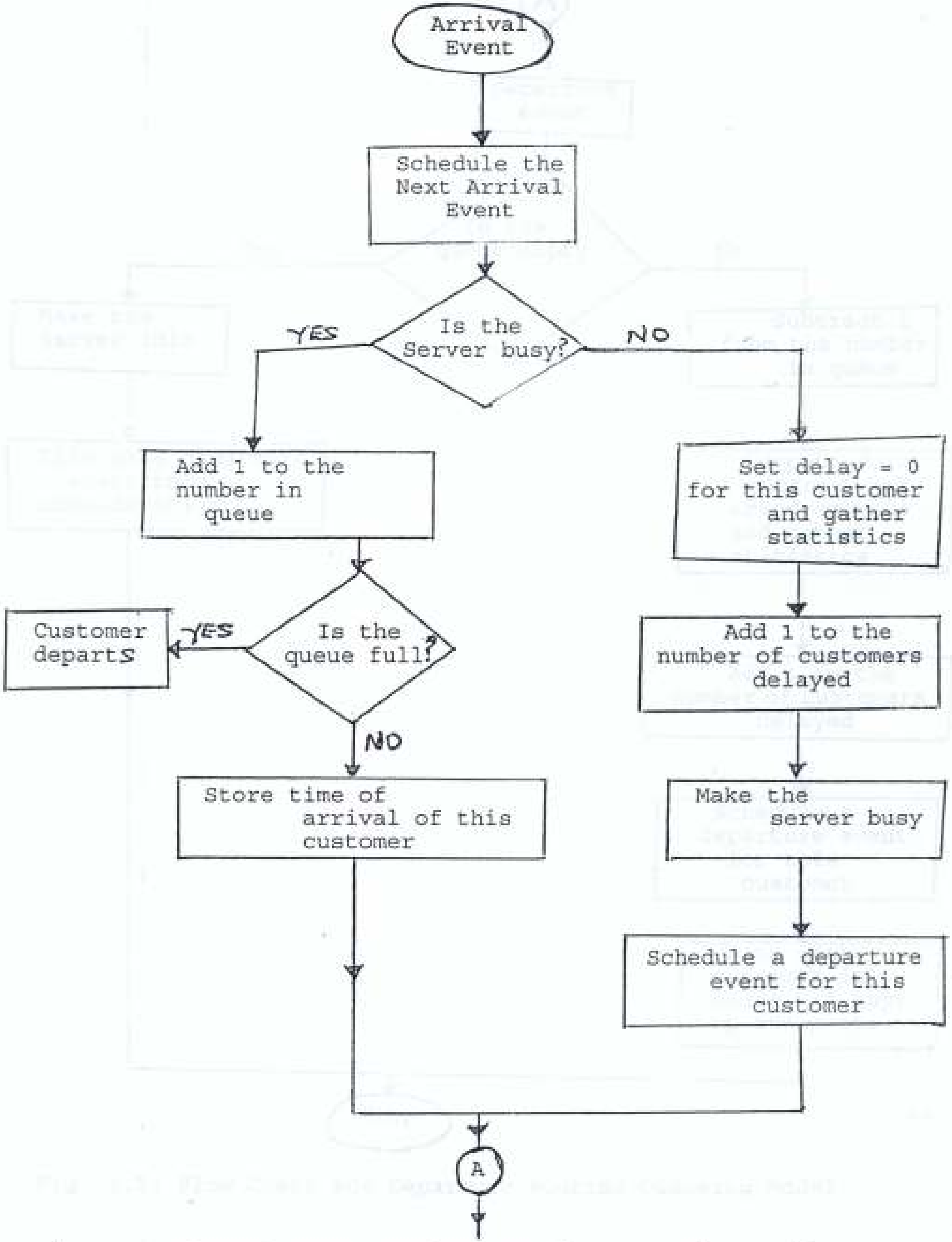


Fig. 3.1: Flow Chart For Arrival Routine, Queueing Model

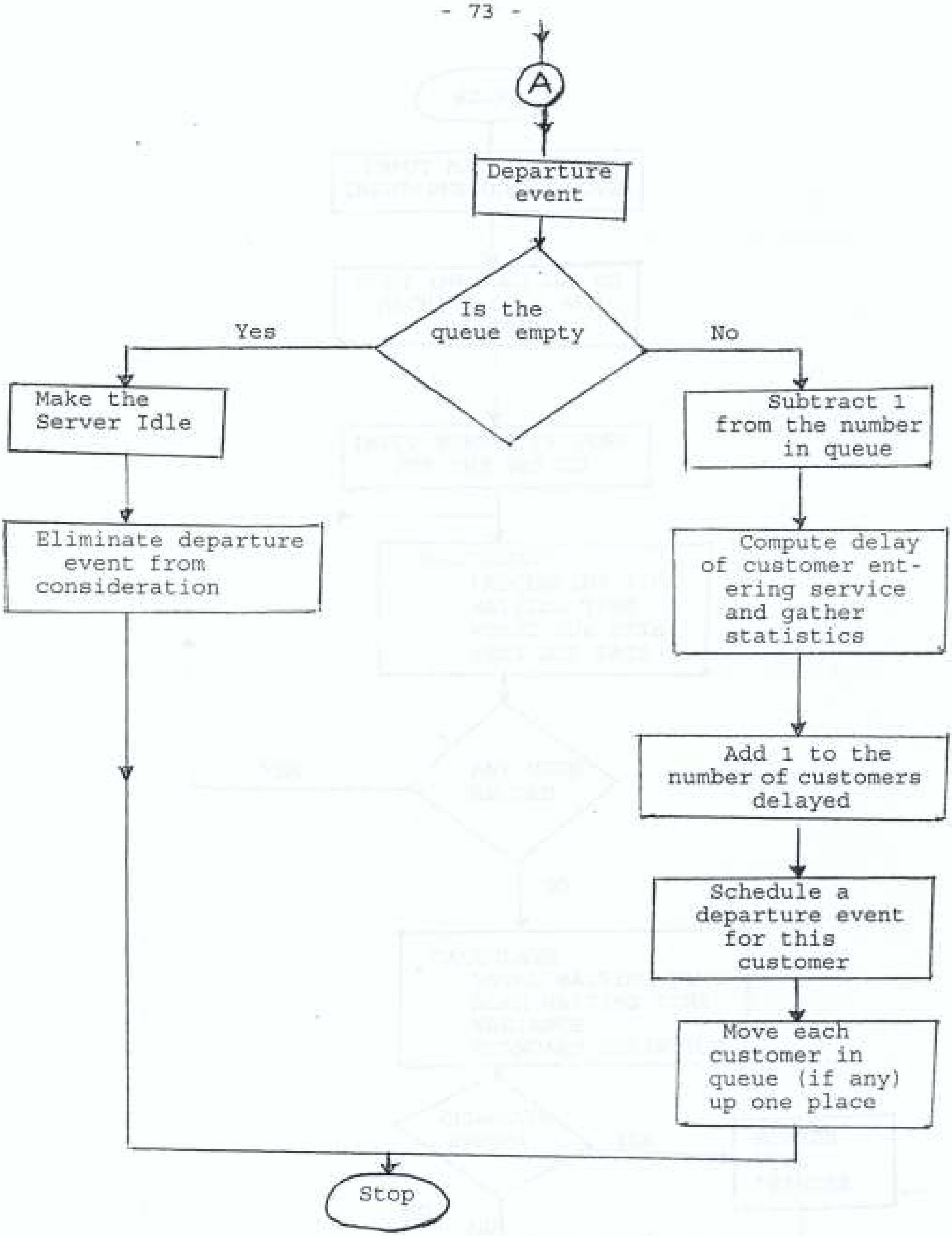


Fig. 3.2: Flow Chart For Departure Routine Queueing Model

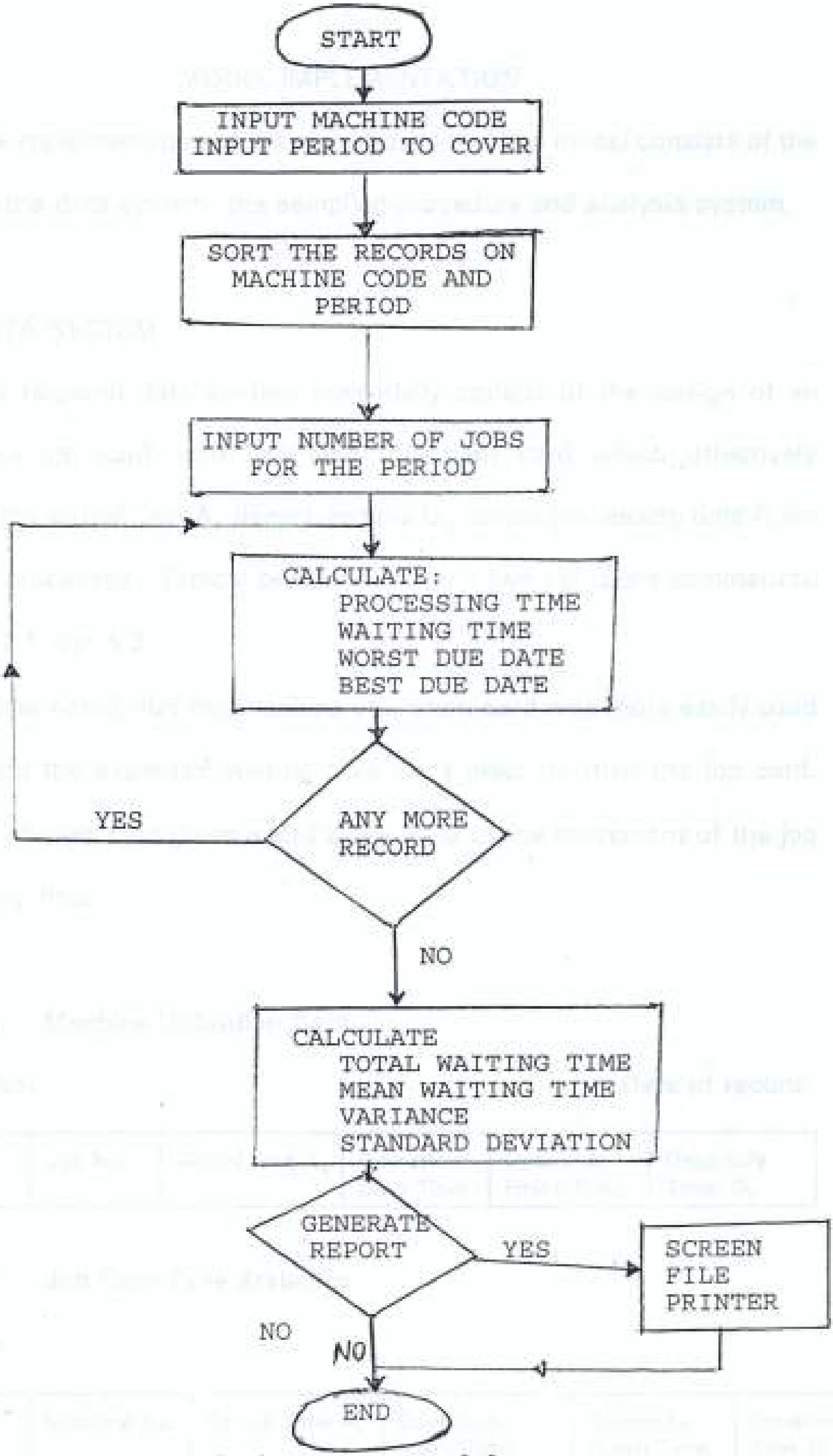


Fig. 3.3: Flow Chart Of The Report Module

CHAPTER FOUR

4.00 MODEL IMPLEMENTATION

The implementation of the empirical application model consists of the design of the data system, the sampling procedure and analysis system.

4.01 DATA SYSTEM

The required data system essentially consist of the design of an appropriate job card an/or machine utilisation card which effectively collected the arrival time $A_{ij,}$ departure time D_{ij}, actual processing time P_{ij} for every job processed. Typical proformas for the two cards are summarized in tables 4.1 and 4.2.

It was noted that the machine utilization card was more easily used to calculate the expected waiting time on a machine than the job card. However, the job card gives a bird's eye view of the movement of the job on the shop floor.

Table 4.1: Machine Utilization Card

Machine no: Date of record:

Serial No.	Job No, i	Arrival time A_{ij}	Operation Start Time	Operation Finish Time	Departure Time, D_{ij}

Table 4.2: Job Card Time Statistics

Job name:

Operation No j	Machine No	Arrival Time A_{ij}	Operation Start, Time	Operation Finish Time	Departure Time D_{ij}

4.02 SAMPLING PROCEDURE AND ANALYSIS

The machine utilization card was the major instrument for the sampling procedure. The card was filled daily and its results summarized on a monthly basis to determine the average waiting time W_j on a machine j for a particular month.

To predict the waiting time for a new month or period, N-month moving average was employed using expected waiting times generated over the current and proceeding N-months. *The collation, retrieval and analysis* of these data was done on a Personal Computer (PC).

4.03 SOURCE OF DATA COLLECTED

The data used in this research work was collected from "DON BOSCO CENTRE", ONDO. This centre was established in the year 1987 by the Catholic missionary under the supervision of Italian Engineers and some Nigeria technicians.

The institution have it in mind to produce skilled technicians in Mechanical Engineering craft and solving mechanical problems of the community by creating a workshop for jobshop. Which was fully commercialized to have enough funds to meet the demand of the institution.

Facilities available in the workshop include:

(i)	Lathe machine	12
(ii)	Milling machine	4
(iii)	Sharpening machine	2
(iv)	Grinding machine	4

(v) Power saw machine 3

(vi) Drilling machine 4

(vii) Press machine 2

(viii) Welding machine 6

(ix) Bending machine 2

Through the permission of the Principal and the Vice-principal, the experiment was performed in this shop and result were collected.

4.04 SOFTWARE DESIGN AND IMPLEMENTATION

The Jobshop Flowtime and due date prediction was implemented using Paradox 4 Relational database management system. The coding language is known as Paradox Application Language (PAL). PAL enables the development of a menu-driven, interactive, user friendly and intelligent software package.

The system keeps a database of all data relating to Jobshop and due-date prediction. Information is stored in files. A file is made up of records. A record is made up attributes arranged in columns in a table. For instance, a record of a particular job handled by machine LMOI would contain such attributes like Arrival Date, Arrival time, Departure time, processing time, waiting time etc. That is, each job handled by a particular machine constitute a record.

4.04.1 FILE STRUCTURE

In designing the structure of a file, the field type and field length are explicitly defined. The field type could be Alphabetic, Numeric, Date or Currency. The field length refers to the maximum number of characters or digits the field or attribute can take. Below is the list of files and their attributes.

JOB: The file contain information relating to all jobs brought to a particular Jobshop. The attributes are machine-number, Job-number, Time of arrival, Date of arrival, starting date, Time finish, finish date , Time finish etc.

1. JOB FILE

No	FIELD NAME	FIELD TYPE	LENGTH
1	JOB - NO	A	6
2	MACHINE - NO	A	6
3	D - ARR	D	
4	TARRM	N	
5	TARRM	N	
6	D - START	D	
7	T - STARTH	N	
8	T - STARTM	N	
9	D - FIN	D	
10	T - FINH	N	
11	T - FINM	N	
12	D - DEP	D	
13	T - DEP	N	
14	T - DEPM	N	
15	T - PROH	N	
16	T - PROM	N	
17	T - WATM	N	

N.B
A = Alphanumeric Character
D = Date the Length is 8
N = Numeric digit which can take maximum of 17 digits.

2. JOBCARD FILE

No	FIELD NAME	FIELD TYPE	LENGTH
1	OPERATION - NO	A	6
2	MACHINE - NO	A	6
3	D - ARR	D	
4	T - ARRH	N	
5	T - ARRM	N	
6	T - STARTH	N	
7	T - STARTM	N	
8	T - FINH	N	
9	T - FINM	N	
10	T - DEPH	N	
11	T - DEPM	N	
12	T - PROH	N	
13	T - PROM	N	

3. TEMPFILE FILE

No	FIELD NAME	FIELD TYPE	LENGTH
1	MACHINE - NO	A	6
2	WSWT	N	
3	WSWTH	N	
4	BSWT	N	
5	BSWTH	N	

FORM VIEW

Paradox 4 Relational database management system allow the design of forms and tables. Hence, user can view a record or a whole file at a time. While forms allow viewing of one record at a time the table allow user to view all records in a file at a time. The form view presents the records in beautiful colours thereby making the computer screen more friendly to the user. The form view for Job file and Jobcard file are shown in the following diagrams:

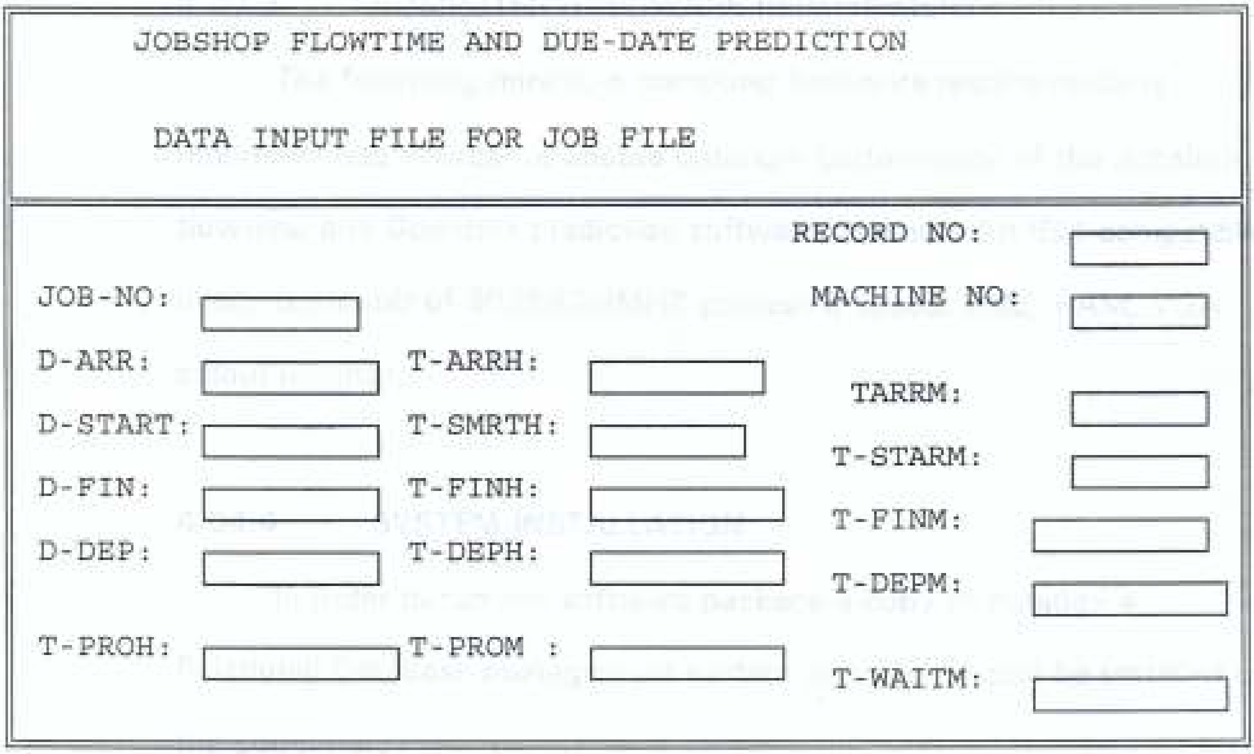


Fig. 4.1: Form view of the job file.

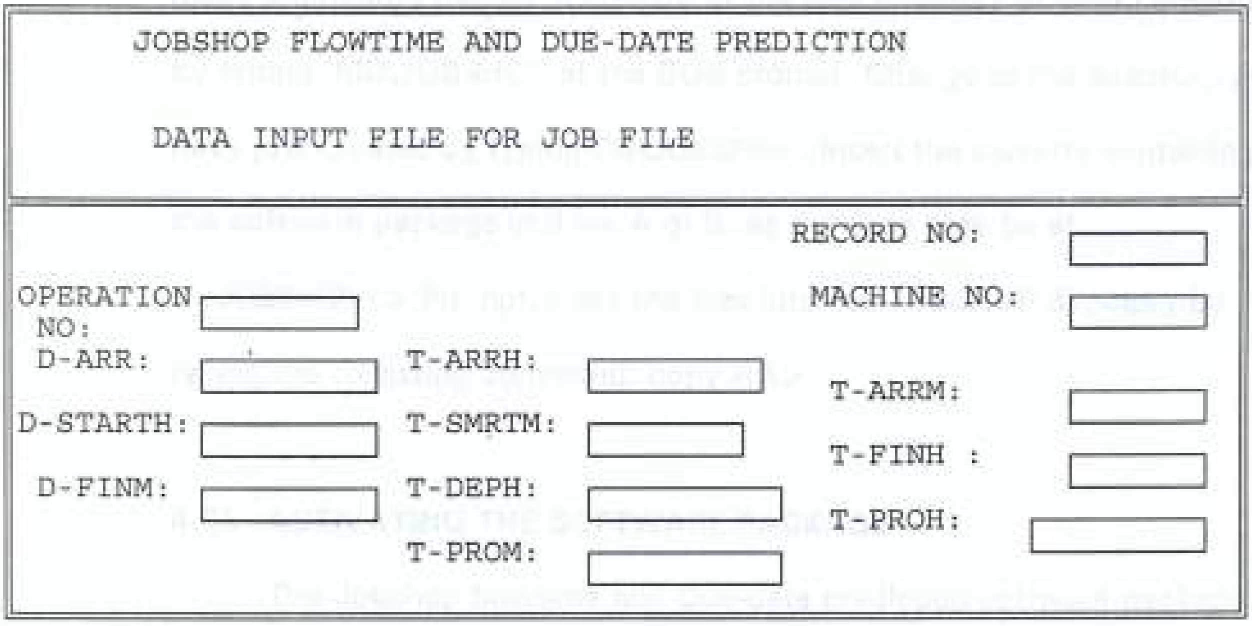


Fig. 4.2: Form view of the jobcard file.

4.04.3 COMPUTER HARDWARE REQUIREMENT

The following minimum computer hardware requirements is recommended in order to ensure optimum performance of the Jobshop flowtime and Due-date prediction software package: An IBM compatible micro-computer of 80286,33MHZ processor speed, 2MB RAM, VGA colour monitor.

4.04.4 SYSTEM INSTALLATION

In order to run the software package a copy of Paradox 4 Relational Database management system software should be installed on the computer.

To install Jobshop flowtime and Due-Date prediction package, make a directory named JOBSHOP at the root directory of your computer by typing MD\JOBSHOP at the DOS prompt. Change to the directory you have just created by typing CD\JOBSHOP. Insert the diskette containing the software package in drive A or B, as the case may be at C:\JOBSHOP\> Prompt, copy the files into the JOBSHOP directory by typing the following command: copy A:\>.

4.05 ACTIVATING THE SOFTWARE PACKAGE

The Jobshop flowtime and Due-date prediction software package can be activated right from C:\> prompt by typing Jobshop and pressing the ENTER key. Immediately this is done, user is taken to the WELCOME SCREEN.

4.04.6 WELCOME SCREEN

The WELCOME SCREEN is beautiful designed with attractive colours. Some animation is introduced to captivate and arouse the interest of the user. The WELCOME SCREEN also contain information about the software package e.g the name of the developer of the package month and year the package was developed, current date and current time of use.

4.04.7 PASSWORD PROCEDURE

Immediately the WELCOME SCREEN clears, the PASSWORD: prompt is displayed. User is expected to supply the correct password in order to enable him gain access into the database and transactions in the software package. The password module is the "key to the main door" of the software package; without which user cannot have access to the facilities inside.

The password serves as the security check into the software package so that only authorized users could gain access to the software package. If incorrect password is supplied, the intending user is logged out of the software package back to the DOS prompt (c:\>), after three unsuccessful attempts. If the password is correct, user is taken to the main menu of the software package. As a means of protecting the password, it is not echoed (does not appear on the screen) when it is being typed.

MENU STRUCTURE

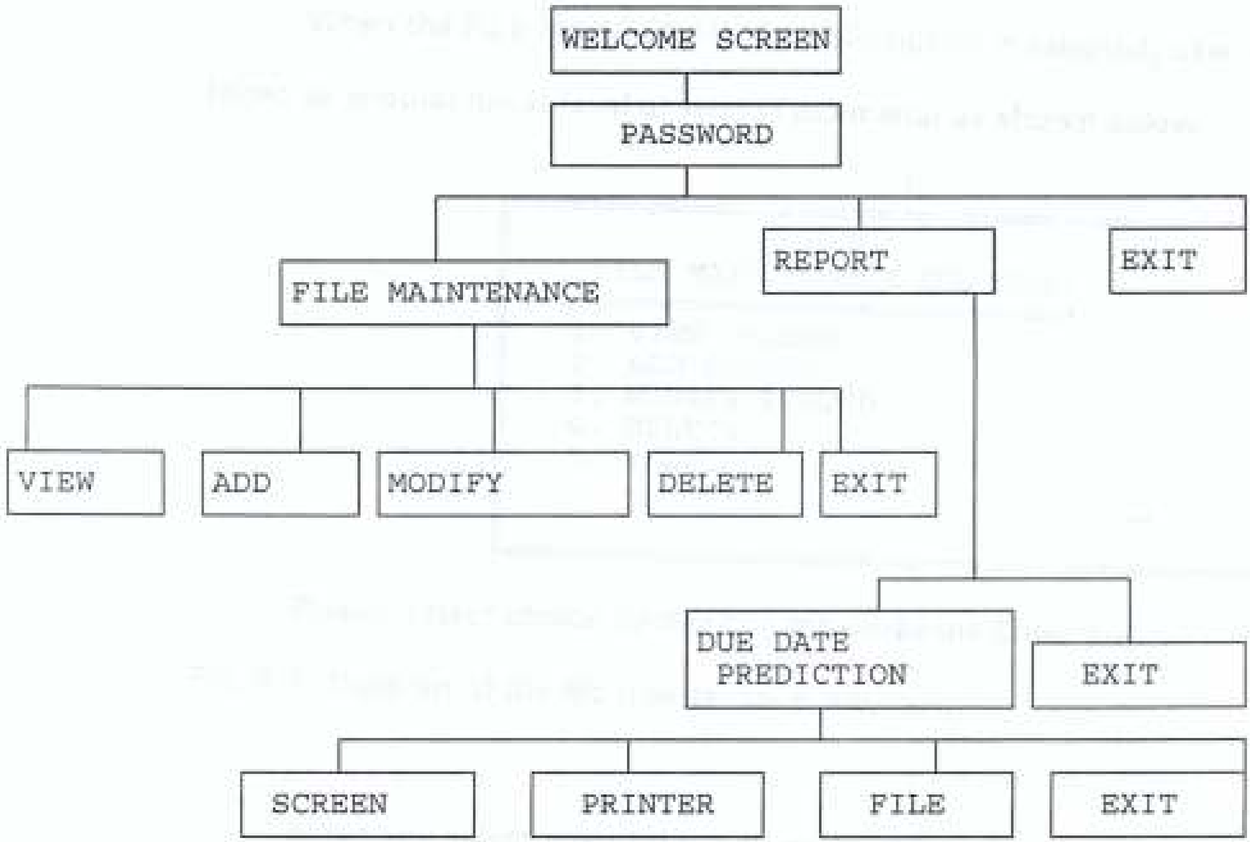


Fig: 4.3: Menu Structure

4.04.8 MAIN MENU

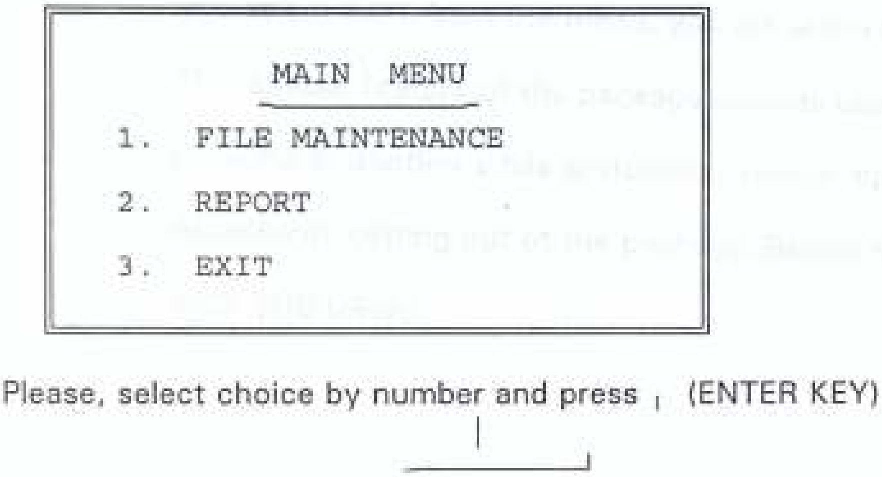


Fig. 4.4: Diagram of the main menu.

4.04.9 FILE MAINTENANCE SUB-MENU

When the FILE MAINTENANCE MENU option is selected, user is taken to another lower level of menu (sub-menu) as shown below:

```
FILE MAINTENANCE SUB-MENU
=========================
1. VIEW RECORD
2. ADD RECORD
3. MODIFY RECORD
4. DELETE
5. EXIT
```

Please, select choice by number and press the Enter Key.

Fig. 4.5: Diagram of the file maintenance sub-menu.

When you select any of the sub-menu options, you are taken to another submenu where a list of all the files in the software package is displayed. You can then select the required file you want to work on. If you select EXIT from the menu, you are taken back to the previous menu. This special feature of the package enables user to move from one level of menu to another while performing various operations without necessarily getting out of the package. Below is an example, using the ADD SUB-MENU.

```
        ADD  SUB-MENU

  1.  JOB FILE

  2.  JOBCARD FILE

  3.  EXIT
```

Fig. 4.6: Diagram of the Add Sub-menu.

Please, select choice by number and press (ENTER KEY)

RECORD KEY

When user select any of the above files for any of the FILE MAINTENANCE Transactions: VIEW, ADD, MODIFY, AND DELETE, he is prompted to supply the MACHINE-NO, JOB-NO AND OPERATION-NO. These three attributes jointly identify a particular record once supplied, the software package will locate the record under consideration incase of MODIFY, VIEW AND DELETE transactions, while incase of ADD transaction a new record is set up entirely.

4.04.10 ADD TRANSACTION

The add transaction allow user to enter fresh records into any of the files. Duplication of records is not allowed.

STEP 1: The system prompts you to enter the record key i.e machine-number, date-of-Arrival, JOB-Number.

STEP 2: The system checks the file to find out whether the record already exist or not of the record already exist, the following message is displayed:"Record already exist..... do you want to Retry (Y/N)?"

STEP 3: If your response is yes, the system gives you another trial to supply the correct record key, else you are returned to the previous menu.

N.B: The system does not allow or accept blank value of record key.

4.04.11 MODIFY TRANSACTION

The modify transaction enables you to modify existing record(s).

STEP 1: "Enter Record key"

STEP 2: Validation: The record key supplied is searched for in the database. If it is not found, the following message is displayed: "Record does not exist .....Do you wish to Retry (Y/N)?" If your response is yes, you are then given another opportunity to enter the correct record key, else you are taken back to the previous menu.

If the correct record key is supplied, the record is displayed in the form view for you to make necessary changes. At the bottom of the screen the following prompt is displayed. "Press F2 to modify another, Esc to quit".

STEP 3: If you press F2, the modified version of the record is saved and you are then prompted to enter record key for the next record to be modified. If you press Esc, the modified version of the record is saved and you are returned to the previous menu.

4.04.12 VIEW TRANSACTION

This menu option enables you to view an existing record. You will not be allowed to modify or append the record.

STEP 1: "Enter the Record key"

STEP 2: Validation: Data validation is carried out as discussed for MODIFY TRANSACTION. Then press F2 to view another record, Esc to Quit.

STEP 3: If you press f2, you are taken back to step 1. You are allowed to view another record. You will be prompted to enter another record key. If you press Esc, you are taken back to the previous menu.

4.04.13 DELETE TRANSACTION

Delete transaction enables you to delete an unwanted or obsolete record from the database. This is a very sensitive operation because once a record is deleted there is no way you can bring it back unless you have the back up (duplicate) copy some where which you can re-input again. Hence, a lot of confirmatory questions are asked to warn you and for you to be sure that you really want the record deleted.

STEP 1: "Enter the Record key"

STEP 2: Validation

STEP 3: If you press F2, the following message is displayed: "Are you sure you want record deleted(Y/N)?" If your response is yes, the system them alerts you: "Record already deleted...... Delete Another (Y/N)" If your response is yes, you are then taken back to step 1, else you are returned to the previous menu.

STEP 4: If you press Esc, you will see the following message displayed:"Quitting without deleting record". You will then be returned to the previous menu.

4.04.14 DUE-DATE PREDICTION REPORT MENU

```
        DUE-DATE PREDICTION
             SUB-MENU
----------------------------------------

     1. PREDICT DUE-DATE
     2. EXIT
```

Please, select choice by number and press (ENTER KEY) to Execute

Fig. 4.7: Diagram of the Due-date prediction sub-menu.

If user chooses REPORT from the main menu, he is taken to the Due-date prediction sub-menu. From the menu, if user selects option 1 (i.e predict Due-date), the Report file "Jobshop, rep" and the "Tempfile" is emptied of previous intermediate reports and records. The system then prompts user to supply the machine code e.g. LMO1. The system sort and selects all records with the machine code supplied and display the list on the screen for the user to see.

The system then asks the user the following question: "Do you wish to continue processing (Y/N)? " If the user type N(No) the processing is terminated but if the response is Y(yes), He is prompted "Enter total Number of jobs". The number of Jobs to be sampled for computing the moving average is then supplied. The system then performs the various calculations leading to the determinations of worst scenario waiting time, and Best scenario waiting time and moves the result to a temporary file called "TEMPFILE.DB".

The system then asks the user whether there is any other machine involved in the job under consideration. If the response is yes, the system then goes back(loop) to the beginning and performs the previous calculations discussed above for the next machine whose code number is supplied.

If the response is No, the system then picks the "JOBCARD.DB" and "TEMPFILE.DB" files and use the appropriate information contained in them to calculate the Worst scenario due-date and time and Best Scenario due-date and time. In addition, the input date used for the calculations are also generated, for each of the machines involved in the job.

When the calculations are completed, the following menu is displayed:

```
SEND REPORT TO:
═══════════════════════════════

    1. SCREEN
    2. PRINTER
    3. FILE
    4. EXIT

Please select [ ]
```

Fig. 4.8: Diagram of report destination.

If user select "screen", the result of the calculations are displayed on the computer screen for user to see.

If user selects "Printer", the result is sent to a computer printer attached to the computer for the production of a paper (hard copy) of the result.

If the user selects "FILE", the result is saved in a file named "JOBSHOP.LIS" for future use.

Finally, if the user selects Exit he is taken to the Due-date prediction submenu.

4.04.15 ERROR MESSAGES: CAUSES AND REMEDY

One of the important features of the software package is its error check facility. It does not accept just any garbage. If user responds wrongly to the various questions asked by the system, he is prompted or alerted so that the user could have the opportunity of making necessary corrections. Below are some of the error messages, their causes and remedy:

1. Invalid option

   Cause: Pressing the wrong key or letter/ number when making menu choice.

   Remedy: Pick the correct option by following the appropriate instructions displayed on the screen relating to the menu choice.

2. Non-Blank value expected

   Cause: Failure to supply the record key before pressing the ENTER KEY when prompted to supply the record key.

   Remedy: Supply the necessary record key.

3. Expecting variable of Numeric or Alpha numeric type.

   Cause: Supplying a number when alpha-numeric characters are required or vice versa.

   Remedy: Supply the correct character type.

4. Printer not Ready

   Cause: Printer not put on (online) or not properly connected to the computer.

   Remedy: Check the connections between the printer and the computer. Also, check that the printer is switched on with the online light on.

CHAPTER FIVE

5.0 CASE STUDIES

In order to test the degree of perfection of the developed software, two case studies were carried out of new jobs.

[A] APPLICATION OF THE SOFTWARE ON A JOB OF MULTI-OPERATIONS THAT REQUIRE ONLY A MACHINE FOR ALL THE OPERATIONS

5.01 PRODUCTION OF A CENTRE ON LATHE MACHINE

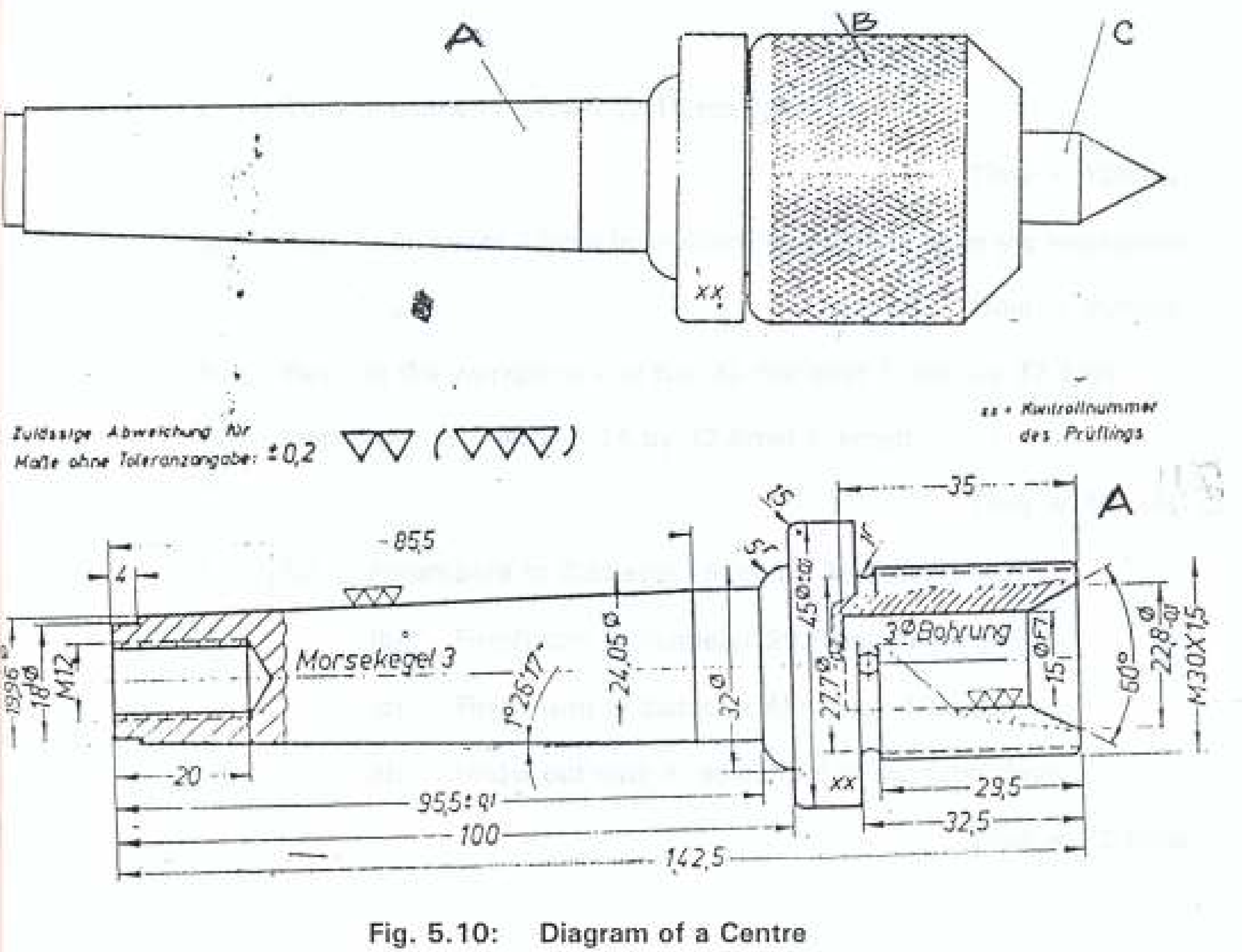


Fig. 5.10: Diagram of a Centre

NAF TTG (1993)

The centre required three parts (i.e A, B and C) to be produced and assembled.

The operation involved in producing these parts were listed out with theoretical time of finishing each operation put into consideration the difficulty, waiting time,and unforseen disturbances.

5.02 COMPONENT "A"

Operations required

1. Hold the work in three jaw chuck. Do the facing operation open up to diameter 10.5mm by 20mm

Time = 20mins

2. Turn to diameter 22mm by 15mm light

Time = 10mins

3. Turn to diameter 43mm by 100mm in length reverse the workpiece

Time = 30mins

4. Reverse the workpiece and turn to diameter 31mm by 32.5mm length Drill to diameter 14 by 32.5mm in length.

Time = 40mins

5. (a) Finish bore to diameter 15mm by 35.0mm length.

   (b) Finish turn to diameter 29.8mm by 32.5mm.

   (c) Finish turn to diameter 45mm by 10mm.

   (d) Under cut with a radius tool of diameter 2mm.

Time = 72 mins

6. Make the taper by making use of the formula

$$\frac{D2 - D1}{2L} \text{ where}$$

D2 = big diameter

D1 = Small diameter

working result = 60°

Time = 130 mins

7. (a) Turn to diameter 32mm by 100mm

(b) Turn to diameter 45mm by 10mm

(c) Tap the end of the component by m12 x 1.5 tap

Time = 130 mins

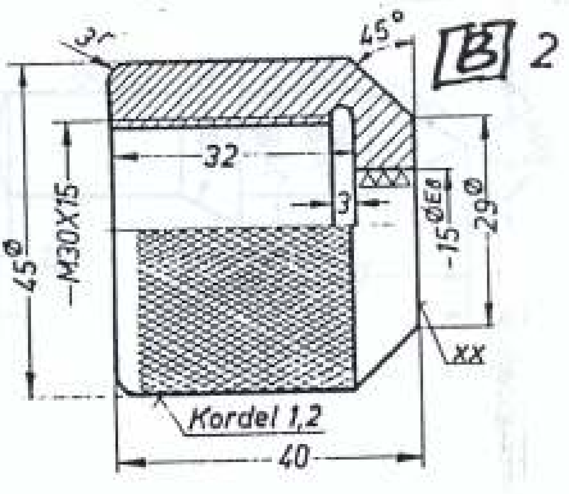
8. With the help of the forming tool, form the radius with diameter 2mm.

Time = 20 mins

9. The taper angle is to be made by using the angle given made the hole to 3mm diameter.

Time = 50 mins

5.02 COMPONENT "B"



Operations required

10. Face the two end to length 40mm

Time = 5 mins

11. Drill the hole to diameter 15mm

Time = 10 mins

12. (a) Hold the work piece with a mandrel and turn to outside diameter to 45mm.

(b) perform the knurlling as well

Time = 30 mins

13. (a) Enlarge the hole to diameter 28.5 by 32mm under cut 3mm dept

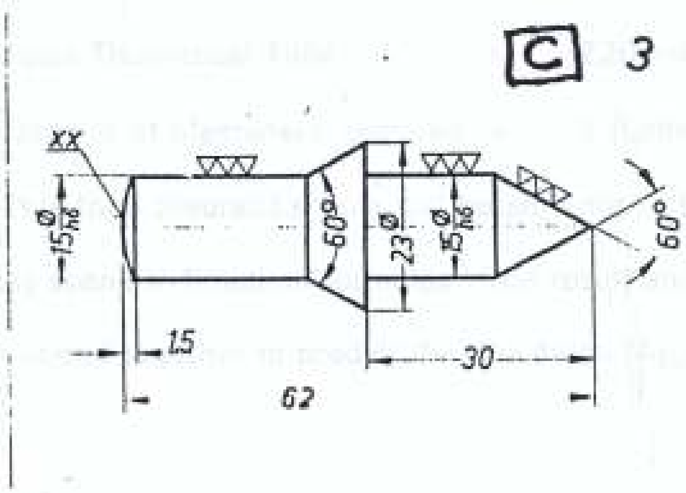
(b) Internal threading of m30 x 1.5

Time = 55 mins

14. Tilt the compound slides to 45° and make the taper side

Time = 15 mins

5.03 COMPONENT "C"



Operations required

15. Face one end turn to diameter 15 by 30mm

Time = 25 mins

16. Tilt top slide to 60° and make the taper angle

Time = 20 mins

17. (a) Turn to diameter 15mm x 25mm

(b) Tilt the top slide to 60°

Time = 45 min

18. Assembling time Time = 10 mins

Estimation of Theoretical Processing Time

Component:	A	=	505 mins
	B	=	1.15 mins
	C	=	90 mins
Assembling time		=	10 mins
Total theoretical time		=	720 mins

Prediction of the Due Date For the Centre Job

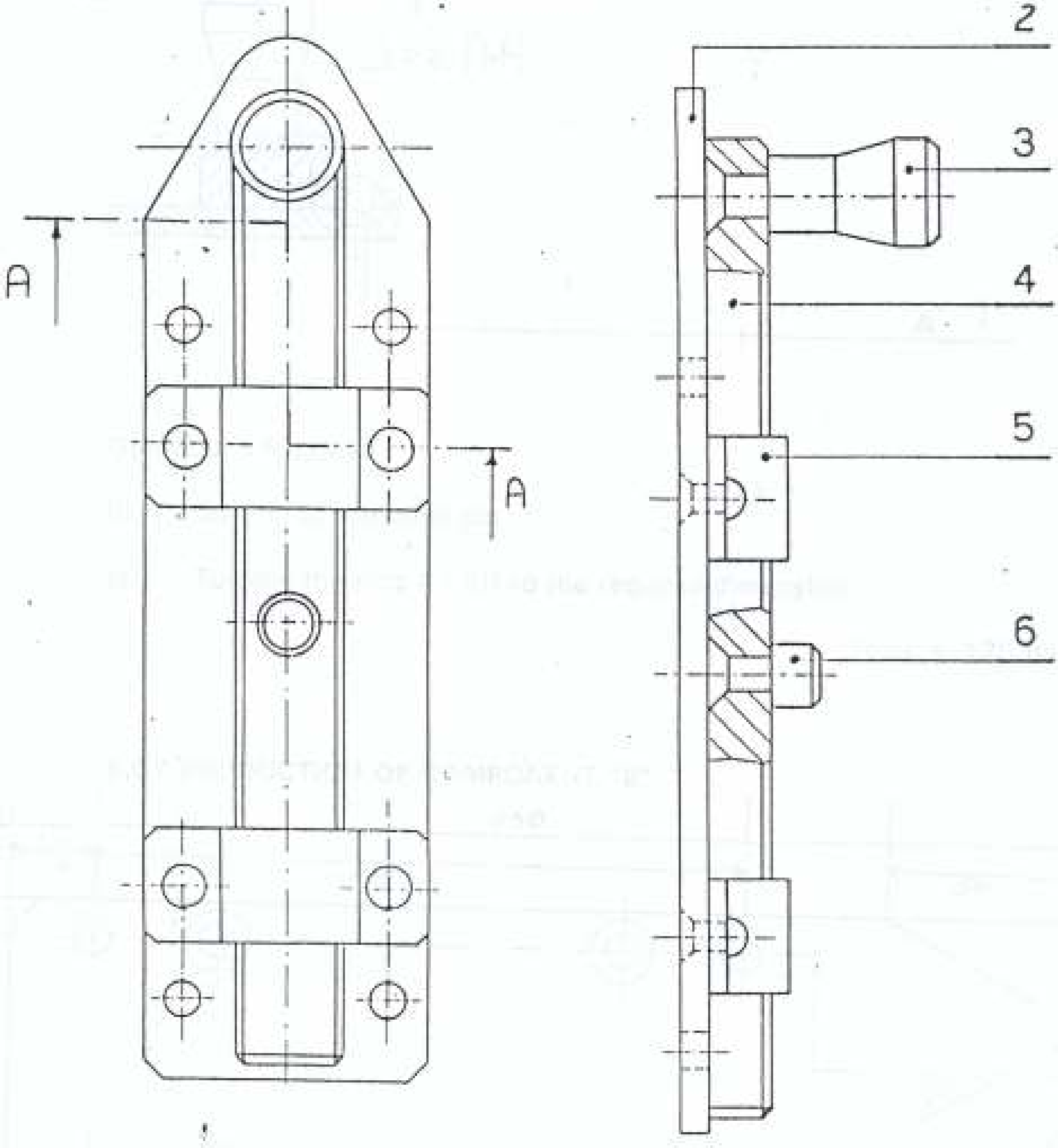
(i) Total Theoretical Time = 720 mins

(ii) Number of Machine(s) required = 1 (Lathe Machine)

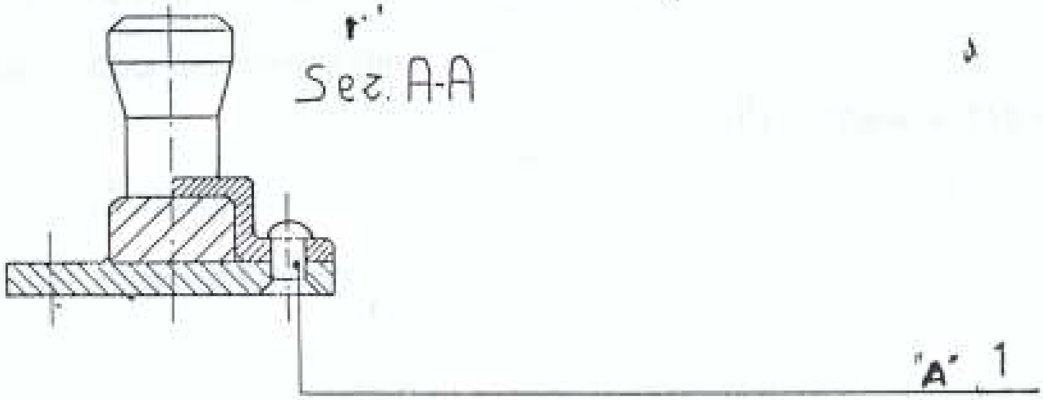
This total theoretical time will be an input to the worst scenarios and Best scenario flowtime formulas. The result and the arrival date of the job added together to predict the due dates.(Appendix II).

[B] APPLICATION OF THE SOFTWARE ON A JOB OF MULTIOPERATIONS ON MULTI-MACHINES.

5.04 PRODUCTION OF A DOOR LOCK



5.06 PRODUCTION OF COMPONENT "A"



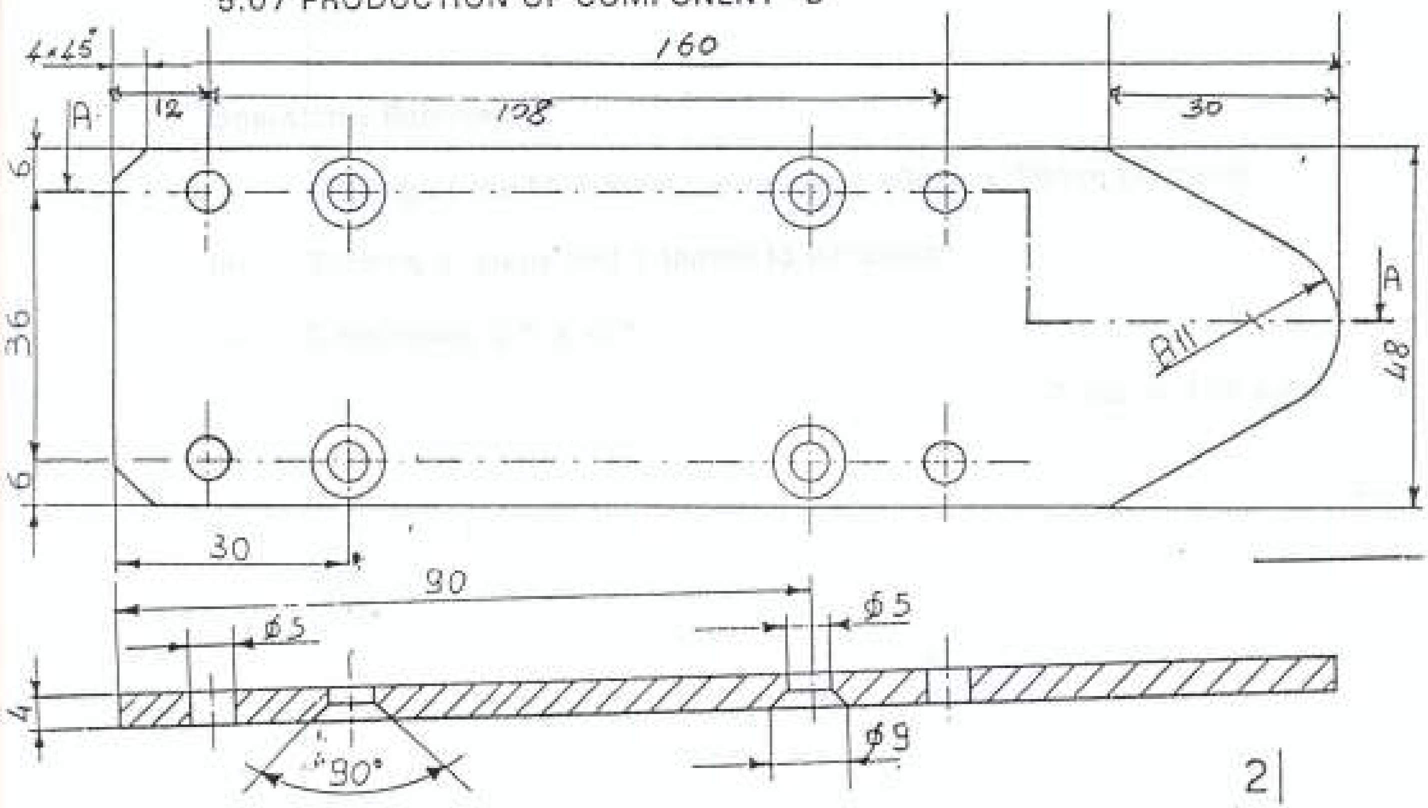
Operations Required

(i) Cutting of the plate pin

(ii) Turning the pins 4 - off to the required dimension

Time = 120 mins

5.07 PRODUCTION OF COMPONENT "B"



Operations Required

(i) Cutting thee flat plate with power saw 50 x 165mm

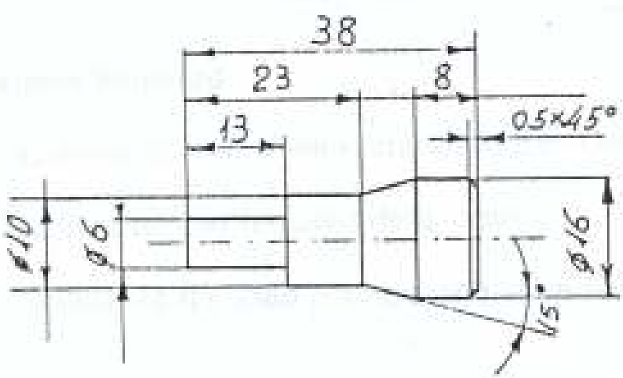
(ii) Milling the plate to required dimension

(iii) Drilling the plate for pins insertion 8 holes

(iv) Countersinking drilling

Time = 110 mins

5.08 COMPONENT "C"



3

Operations Required

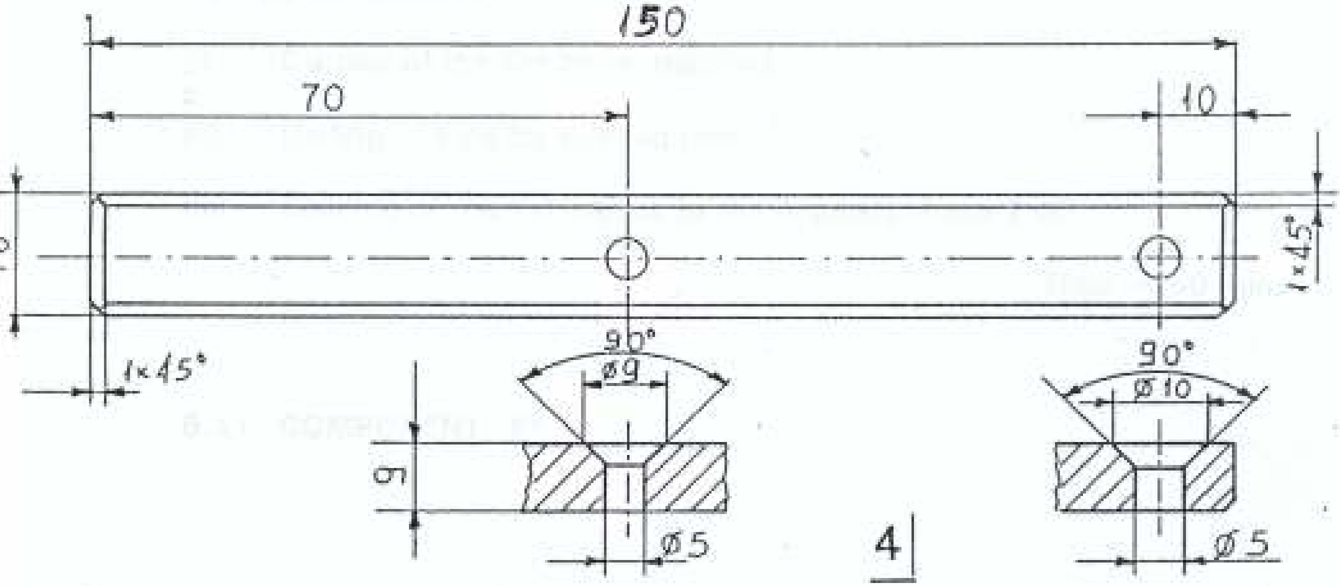
(i) Cutting of the Mild Steel rod required 40mm x 18mm diameter

(ii) Turning 3 steps and 1 tapper to dimension

(iii) Chamfering 0.5 x 45°

Time = 120 mins

5.09 COMPONENT "D"



Operations Required

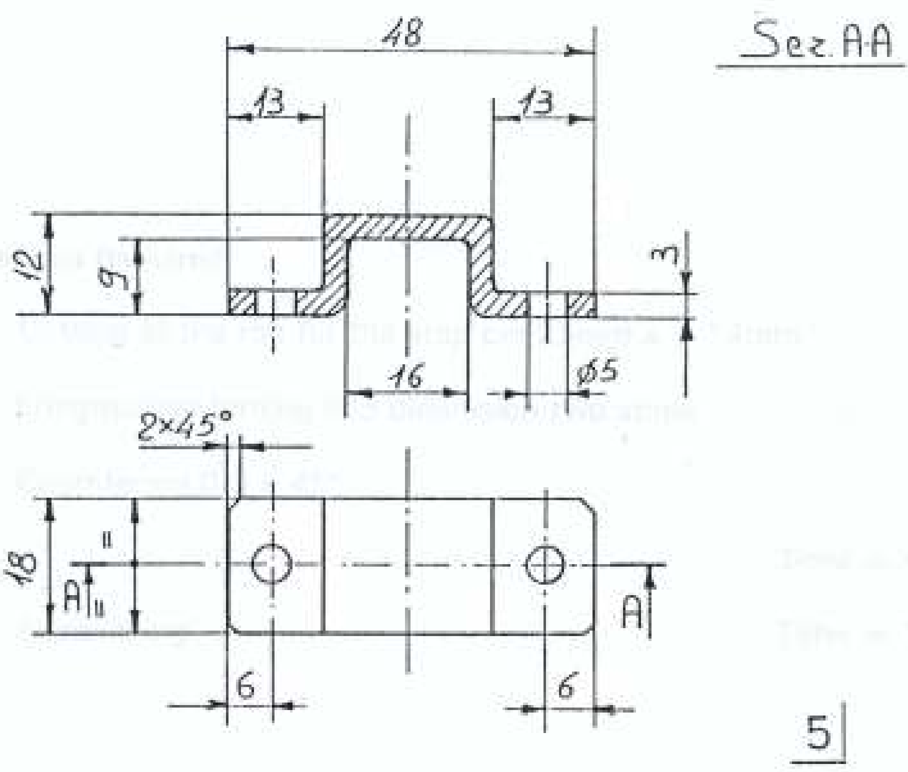
(i) Cutting of Mild Steel rectangular bar 18mm x ϕ 153mm

(ii) Milling to the required dimension

(iii) Drilling of the stop pin hole and knob hole

Time = 115 mins

5.10 COMPONENT "E"



Operations Required

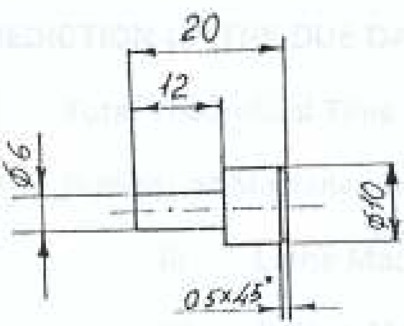
(i) Cutting of the flat metal required

(ii) Drilling of hole for riveting pins

(iii) Bending of the flat metals to the required shape 2 off

Time = 50 mins

5.11 COMPONENT "F"



6

Operations Required

(i) Cutting of the rod for the stop pin 25mm x ø 14mm

(ii) Longitudinal turning into dimension two steps

(iii) Chamfering 0.5 x 45°

Time = 40 mins

Assembling

Time = 15 mins

ESTIMATION OF THEORETICAL PROCESSING TIME

Component	A	=	120 mins
	B	=	110 mins
	C	=	120 mins
	D	=	115 mins
	E	=	50 mins
	F	=	40 mins
Assembling Time		=	<u>15 mins</u>
Total Theoretical Time			<u>570 mins</u>

5.12 PREDICTION OF THE DUE DATE FOR THE DOOR LOCK JOB

(a) Total Theoretical Time = 570 mins

(b) Number of Machines Required = 6

- (i) Lathe Machine
- (ii) Drilling Machine
- (iii) Milling Machine
- (iv) Power Saw machine
- (v) Bending Machine
- (vi) Hydraulic Press Machine

The total theoretical time above (570 mins) will be an input to the Worst Scenarios and Best Scenario flowtime formulas. The result and the arrival date of the new job added together to predict the due dates as well as the time (Appendix *III*).

The theoretical time for each case study was an input on the job card in the computing system.

The computer system after knowing the number of machines as-well as their code number the system selects all jobs executed on use and calculates:

(i) processing time for each sampled job

(ii) Waiting time for each sampled job

(iii) Total waiting time for all jobs

(vi) Mean waiting time

(v) Variance

(vi) Standard deviation

(vii) Worst case scenario waiting time

(viii) Best case scenario waiting time

(ix) Most likely scenario waiting time

After these the system calculates the worst, best and most likely scenario flowtime (FT_1,FT_2,FT_3) by making use of total theoretical processing time and total scenario waiting times calculated in (vii, viii and ix).

The system finally calculate the worst scenario, Best scenario and most likely scenario due-dates using the formula

$$WSDD_i = arrdnew + F_{T1}$$

$$BSDD_i = arrdnew + F_{T2}$$

$$MLSDD_i = arrdnew + F_{T3}$$

where arrdnew is the date the new job is brought.

The results for these cases were shown in appendix III and IV.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

A computer application oriented software for predicting flow time and due dates for a job has been developed, tested and gave a good result. The software is capable of prescribing a range of due dates to reflect the best and worst possible scenarios.

This range will greatly assist management in negotiations with prospective customers. The software will be applicable in simple job shops.

The set objectives of predicting the completion time of a new job improving performance of a job shops; improving shops ability to execute jobs within due dates were achieved.

The methodology employed which implicit accommodates: job characteristics, shop status, system characteristics and delaying factors external to the shop proved successful.

RECOMMENDATION

Findings of this research indicate that production manager of job shops should develop the due date assignment rules that are dependent on the characteristics of their own production systems. By analyzing historical production data, those factors that have significant effects on completion times of jobs in their own shops can be identified, and then due date rules can be developed based on these factors.

If due-dates fell on day(s) of the holiday or Sundays, user of this software should add these days to the generated output result from the computer system.

Improvement can still be made on this software to be able to predict production lost, charges for customers, maintenance period as well as maintenance cost of each machine.

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APPENDIX I

```
;SCRIPT:JOBSHOP.SC
;PROGRAM TO DISPLAY THE WELCOME MESSAGE TO JOBSHOP
;DATE: MAY, 1998

CLEAR
@1,1 ?? "TIME: " + STRVAL (TIME())
@1,64 ?? "DATE: " + STRVAL (TODAY())
proc welcome()
paintcanvas attribute 79 12,20,12,59
sleep 500
paintcanvas attribute 112 9,15,15,64
sleep 500
paintcanvas attribute 80 6,10,18,69
sleep 500
paintcanvas attribute 96 3,5,21,74
sleep 500
paintcanvas attribute 31 0,0,24,79
style attribute 31
sleep 500
style reverse, blink
@12,27 ?? "WELCOME TO ====>"
style
sleep 3000
endproc
PROC BYE()
paintcanvas fill chr(176) attribute 31 0,0,24,79
sleep 500
paintcanvas attribute 47 3,5,21,74
sleep 500
paintcanvas attribute 80 6,10,18,69
sleep 500
paintcanvas attribute 79 9,15,15,64
sleep 500
paintcanvas attribute 96 12,20,12,59
style attribute 31
sleep 2000
endproc
CLEAR
welcome()
paintcanvas attribute 217 0,0,24,79
style blink,reverse
@10,10 ??    "COMPUTERISED JOBSHOP FLOWTIME AND DUE-DATE PREDICTION
SLEEP 5000
style
@12,10 ??    "A MASTER OF TECHNOLOGY IN MECHANICAL ENGINEERING
         PROJECT"
SLEEP 1500
CLEAR
bye()
@13,15 ??     "DEVELOPED BY: AKINNULI O.B  (MATRIC NO:85/447 )"
@14,15 ??     "DEPARTMENT OF MECHANICAL ENGINEERING, "
@15,15 ??     "FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA"
@16,25 ??     "  (C) AUGUST, 1997"
SLEEP 5000
@20,20 ?? "Press Any Key To Continue....."
style
x = upper(chr(getchar()))
PLAY "PWD1"
```

```
; PROGRAM:      Mainmen.sc
; DESCRIPTION: Program opens the main menu
; DATE:         MAY, 1998.


;RESPONSE = " "
WHILE TRUE
    CLEAR
 PAINTCANVAS BORDER FILL CHR(177) ATTRIBUTE 15 5,10, 16, 67
    STYLE attribute 30
    @ 8, 25 ?? "         MAIN MENU          "
    @ 9, 25 ?? "      ________________      "
    @ 10,25 ?? "   1.  UPDATE TRANSACTIONS  "
    @ 11,25 ?? "   2.  QUERY TRANSACTIONS   "
    @ 12,25 ?? "   3.  EXIT                 "
    @ 17,15 ?? "SELECT CHOICE BY NUMBER AND PRESS ENTER KEY [ ]"
    @17,60 ACCEPT "A1" TO RESPONSE
    SWITCH
      . CASE RESPONSE = "1":
             CLEAR
             PLAY "UPDATE"
       CASE RESPONSE = "2":
             CLEAR
             PLAY "INFORET"
       CASE RESPONSE = "EXIT":
             DO_IT!
             CLEAR
             BEEP BEEP
             Play "bye"
        OTHERWISE:
             BEEP BEEP
             CLEAR
             @10,20 ?? "INVALID OPTION!! PLEASE, SELECT CORRECTLY."
             SLEEP 1500
             LOOP
        ENDSWITCH
        upimage
        CLEARIMAGE
        CLEARALL
        RETURN
   endwhile
```

```
; PROGRAM:      UPDATE.SC
; DESCRIPTION:  UPDATE sub-menu
; DATE:         April, 1997.


RESPONSE = " "
WHILE TRUE;(RESPONSE <> "ESC")
CLEAR
 PAINTCANVAS BORDER FILL CHR(177) ATTRIBUTE 15 5,10, 16, 67
    STYLE attribute 30
    @ 8, 23 ?? "   U P D A T E   S U B M E N U   "
    @ 9, 23 ?? "   ============================   "
    @ 10,23 ?? "      1.    VIEW RECORD(S)        "
    @ 11,23 ?? "      2.    ADD RECORD(S)         "
    @ 12,23 ?? "      3.    MODIFY RECORD(S)      "
    @ 13,23 ?? "      4.    DELETE RECORD(S)      "
    @ 14,23 ?? "      5.    EXIT                  "
    @ 17,15 ?? "SELECT CHOICE BY NUMBER AND PRESS ENTER KEY [ ]"
    @17,60 ACCEPT "A1" TO RESPONSE
    SWITCH
        CASE RESPONSE = "1":
             CLEAR
             PLAY "JOBVIEW"
       CASE RESPONSE = "2":
             PLAY "JOBADD"
       CASE RESPONSE = "3":
             PLAY "JOBMOD"
       CASE RESPONSE = "4":
             PLAY "JOBDEL"
       CASE RESPONSE = "5":
             CLEARALL
             CLEAR
             PLAY "MAINMEN"
        OTHERWISE:
             BEEP BEEP
             CLEAR
             @10,20 ?? "INVALID OPTION!! PLEASE, SELECT CORRECTLY."
             SLEEP 1500
             LOOP
        ENDSWITCH
         upimage
         CLEARIMAGE
         CLEARALL
        ; PLAY "COMMENU"   ;RETURN
ENDWHILE
```

```
; PROGRAM:      INFORET.SC
; DESCRIPTION: Query Transaction Menu
; DATE:         January, 1998


WHILE TRUE
;RELEASE PROCS ALL
;RELEASE VARS ALL
CLEAR
CANVAS OFF
PAINTCANVAS BORDER FILL CHR(177) ATTRIBUTE 98 0,0,24,79
PAINTCANVAS BORDER FILL CHR(175) ATTRIBUTE 241 2,4,22,76
PAINTCANVAS ATTRIBUTE 112 4,6,20,73
  STYLE attribute 31
    @ 8,20 ??  "         REPORT MODULE       "
    @ 9,20 ??  "        ═════════════════     "
    @ 10,20 ?? " 1. DUE DATE PREDICTION      "
    @ 11,20 ?? " 2. JOBCARD REPORT           "
    @ 12,20 ?? " 3. EXIT                     "
CANVAS ON
    @ 16,10 ?? "Select choice by number and press <┘ to execute [
] "
    @ 16,60 ACCEPT "A1" TO choice
    SWITCH
        CASE CHOICE = "1" OR CHOICE = UPPER("1"):
             CLEAR
             PLAY "DELREP"
       CASE CHOICE = "2":
             CLEAR
             PLAY "JOBCARD"
       CASE CHOICE = "3":
             CLEAR
             PLAY "MAINMEN"
       OTHERWISE:
             BEEP BEEP
            CLEAR
             STYLE ATTRIBUTE 159
             @10,20 ?? "INVALID OPTION!! PLEASE, SELECT CORRECTLY"
             STYLE
             SLEEP 1500
            LOOP
        ENDSWITCH
 ENDWHILE
```

```
IF ISFILE ("JOBNEW.REP") THEN
   RUN NOREFRESH "DEL JOBNEW.REP"
ENDIF
PLAY "TEMPEMTY"

STYLE ATTRIBUTE 207
@12,12 ?? "TEMPORARY FILE IS BEING EMPTIED...."
SLEEP 2000
VIEW "TEMPFILE"
IF NOT ISEMPTY("TEMPFILE") THEN
   EMPTY "TEMPFILE"
   CLEAR
   CLEARALL
   PLAY "JOBNEW21"
ELSE
   CLEAR
   CLEARALL
   PLAY. "JOBNEW21"
ENDIF
```

```
;NAME: JOBNEW21.SC
;DESCRIPTION: SCRIPT TO GENERATE PREDICTIONS OF DUE DATES
;DATE: JANUARY, 1998
;WHILE TRUE

CLEAR
     paintcanvas attribute 46 0,0,24,79
     style attribute 79
     @10,10 ?? "Please, enter Machine Code (e.g. LM01): "
     @10,52 accept "a6" to machineno
     machineno = upper(machineno)
clear
View "job2"
moveto [machine-no]
act = machineno

Query

 Job2 | JOB-NO | MACHINE-NO  | D-ARR | T-ARRH | T-ARRM | D-START |
      | Check  | Check -act  | Check | Check  | Check  | Check   |
      |        |             |       |        |        |         |

 Job2 | T-STARTH | T-STARTM | D-FIN | T-FINH | T-FINM | D-DEP |
      | Check    | Check    | Check | Check  | Check  | Check |
      |          |          |       |        |        |       |

 Job2 | T-DEPH | T-DEPM | T-PROH |T-PROM | T-WAITM |
      | Check  | Check  | Check  | Check | Check   |
      |        |        |        |       |         |

Endquery
do_it!
CLEAR
CLEARALL
VIEW "ANSWER"
wait table
  MESSAGE "PRESS F2 TO CONTINUE"
until "F2"
if retval = "F2" then
  clear
 clearall
endif
paintcanvas attribute 46 0,0,24,79
style attribute 79

@12,10 ?? "DO YOU WISH TO CONTINUE PROCESSING (Y/N)?: "
     STYLE
     ACCEPT "A1" TO RESP
IF UPPER(RESP) = "N" THEN
     CLEARALL
```

```
     RETURN
ENDIF

CLEAR
paintcanvas attribute 31 0,0,24,79
style attribute 79
@14,12 ?? "ENTER TOTAL NUMBER OF JOBS [E.G. 12]: "
ACCEPT "N" TO NJ
STYLE
sleep 1500
TW = 0
TMD2 = 0
TOTVARI = 0
TWH = 0
TMDH2 = 0
TOTVARIH = 0
LINECOUNT = 0
VIEW "ANSWER"
MOVETO [JOB-NO]
machineno = [machine-no]
   WHILE NOT EOT()
message "Processing ", machineno, "  Record No: ", Recno()
        JOBNO = [JOB-NO]
        DARR = [D-ARR]
        TARRH = [T-ARRH]
        TARRM = [T-ARRM]
        DSTART = [D-START]
        TSTARTH = [T-STARTH]
        TSTARTM = [T-STARTM]
        DFIN = [D-FIN]
        TFINH = [T-FINH]
        TFINM = [T-FINM]
        DDEP = [D-DEP]
        TDEPH = [T-DEPH]
        TDEPM = [T-DEPM]
        TPROH = [T-PROH]
        TPROM = [T-PROM]
        TWAITM = [T-WAITM]
              tprom = tfinm - tstartm
              TPROH = TFINH - TSTARTH
              WIJH = TDEPH - TPROH - TARRH
              Wij = tdepm - tprom - tarrm  ;calculates waiting time
              TW = TW + Wij ;calculates total waiting time
              TWH = TWH + WIJH
              SKIP 1
ENDWHILE
WJH = TWH/NJ
Wj = TW/NJ  ;calculates mean waiting time for machine j for a given
period

PLAY "JOBNEW41"
CLEAR
```

```
;NAME: JOBNEW41.SC
;DESCRIPTION: SCRIPT TO GENERATE PREDICTIONS OF DUE DATES
;DATE: JANUARY, 1998
;WHILE TRUE

B = ":JOBNEW.REP"
proc heading()                                                    ;procedure prints
heading

PRINT FILE B SPACES (5), FORMAT("W170,AL","COMPUTERIZED JOB SHOP FLOWTIME AND
DUE DATE PREDICTION"),"\N",
                SPACES  (5),   FORMAT  ("W21,AL","REPORT  FOR  MACHINE  NO:  "),
FORMAT("W10,AL",MACHINENO),"\N",
                SPACES (5), FORMAT("W17,AL", "DATE OF REPORT:"),format("D2,al",
                today()), "\n\n",
                SPACES (5), FORMAT("W167,AC",FILL("-",167)),"\N",
                SPACES (5), format("w2,al","|"),format("w10,ac","JOB NO"), "|",
                format("w10,AC","D-ARR"), "|", format("w10,AC","T-ARRH"), "|",
                format("w10,ac","T-ARRM"),"|", format("w10,ac","D-START"),"|",
                format("w10,ac","T-STARTH"), "|", format("w10,ac","T-STARTM"),"|",
                format("w10,AC","D-FIN"), "|", format("w10,AC","T-FINH"), "|",
                format("w10,ac","T-FINM"),"|",format("w10,ac","D-DEP"),"|",
                format("w10,ac","T-DEPH"),"|",format("w10,ac","T-DEPM"),"|",
               format("w10,ac","T-PROM"),"|",format("w10,ac","T-WAITM"),"|","\N",
                SPACES (5), FORMAT("W167,AC",FILL("-",167)),"\N"
endproc
proc println()

PRINT FILE B SPACES (5), format("w2,al","|"),format("w10,ac",JOBNO), "|",
                format("D10,AR",DARR), "  |", format("w10.2,eb",TARRH), "|",
                format("w10.2,eb",TARRM),"|", format("D10,AR",DSTART)," |",
                format("w10.2,eb",TSTARTH), "|", format("w10.2,eb",TSTARTM), "|",
                format("D10,AR",DFIN), "  |", format("w10.2,eb",TFINH), "|",
                format("w10.2,eb",TFINM),"|",format("D10,AR",DDEP)," |",
                format("w10.2,eb",TDEPH),"|",format("w10.2,eb",TDEPM),"|",
                format("w10.2,eb",TPROM),"|",format("w10.2,eb",Wij),"|","\N",
SPACES (5), FORMAT("W167,AC",FILL("-",167)),"\N"
endproc
proc NJJ()                                                        ; prints
number of jobs sampled
PRINT  FILE  B   SPACES  (5),  FORMAT("W27,AL","NUMBER  OF  JOBS  SAMPLED  =
"),FORMAT("W10.2,EB",NJ),"\N"
endproc
proc TWW()                                                        ; prints
total waiting time
PRINT  FILE  B   SPACES  (5),  FORMAT("W30,AL","TOTAL  WAIT  TIME  (MINUTES)  =
"),FORMAT("W10.2,EB",TW),"\N"
endproc
proc WJJ()                                                        ; prints
mean waiting time
PRINT  FILE  B   SPACES  (5),  FORMAT("W30,AL","MEAN  WAIT  TIME  (MINUTES)  =
"),FORMAT("W10.2,EB",WJ),"\N"
endproc
proc VARI()                                                              ;
prints variance
PRINT    FILE    B       SPACES     (5),    FORMAT("W20,AL","VARIANCE     =
"),FORMAT("W10.2,EB",TOTVARI),"\N"
endproc
proc STDE()                                                              ;
prints standard deviation
PRINT    FILE    B       SPACES     (5),    FORMAT("W20,AL","STANDARD   DEVIATION   =
"),FORMAT("W10.2,EB",STD),"\N"
endproc
proc pagebrk()                                                           ;
```

```
pagebrake
        print file 8 "\f"
endproc
clear
paintcanvas attribute 46 0,0,24,79
style attribute 31
View "job2"
moveto [machine-no]
act = machineno

Query

 Job2 | JOB-NO  | MACHINE-NO  | D-ARR  | T-ARRH | T-ARRM  | D-START |
      | Check   | Check -act  | Check  | Check  | Check   | Check   |
      |         |             |        |        |         |         |

 Job2 | T-STARTH | T-STARTM | D-FIN  | T-FINH | T-FINM | D-DEP |
      | Check    | Check    | Check  | Check  | Check  | Check |
      |          |          |        |        |        |       |

 Job2 | T-DEPH | T-DEPM | T-PROH | T-PROM |T-WAITM |
      | Check  | Check  | Check  | Check  | Check  |
      |        |        |        |        |        |

 Endquery
 do_it!
 sleep 1500
 TW = 0
 TMD2 = 0
 TOTVARI = 0
 TOTTPROH = 0
 TOTTPROM = 0
 TWH = 0
 TMDH2 = 0
 TOTVARIH = 0
 TOTTPROMH = 0

 LINECOUNT = 0
 VIEW "ANSWER"
 machineno = [machine-no]
 HEADING()
    WHILE NOT EOT()
 message "Processing Record No.", Recno()
          JOBNO = [JOB-NO]
          DARR = [D-ARR]
          TARRH = [T-ARRH]
          TARRM = [T-ARRM]
          DSTART = [D-START]
          TSTARTH = [T-STARTH]
          TSTARTM = [T-STARTM]
          DFIN = [D-FIN]
          TFINH = [T-FINH]
          TFINM = [T-FINM]
          DDEP = [D-DEP]
          TDEPH = [T-DEPH]
          TDEPM = [T-DEPM]
          TPROH = [T-PROH]
          TPROM = [T-PROM]
          TWAITM = [T-WAITM]
                tprom = tfinm - tstartm
                TPROH = TFINH - TSTARTH
```

```
            tottprom = tottprom + tprom ; calculates total processing time for
all the sampled jobs
            TOTTPROH = TOTTPROH + TPROH
            avetprom = tottprom/NJ ; calculates average processing time
            AVETPROH = TOTTPROH/NJ
            WIJH = TDEPH - TPROH -TARRH
            Wij = tdepm - tprom - tarrm  ;calculates waiting time
            TW = TW + Wij ;calculates total waiting time
            TWH = TWH + WIJH
        MD = Wij - Wj         ;calculates mean deviation
        MD2 = MD*MD
        MDH = WIJH - WJH
        MDH2 = MDH*MDH         ;calculates square of mean deviation
VARI = (MD2) / (NJ - 1) ;calculates variance for machine j for a given period
VARIH = (MDH2) / (NJ - 1)
TOTVARI = TOTVARI + VARI
TOTVARIH = TOTVARIH + VARIH
Fi1 = 0
FI2 = 0
        linecount = linecount + 1
        println()
        SKIP 1
    IF LINECOUNT > 54 THEN
       PAGEBREAK()
       HEADING()
       LINECOUNT = 0
    ENDIF
ENDWHILE
STD = SQRT(TOTVARI) ;calculates standard deviation
STDH = SQRT(TOTVARIH) ;calculates standard deviation

WSWT = WJ + (3*STD)      ;calculates worst scenario waiting time
WSWTH = WJH + (3*STDH)      ;calculates worst scenario waiting time
BSWT = WJ - (3*STD)       ;calculates best scenario waiting time
BSWTH = WJH - (3*STDH)      ;calculates best scenario waiting time
SLEEP 5000
NJJ()
TWW()
WJJ()
VARI()
STDE()
PAGEBRK()
PLAY "WAITH"
CLEAR
```

```
;SCRIPT NAME: WAITM.SC
;DESCRIPTION: SCRIPT TO TRANSFER RECORDS TO TEMPFILE FILE
;DATE:          JANUARY, 1998

CLEAR
PAINTCANVAS ATTRIBUTE 46 0,0,24,79
style attribute 207
@10,10 77 "GENERATING TEMPFILE, PLEASE WAIT... "

VIEW "TEMPFILE"
MOVETO [MACHINE-NO]
EDITKEY
IF ISEMPTY("TEMPFILE") THEN
   [MACHINE-NO] = MACHINENO
 [WSWT] = WSWT
 [WSWTH] = WSWTH
 [BSWT] = BSWT
 [BSWTH] = BSWTH

 ELSE
  END
   DOWN
   EDITKEY
    [MACHINE-NO] = MACHINENO
    [WSWT] = WSWT
    [BSWT] = BSWT
    [WSWTH] = WSWTH
    [BSWTH] = BSWTH
 ENDIF
 DO_IT!
 CLEAR
 CLEARALL
 PAINTCANVAS ATTRIBUTE 31 0,0,24,79
 STYLE ATTRIBUTE 207
 @12,10 ?? "ANY OTHER MACHINE (Y/N)?: "
      STYLE
      ACCEPT "A1" TO RESP
 IF UPPER(RESP) = "N" THEN
      CLEARALL
      PLAY "JOBFIN22"
 ELSE IF UPPER(RESP) = "Y" THEN
     CLEAR
     CLEARALL
     PLAY "JOBNEW21"
 ENDIF
 ENDIF
```

```
        k = round((40 - ((len(m)/2)+6)),0)
        @11,k ?? m
        x=getchar()
        clear
        style
endswitch
endwhile
style

;NAME: JOBCARD.SC
;DESCRIPTION: SCRIPT TO GENERATE JOBCARD REPORT
;DATE: JANUARY, 1998
;WHILE TRUE

CLEAR
PAINTCANVAS ATTRIBUTE 46 0,0,24,79
STYLE ATTRIBUTE 31

B = "JOBCARD.REP"
proc heading()                                                    ;procedure prints heading

PRINT FILE B SPACES (5), FORMAT("W149,AL","COMPUTERISED JOB SHOP FLOWTIME AND DUE DATE PREDICTION"),"\N",
             SPACES (5), FORMAT("W17,AL", "JOB CARD REPORT"), "\n",
             SPACES (5), FORMAT("W17,AL", "DATE OF REPORT:"),format("D2,al", today()), "\n\n",
             SPACES (5), FORMAT("W149,AC",FILL("-",149)),"\N",
             SPACES (5), format("w2,al","¦"),format("w12,ac","OPERATION NO"), "¦",
             format("w12,ac","MACHINE NO"), "¦",format("w10,AC","D-ARR"), "¦",
             format("w10,AC","T-ARRH"), "¦",format("w10,ac","T-ARRM"),"¦",
             format("w10,ac","T-STARTH"), "¦", format("w10,ac","T-STARTM"), "¦",
             format("w10,AC","T-FINH"), "¦",format("w10,ac","T-FINM"),"¦",
             format("w10,ac","T-DEPH"),"¦",format("w10,ac","T-DEPM"),"¦",
             format("w10,ac","T-PROH"),"¦",format("w10,ac","T-PROM"),"¦","\N",
             SPACES (5), FORMAT("W149,AC",FILL("-",149)),"\N"
endproc
proc println()

PRINT FILE B SPACES (5), format("w2,al","¦"),format("w12,ac",OPNO), "¦",
             format("w12,ac",MACHNO), "¦",format("D10,AR",DARR), "  ¦",
             format("w10.2,eb",TARRH), "¦",format("w10.2,eb",TARRM),"¦",
             format("w10.2,eb",TSTARTH), "¦", format("w10.2,eb",TSTARTM), "¦",
             format("w10.2,eb",TFINH), "¦",format("w10.2,eb",TFINM),"¦",
             format("w10.2,eb",TDEPH),"¦",format("w10.2,eb",TDEPM),"¦",
             format("w10.2,eb",TPROH),"¦",format("w10.2,eb",TPROM),"¦", "\N",
             SPACES (5), FORMAT("W149,AC",FILL("-",149)),"\N"

endproc
proc pagebrk()                                                             ; pagebrake
        print file B "\f"
endproc
SNO = 0
LINECOUNT = 0
VIEW "JOBCARD"
HEADING()
style attribute 207
@12,10 ?? "Processing Jobcard Records, Please Wait..."

WHILE NOT EOT()
message "Processing Record No.", Recno()
        OPNO = [OPERATION-NO]
        MACHNO = [MACHINE-NO]
        DARR = [D-ARR]
        TARRH = [T-ARRH]
        TARRM = [T-ARRM]
        TSTARTH = [T-STARTH]
        TSTARTM = [T-STARTM]
        TFINH = [T-FINH]
        TFINM = [T-FINM]
        TDEPH = [T-DEPH]
        TDEPM = [T-DEPM]
        TPROH = [T-PROH]
        TPROM = [T-PROM]
```

```
        linecount = linecount + 1
        sno = sno + 1
        println()
        SKIP 1
    IF LINECOUNT > 54 THEN
       PAGEBREAK()
       HEADING()
       LINECOUNT = 0
    ENDIF
ENDWHILE
CLEAR
while true
paintcanvas attribute 79 7,25,16,54
paintcanvas attribute 31 6,27,6,56
paintcanvas attribute 31 6,55,15,56
style attribute 79
@ 8,33 ?? "SEND REPORT TO:"
@ 9,33 ?? "==============="
@11,34 ?? " 1. SCREEN "
paintcanvas attribute 78 11,38,11,38
@12,34 ?? " 2. PRINTER"
paintcanvas attribute 78 12,38,12,38
@13,34 ?? " 3. FILE    "
paintcanvas attribute 78 13,38,13,38
@14,34 ?? " 4. EXIT    "
paintcanvas attribute 78 14,39,14,39
@16,32 ?? "Please select [ ]"
choice = "a1"
@16,47 choice = upper(chr(getchar()))
switch
   case choice = "4" or choice = upper("x"):
        clear
        upimage
        clearimage
        play "inforet"
   case choice = "1" or choice = upper("s"):
        clear
        style attribute 31
        cursor off
        m = "USE ARROW KEYS (\17\196, \24, \25, \196\16) TO MOVE AROUND WHEN VIEWING"
        j = "AND PRESS ALT, \17\217, & 'X' TO QUIT."
        k = round((40 - (len(m)/2)),0)
        t = round((40 - (len(j)/2)),0)
        @11,k ?? m
        @12,t ?? j
        message "Press any key to view"
        x=getchar()
        clear
        run big "edit JOBCARD.REP"
        cursor normal
        style
   case choice = "2" or choice = upper("p"):
        clear
        style attribute 31
        m = "Please ensure your Printer is on, with wide paper fed"
        k = round((40 - (len(m)/2)),0)
        @11,k ?? m
        message "Press any key to print..."
        x=getchar()
        clear
        cursor off
        message "Checking printer status, please wait..."
        if not printerstatus() then
          beep
          message "Printer not ready, check please..."
          sleep 1000
          else
            run "type JOBCARD.REP > prn"
        endif
        clear
        style
        cursor normal
```

```
    case choice = "3" or choice = upper("f"):
         clear
         style attribute 31
         m = "File is stored in file \"JOBCARD.LIS\", press any key to go"
         k = round((40 - ((len(m)/2)+6)),0)
         @11,k ?? m
         x=getchar()
         clear
         style
  endswitch
  endwhile
  style
```

```
;NAME: JOBFIN23.SC
;DESCRIPTION: SCRIPT TO GENERATE PREDICTIONS OF DUE DATES
;DATE: AUGUST, 1998
;WHILE TRUE

B = "JOBNEW.REP"
PROC HEADING1()
PRINT FILE B SPACES (5), FORMAT("W139,AL","COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION"),"\N",
        SPACES (5), FORMAT ("W35,AL","INPUT/OUTPUT DATA FOR THE NEW JOB "),"\N",
        SPACES (5), FORMAT("W17,AL", "DATE OF REPORT:"),format("D2,al", today()), "\n\n",
        SPACES (5), FORMAT("W130,AC",FILL("=",130)),"\N",
        SPACES (5), format("w2,al","|"),format("w15,AC","DATE-ARRIVED"), "|",
        format("w15,AC","TIME-ARRIVED"), "|",
        format("w15,AC","WORST DUE-DATE"), "|", format("w15,AC","WORST DUE-TIME"), "|",
        format("w15,AC","BEST DUE-DATE"), "|", format("w15,AC","BEST DUE-TIME"), "|",
        format("w15,AC","MOST LIKE.D-DATE"), "|",format("w15,AC","MOST LIKE.D-TIME"), "|","\N",
        SPACES (5), FORMAT("W130,AC",FILL("=",130)),"\N"
endproc

proc println1()
PRINT FILE B SPACES (5), format("w2,al","|"),format("D5",ARRDNEW), "      |",
format("w15.2,EB",ARRTIMEH), "|",
        format("D5",WSDDi), "      |", format("w9,EB",X1), ".", format("w3,EZ",Z1),"  |",
        format("D5",BSDDi), "      |", format("w9,EB",X2), ".", format("w3,EZ",Z2),"  |",
        format("D5",MLSDDi), "      |", format("w9,EB",X3), ".", format("w3,EZ",Z3),"  |","\N",
        SPACES (5), FORMAT("W130,AC",FILL("-",130)),"\N"
endproc

proc println2()
PRINT FILE B SPACES (5), format("w2,al","|"),format("D5",ARRDNEW), "      |",
format("w15.2,EB",ARRTIMEH), "|",
        format("D5",WSDDi), "      |", format("w15.2,EB",WSDDiHFIN), "|",
        format("D5",BSDDi), "      |", format("w15.2,EB",BSDDiHFIN),"|",
        format("D5",MLSDDi), "      |", format("w15.2,EB",MLSDDiHFIN),"|","\N",
        SPACES (5), FORMAT("W130,AC",FILL("-",130)),"\N"
endproc


proc pagebrk()                                              ; pagebrake
   print file B "\f"
endproc
paintcanvas attribute 46 0,0,24,79
style attribute 31
@9,20 ?? "PROCESSING BEGINS AT  ",TIME()
;clear
@12,20 ?? "PROCESSING IS ON, PLEASE WAIT"
?? "....."
STYLE
sleep 1500
CLEAR
paintcanvas attribute 31 0,0,24,79
style attribute 46
@10,5 ?? "ENTER THE ARRIVAL DATE OF THE NEW JOB [E.G: 01.01.98]: "
   accept "D" picture "##.##.##" required to  arrdnew

@12,5 ?? "ENTER THE ARRIVAL TIME OF THE NEW JOB [E.G: 08.00]: "
   accept "N" picture "##.##" required to  arrtimeh
```

```
CLEAR
TW = 0
TOTTPROM = 0
TOTWSWT = 0
TOTBSWT = 0
TWH = 0
TOTTPROMH = 0
TOTWSWTH = 0
TOTBSWTH = 0

LINECOUNT = 0
HEADING1()

VIEW "JOBCARD"
MOVETO "JOBCARD"
MOVETO [T-PROM]

WHILE NOT EOT()
message "Processing Record No.", Recno()

        TPROM = [T-PROM]
        TOTTPROM = TOTTPROM + TPROM
        TPROH = [T-PROH]
        SKIP 1
ENDWHILE

VIEW "TEMPFILE"
MOVETO [WSWT]
WHILE NOT EOT()

            WSWT = [WSWT]
            BSWT = [BSWT]
            TOTWSWT = TOTWSWT + WSWT
            TOTBSWT = TOTBSWT + BSWT
            WSWTH = [WSWTH]
            BSWTH = [BSWTH]
            TOTWSWTH = TOTWSWTH + WSWTH
            TOTBSWTH = TOTBSWTH + BSWTH
            SKIP 1
ENDWHILE
        FT1 = (TOTTPROM + TOTWSWT)/480  ;FLOWTIME IN DAYS (WORST SCENARIO)
        FT2 = (TOTTPROM + TOTBSWT)/480  ;FLOWTIME IN DAYS (BEST SCENARIO)
        FT3 = (FT1 + FT2)/2

        N1 =  ROUND(FT1,0)
        FRACTIONDAY1 = FT1 - N1
        N2 =  ROUND(FT2,0)
        FRACTIONDAY2 = FT2 - N2
        N3 =  ROUND(FT3,0)
        FRACTIONDAY3 = FT3 - N3

       IF FT1 < 1 THEN
          n1 = FT1 * 8
          n2 = FT2 * 8
          n2 = FT3 * 8

         WSDDT = n1 + 8
         BSDDT = n2 + 8
```

```
        MLSDDT = n3 + 8

        X1 =  INT(WSDDT) ;ACTUAL NO OF HOURS
        X2 =  INT(BSDDT) ;ACTUAL NO OF HOURS
        X3 =  INT(MLSDDT) ;ACTUAL NO OF HOURS


        IF X1 < 8  THEN
           X1 = ROUND((X1 + 8),2)
        ENDIF
        IF X2 < 8 THEN
           X2 = ROUND((X2 + 8),2)
        ENDIF
        IF X3 < 8 THEN
           X3 = ROUND((X3 + 8),2)
        ENDIF

        Y1 =  WSDDT - X1       ;FRACTION OF HOUR LEFT
        Y2 =  BSDDT - X2       ;FRACTION OF HOUR LEFT
        Y3 =  MLSDDT - X3      ;FRACTION OF HOUR LEFT

        Z1 =  ABS(Y1)  ;CONVERTS FRACTION OF HOUR TO MINUTES
        Z2 =  ABS(Y2)  ;CONVERTS FRACTION OF HOUR TO MINUTES
        Z3 =  ABS(Y3)  ;CONVERTS FRACTION OF HOUR TO MINUTES
    ELSE
        n1 = (FT1 - N1) * 8
        n2 = (FT2 - N2) * 8
        n3 = (FT3 - N3) * 8
        WSDDT = n1 + 8
        BSDDT = n2 + 8
        MLSDDT = n3 + 8
        X1 =  ROUND(WSDDT,0) ;ACTUAL NO OF HOURS
        X2 =  ROUND(BSDDT,0) ;ACTUAL NO OF HOURS
        X3 =  ROUND(MLSDDT,0) ;ACTUAL NO OF HOURS

        IF X1 < 8  THEN
           X1 = ROUND((X1 + 8),2)
        ENDIF
        IF X2 < 8 THEN
           X2 = ROUND((X2 + 8),2)
        ENDIF
        IF X3 < 8 THEN
           X3 = ROUND((X3 + 8),2)
        ENDIF

        Y1 = WSDDT - X1       ;FRACTION OF HOUR LEFT
        Y2 = BSDDT - X2       ;FRACTION OF HOUR LEFT
        Y3 = MLSDDT - X3      ;FRACTION OF HOUR LEFT

        Z1 =  ABS(Y1)   ;CONVERTS FRACTION OF HOUR TO MINUTES
        Z2 =  ABS(Y2)  ;CONVERTS FRACTION OF HOUR TO MINUTES
        Z3 =  ABS(Y3)  ;CONVERTS FRACTION OF HOUR TO MINUTES

ENDIF

WSDDi = arrdnew + FT1     ;calculates worst scenario due-date
BSDDi = arrdnew + FT2     ;calculates best scenario due-date
```

```
MLSDDi = arrdnew + FT3        ;calculates best scenario due-date

IF Y1 = 0 THEN ,
  WSDDi = 16.00
ENDIF
IF Y2 = 0 THEN
  BSDDi = 16.00
ENDIF
IF Y3 = 0 THEN
  MLSDDi = 16.00
ENDIF
println1()

CLEAR
paintcanvas attribute 79 0,0,24,79
STYLE ATTRIBUTE 31
@9,20 ?? "PROCESSING COMPLETED AT  ",TIME()
@10,20 ?? "THANKS"
?? "....."
STYLE
sleep 3000

CLEAR
while true
paintcanvas attribute 79 7,25,16,54
paintcanvas attribute 31 6,27,6,56
paintcanvas attribute 31 6,55,15,56
style attribute 79
@ 8,33 ?? "SEND REPORT TO:"
@ 9,33 ?? "==============="
@11,34 ?? " 1. SCREEN "
paintcanvas attribute 78 11,38,11,38
@12,34 ?? " 2. PRINTER"
paintcanvas attribute 78 12,38,12,38
@13,34 ?? " 3. FILE   "
paintcanvas attribute 78 13,38,13,38
@14,34 ?? " 4. EXIT   "
paintcanvas attribute 78 14,39,14,39
@16,32 ?? "Please select [ ]"
choice = "a1"
@16,47 choice = upper(chr(getchar()))
switch
   case choice = "4" or choice = upper("x"):
        clear
        upimage
        clearimage
        play "inforet"
   case choice = "1" or choice = upper("s"):
        clear
        style attribute 31
        cursor off
        m = "USE ARROW KEYS (\17\196, \24, \25, \196\16) TO MOVE AROUND WHEN VIEWING"
        j = "AND PRESS ALT, \17\217, & 'X' TO QUIT."
        k = round((40 - (len(m)/2)),0)
        t = round((40 - (len(j)/2)),0)
        @11,k ?? m
        @12,t ?? j
        message "Press any key to view"
        x=getchar()
```

```
        clear
        run big "edit JOBNEW.REP"
        cursor normal
        style
    case choice = "2" or choice = upper("p"):
        clear
        style attribute 31
        m = "Please ensure your Printer is on, with wide paper fed"
        k = round((40 - (len(m)/2)),0)
        @11,k ?? m
        message "Press any key to print..."
        x=getchar()
        clear
        cursor off
        message "Checking printer status, please wait..."
        if not printerstatus() then
          beep
          message "Printer not ready, check please..."
          sleep 1000
          else
            run "type JOBNEW.REP > prn"
        endif
        clear
        style
        cursor normal
    case choice = "3" or choice = upper("f"):
        clear
        style attribute 31
        m = "File is stored in file \"JOBNEW.REP\", press any key to go"
        k = round((40 - ((len(m)/2)+6)),0)
        @11,k ?? m
        x=getchar()
        clear
        style
endswitch
endwhile
style
```

Appendix II

COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION
JOB CARD REPORT
DATE OF REPORT: June 12, 1998

OPERATION NO	MACHINE NO	D-ARR	T-ARRH	T-ARRM	T-STARTH	T-STARTM	T-FINH	T-FINM	T-DEPH	T-DEPM	T-PROH	T-PROM
1	LM01											120.00
2	LM01											110.00
3	LM01											120.00
4	LM01											115.00
5	LM01											50.00
6	LM01											40.00
7	LM01											15.00

COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION
REPORT FOR MACHINE NO: LM01
DATE OF REPORT: AUGUST 24, 1998

JOB NO	D-ARR	T-ARRH	T-ARRM	D-START	T-STARTH	T-STARTM	D-FIN	T-FINH	T-FINM	D-DEP	T-DEPH	T-DEPM	T-PROM	T-WAITM
001	4/10/97	8.00	480.00	2/10/97	8.10	490.00	2/10/97	8.40	520.00	2/10/97	8.45	525.00	30.00	15.00
002	7/10/97	8.20	500.00	2/10/97	8.50	530.00	2/10/97	9.45	585.00	2/10/97	9.50	590.00	55.00	35.00
003	5/10/97	9.40	580.00	2/10/97	9.56	596.00	2/10/97	10.25	625.00	2/10/97	10.29	629.00	29.00	20.00
004	2/10/97	9.40	580.00	2/10/97	10.35	635.00	2/10/97	15.45	945.00	2/10/97	15.55	955.00	310.00	65.00

NUMBER OF JOBS SAMPLED = 4.00
TOTAL WAIT TIME (MINUTES) = 135.00
MEAN WAIT TIME (MINUTES) = 33.75
VARIANCE = 506.25
STANDARD DEVIATION = 22.50

COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION
REPORT FOR MACHINE NO: MM02
DATE OF REPORT: AUGUST 24, 1998

JOB NO	D-ARR	T-ARRH	T-ARRM	D-START	T-STARTH	T-STARTM	D-FIN	T-FINH	T-FINM	D-DEP	T-DEPH	T-DEPM	T-PROM	T-WAITM
002	6/10/97	9.55	595.00	6/10/97	10.00	600.00	6/10/97	11.25	685.00	6/10/97	13.30	690.00	85.00	10.00
003	7/10/97	11.30	690.00	6/10/97	11.40	700.00	6/10/97	11.42	702.00	6/10/97	13.33	813.00	2.00	121.00
004	6/10/97	13.30	810.00	6/10/97	13.33	813.00	6/10/97	13.30	810.00	6/10/97	15.55	955.00	- 3.00	148.00
014	3/10/97	8.25	505.00	4/10/97	8.35	565.00	4/10/97	10.30	630.00	4/10/97	10.37	637.00	65.00	67.00
015	4/10/97	10.05	605.00	4/10/97	10.40	640.00	4/10/97	15.20	920.00	4/10/97	15.28	928.00	280.00	43.00
016	4/10/97	10.36	636.00	4/10/97	15.40	940.00	5/10/97	9.30	1150.00	5/10/97	9.45	1165.00	210.00	319.00

NUMBER OF JOBS SAMPLED = 6.00
TOTAL WAIT TIME (MINUTES) = 708.00
MEAN WAIT TIME (MINUTES) = 118.00
VARIANCE = 12240.00
STANDARD DEVIATION = 110.63

COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION
REPORT FOR MACHINE NO: PSM05
DATE OF REPORT: AUGUST 24, 1998

JOB NO	D-ARR	T-ARRH	T-ARRM	D-START	T-STARTH	T-STARTM	D-FIN	T-FINH	T-FINM	D-DEP	T-DEPH	T-DEPM	T-PROM	T-WAITM
010	3/10/97	8.50	530.00	2/10/97	10.05	605.00	2/10/97	10.10	610.00	2/10/97	10.12	612.00	5.00	77.00
011	4/10/97	10.00	600.00	4/10/97	10.03	603.00	4/10/97	10.05	615.00	4/10/97	10.07	617.00	12.00	5.00
012	4/10/97	11.20	680.00	4/10/97	11.22	682.00	4/10/97	11.40	700.00	4/10/97	11.45	705.00	18.00	7.00
013	5/10/97	14.00	840.00	4/10/97	14.03	843.00	4/10/97	14.18	858.00	4/10/97	14.23	863.00	15.00	8.00

NUMBER OF JOBS SAMPLED = 4.00
TOTAL WAIT TIME (MINUTES) = 97.00
MEAN WAIT TIME (MINUTES) = 24.25
VARIANCE = 1238.25
STANDARD DEVIATION = 35.19

COMPUTERISED JOB-SHOP FLOWTIME AND DUE-DATE PREDICTION
INPUT/OUTPUT DATA FOR THE NEW JOB
DATE OF REPORT: AUGUST 24, 1998

DATE-ARRIVED	TIME-ARRIVED	WORST DUE-DATE	WORST DUE-TIME	BEST DUE-DATE	BEST DUE-TIME	MOST LIKE.D-DAT	MOST LIKE.D-TIM
24-Aug-98	8.00	26-Aug-98	13. 08	24-Aug-98	12. 08	25-Aug-98	12. 08