THE PERFORMANCE OF THE SPT-T RULE ON A MULTIPRODUCT, MULTIFACILITY PRODUCTION SYSTEM

by

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We hereby recommend that the thesis entitled "The Performance of the SPT-T Rule on a Multiproduct, Multifacility Production System" submitted by Orhan Şahin be accepted in partial fulfillment of the requirements for the Degree of Master of Science in Industrial Engineering, School of Engineering, Boğaziçi University.

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ABSTRACT

This thesis deals with the implementation of the Shortest Processing Time Scheduling Rule with Truncation Process (SPT-T) at the Parts Production Plant of Çukurova İnşaat Makinaları Sanayi ve Ticaret A.Ş. (Çimsataş) to improve the performance of the plant by:

1- Decreasing the level of work-in-process inventory
2- Better utilization of the machine centers
3- Realizing higher inventory turnover
4- Decreasing the number of tardy jobs.

For this purpose, a general simulation model has been developed for a multiproduct, multifacility and deterministic job-shop scheduling system to study the effects of the SPT-T rule on the performance of the plant.

The actual data from the Parts Production Plant were used in the simulation model in order to better compare the actual performance with the one given by the model. The comparison of the two sets of results thus obtained suggests that it is possible to

i- decrease the actual work-in-process inventory level by more than 50% without causing any infavourable effects on tardiness,

ii- decrease the average tardiness by 70% and the number of tardy jobs by 55%,

iii- utilize the shops 50% better than the actual case,

iv- identify the machines which are bottlenecks in production system and hence to indicate technological needs for investment planning.

ÖZET

Bu tez SPT-T tipi iş-çizelgeleme kuralının uygulanmasıyla, Çukurova İnşaat Makinaları Sanayi ve Ticaret A.Ş. (Çimsataş) Parça Üretim Tesislerinin performansını aşağıda belirtilen sahalarda geliştirmek amacıyla yapılmıştır:

1- Ara stok düzeyini azaltmak
2- Makina kapasitelerinin daha iyi kullanımını sağlamak
3- Daha yüksek stok devir hızı sağlamak
4- Artısal gecikmeli işlerin sayısını azaltmak.

SPT-T tipi iş çizelgeleme kuralının söz konusu üretim tesisinin performansı üzerindeki etkisini görmek amacıyla çok ürünlü, çok tezgahlı ve gerekirci tezgah yükleme sistemi için bir benzetim modeli geliştirilmiştir.

Toplanan verilere göre çalıştırılan benzetim modelinin sonuçları ile üretim tesisinde gözlemlenen performans karşılaştırılarak:

i- artısal gecikme üzerinde istenmeyen sonuçlara neden olmadan gerçek ara stok düzeyinin % 50'den fazla azaltılmasının,

ii- ortalama artısal gecikmenin % 70 ve artısal gecikmeli işlerin sayısının % 55 oranında azaltılmasının,

iii- sistemden yararlanma oranının % 50 arttırılmasının,

iv- üretim sisteminde darboğaz yaratan makinaların saptanması ve böylece yatırım planlaması için gereken teknolojik gereksinimlerin belirlenmesinin

mümkün olabileceği görülmüştür.

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I. INTRODUCTION

In this thesis, a real life n/m job shop scheduling problem at the Parts Production Plant of Çimsataş has been studied. It has been observed that one of the main problem of the existing plant was the high level of work-in-process inventory, which has an average value of 85 million TL per month. In addition to the high level of work-in-process inventory, there are others problems such as:

1- Low stock turnover
2- Underutilization of man-machine capacity
3- Increase in the number of tardy jobs.

Therefore, in this study, the emphasis has been on the production scheduling in order to improve the existing undesired situation.

The result of this study suggest that one first has to determine the economic lot sizes of the parts to be produced (jobs) and then to sequence the jobs thus defined in accordance with the selected scheduling rule SPT-T. More specifically,

i- incoming orders first should be converted into economic lot-sizes

ii- the economic lot-sizes are to be considered as "jobs" in production scheduling iii- the job designed thus are to be sequenced according to the SPT-T rule.

A simulation model has been developed in order to study the effects of the proposed scheduling rule SPT-T on the performance of the plant. The simulation results indicate that it is possible to improve the performance of the production system with respect to work-in-process inventory level, average tardiness, shop utilization and capacity planning.

It is shown that the level of work-in-process inventory can be decreased by more than 50% without causing any unfavourable effects on tardiness, since number of jobs in the system are decreased by assigning priorities to the jobs according to the SPT-T rule.

Sequencing the jobs by taking into consideration their due-dates and processing times it is possible to decrease the average tardiness by 70% and the number of tardy jobs by 55%.

It is also shown that it is possible to utilize the shop 50% better than actual case by the use of SPT-T rule, which also identifies the real bottlenecks of the system.

Chapter 2 explains in detail the characteristics of manufacturing company under study such as company products, available production technology and facilities.

Chapters 3 describes the existing production inventory system, which is the main source of the problems arising in the system. The detailed definition of these problems are given in Chapter 4.

The relationship between the inventory level and the scheduling rules are explained in Chapter 5.

Various scheduling rules such as, SPT, S/OPN, SPT-T and their impacts on the system are explained in Chapter 6.

The effects of the SPT-T rule on the performance of the shop is explained in Chapter 7 by the use of simulation model, results of which are compared with the actual case.

The implementation of recommended procedure of this study on the system is explained in Chapter 8.

2. CHARACTERISTICS OF THE MANUFACTURING COMPANY

This section summarizes the general characteristics of the manufacturing company under study namely, company products, production facilities, and technology in use, main markets and other properties related to the production-inventory system.

2.1. COMPANY PRODUCTS

Çukurova İnşaat Makinaları Sanayi ve Ticaret A.Ş. (in short, Çimsataş) is a leading automotive company in Mersin, with its own Foundry and Forging Plant. Çimsataş is producing construction machines and their parts. The present annual capacity of this factory is 300 Track loaders and 1500 Complete undercarriage parts for all crowler-type construction machines. The undercarriage parts produced in this factory is classified as follows,

- Pins
- Track Link Bushings
- Track Links
- Track Shoes
- Track Roller Shafts
- Track Rollers
- Track Roller Bearing Assembly
- Track Roller End Collars
- Sprocket Segments

. Front Idlers

. Track Link Assemblies

Çimsataş is also supplying various automotive companies in Turkey with rough forgings and castings; machined and head treated components.

At the present, casting, machining and heat treatment of the above products are performed at the existing facilities. However, the blue-print and technical specifications of these products as well as the technological know-how are provided by the Caterpillar Tractor Company under license agreement.

2.2. PRODUCTION TECHNOLOGY AND FACILITIES

The production facility of Çimsataş which covers a production area of 15.000 m^2 consists of the following plants:

1- Parts Production Plant

2- Machine Assembly Plant

3- Forging Plant (due in 1982)

4- Foundry.

To give an idea about the production technology and facilities at this factory, a brief explanation about Cimsataş Quality Control Laborotories, Engineering Design Office, and Tools, Fixtures and Dies Production Department will also be provided in this section.

2.2.1. Parts Production Plant

This plant produces undercarriage components and various parts for construction machines. This plant is divided into two main facilities.

i- Machining Facility
ii- Heat Treatment Facility

Raw material enters the machining facility in the form of rough forgings in case of forged parts, rough castings in case of cast parts, and in the form of steel profiles and bars in case of shoes, pins and bushings. These materials go through the machinery operation on various special turning, milling and cutting machines in this facility.

The second facility of this plant is the heat treatment facility. It is under the same roof with the machining facility. All kinds of heat-treating (hardening, tempering, stress relieving, normalizing, annealing) operations are done in this facility. The temperature-controlled, electric-heated roller hearth, special-purpose heat-treating furnaces are used in these operations. This plant also has gas carburizers, flame hardening units, and induction heating units for hardening operations of parts.

Materials handling in this plant is carried out in baskets between the machining centers. Without this operation "small mass production" (which is thought to be the most suitable type of production in the existing plant) would stop. In order to provide for future materials handling requirements, the machine layout is arranged so that a conveyor system can be installed later on The detailed description of this plant i.e., production facilities and machine layout is given in the Appendix. To give an idea of the production process at this plant, a typical product, the link, will be taken as an example. The production of link consists of the following stages.

- Milling
- Direct Hardening
  - Links are heated to austenizing temperatures in electric heated roller hearth furnaces and quenched
  - Quenched links are tempered in electric heated roller hearth furnaces to accomplish the desired hardness level
  - Surfaces of the links which are in contact with the rollers are re-hardened in special induction heating equipment to a higher hardness value, in order to minimize the wear of the surface
- Boring
- Broaching
- Quality Control. To ensure the production of high quality links, tensile and impact tests are performed at every stage on the production line.

The other products also go through similar production processes and quality control tests.

2.2.2. Machine Assembly Plant

Construction machines are made in the Machine Assembly Plant. Production started in 1981 with 955L Traxcavators. Track type tractors, wheel loaders, motor graders, dump trucks, and highway tractors are also planned to be assembled in this plant.

The source of raw materials and parts for the above products can be classified in three groups.

1- Parts Production Plant of the Company

2- Local Suppliers

3- Imported Parts.

Presently the raw material and various parts of the 955L Traxcavator are being obtained from above sources. The parts thus obtained are assembled by using adjustable fixtures and toolings in the following production and auxiliary facilities of this plant. These are:

- Manufacturing machine shops for several parts of the products
- Plate and sheet metal working and profile forming shops
- Welding areas
- Heat treatment areas
- Subassembly sections
- Wash and paint areas
- Tools and fixtures manufacturing and maintenance shops

- Quality Control department
- Main Assembly lines for
  - .. Track-type construction machines
  - .. Wheel-type construction machines
  - .. Lift tracks
  - .. Track and highway tractors
- Performance tests area
- Materials storage buildings
- Spare parts, tools and fixture storage buildings
- Mechanical and electrical maintenance department
- Boiler and central heating facilities
- Transformer substation.

2.2.3. Forging Plant

The construction of the forging plant is progressing rapidly. The forging plant is scheduled for operation in 1982, with a capacity of 12.500 tons/year.

This plant will supplies rough forgings to the Parts Production Plant mainly for the production of undercarriage parts. Rough forging requirement of various automotive industries will also met by this plant.

In this plant, production will be entirely made on 4500 tons and 2500 tons mechanical maxi-presses where billets are heated by induction heating equipment. The annual forging production capacity of 12.000 tons will be increased in the future in order to be able to meet the increasing demand for high quality rough forgings of the automotive industry.

All dies and fixtures used in this plant will be produced in the Die Making Department of Çimsataş.

2.2.4. Foundry

Çimsataş Foundry was started up in 1979 to provide quality castings for the Parts Production Plant and automotive industry. It can produce castings of alloy and non-alloy stell, sphero and gray iron.

This Fonudry has a capacity of 2500 tons/year and a casting piece part size capacity of 800 kg/net.

In this plant, quality tests of every types of castings are performed in quality control labs to meet high quality requirements of Parts Production Plant.

2.2.5. Quality Control Laboratories

Çimsataş Quality Control labs have a wide range of facilities for chemical analysis, testing and determining mechanical properties of alloy steels, sphero, gray iron and non-ferrous materials.

Chemical contents of ferrous and non-ferrous materials of up to 20 elements are determined through wet methods as well as by use of the most sophisticated equipment like emission spectrometer.

The parts produced in Çimsataş are tested for their mechanical properties such as tensile/impact strength and elongation. Facilities are also available for microstructural analysis, non-destructive testing and hardness measurements.

2.2.6. Engineering and Design Office

This office is responsible for preparing efficient production methods for all units.

Designing of tools and fixtures, developing prototype production and realization of expansion projects are also among the responsibilites of the Engineering and Design office.

2.2.7. Tools, Fixtures and Dies Production Department

The most up-to-date machinery and equipment may be found in this department of the factory. Dies of the most complicated forged components will be produced in this department with the use of precise copy milling, pantograph milling and spark erosion machines.

Various dies and fixtures for machining and heat-treatment operations are produced in this department with the highest precision.

2.3. CUSTOMERS

A brief explanation about the users of construction machines in Turkey is given in this section, because these users are the main customers of the undercarriage parts, of the construction machines.

In Turkey the construction machines are owned and used by the following associations and sectors.

1- Public Sector

. Highways, Water and Electricity Department (Y.S.E)

. State Highway Department (Y.C.K)

. State Hydraulic Department (D.S.İ)

. Land Water Department (Toprak-Su)

2- Private Sector

3- Armed Forces (Army, Air Forces, and Navy)

4- Provinces and Municipalities.

The public and private sectors are the largest users of the construction machines. They obtain the machines either directly from the manufacturers or through their agents; they can also obtain the machines from the domestic market.

The machinery owned by the Armed Forces is mostly provided through foreign aid.

Provinces and Municipalities obtain their machinery mostly through donations.

All the above sectors use construction machines in different areas for various purposes. Table 2.1 shows the distribution of this usage according to sectors.

TABLE 2.1

USAGE OF CONSTRUCTION MACHINES DISTRIBUTION ACCORDING TO SECTORS

SECTOR	PERCENT
Irrigation (Village Development)	37
Road Construction	20
Hydraulic Works	18
Mining	13
Forest Road Construction	10
Others	2
TOTAL	100

3. DESCRIPTION OF THE EXISTING PRODUCTION-INVENTORY SYSTEM

This section describes the existing production inventory system in "Parts Production Palnt" for which aggregate production planning is made on the basis of customer orders, inventory, and production capacity. In addition, a brief explanation of the interfunctional dependencies in the organization will be given, such as the interactions between the functions of production, marketing, and procurement, and so on.

3.1. DEMAND

The demand which is used in determining the production level of "Parts Production Plant" can be classified in two groups

1- Demand due to the Machine Assembly Plant

2- Demand which comes directly from the customer

  a) For finished products (e.g. Track Link Assemblies)

  b) For semifinished products (e.g. Subcomponents of the finished products) Now details follow.

3.1.1. Demand Due To The Machine Assembly Plant

All of the undercarriage parts of this plant are supplied by the Parts Production Plant. Since the only product of the Machine Assembly Plant is the track-type loader presently, the production amount of this product determines the whole demand, for undercarriage parts, which comes from the Machine

Assembly Plant.

The number of track-type loaders which will be produced during a period of one year is determined generally two or three months before the production period, and distributed over months. This data, which is transferred to Parts Production Plant, determines the quantity of finished products to be supplied to the Machine Assembly Plant. These finished products consist of several subcomponents, which are assembled in Parts Production Plant to form the finished product. Therefore the main demand, which comes from the Machine Assembly Plant, consists of these subcomponents. The production of these subcomponents are calculated according to the following formula

$$D_i = a_{ij} \times P_j \tag{1}$$

where D_i : Quantity to be produced of subcomponent;

a_i : Amount of subcomponent used to produce one unit of the finished product;

P_j : Demand for finished product.

The above formula gives the quantities to be produced of subcomponents in a given period and these quantities are uniformly distributed over the months throughout the year.

3.1.2. Demand Which Comes Directly From The Customer

The forecasting of the demand due to customers is done by the sales department. The expected sales for the following year is estimated by this department and the results are conveyed to the Parts Production Plant at least two or three months before the beginning of the following production period in the form of

i- Demand for finished products: As explained in the previous section finished products consist of several subcomponents, and therefore the expected sales of finished products determine the production levels of subcomponents according to the explanation and Formula(1) in section 3.1.1,

ii- Demand for semifinished products (Subcomponents): In some cases there is a demand from the market for the sub-component, mostly from the users of the finished products. Therefore the expected sales of subcomponents as spare parts is directly taken as the quantity to be produced by Parts Production Plant.

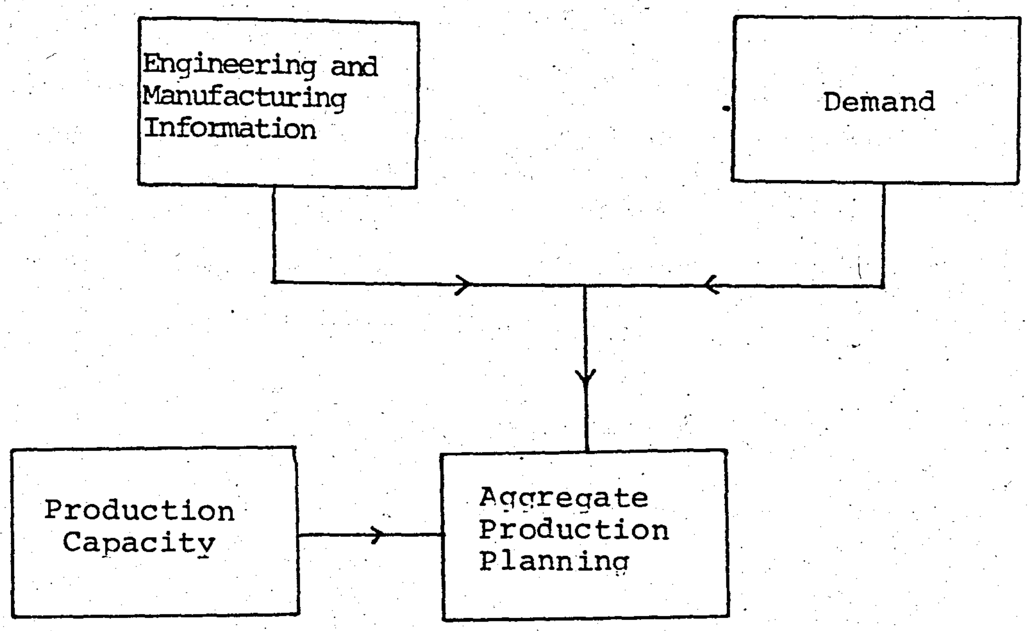
3.2. AGGREGATE PRODUCTION PLANNING

The term "aggregate production planning" is always conceived as some sort of capacity study, where current man and machine capacities would be established. It is significant to know what the capacity, capability and potential of a job is. But the important question before determining capacity availability is to determine the capacity requirements. In other words, how much capacity is needed.

The aggregate production planning in Parts Production Plant largely depends on how men and machines are actually utilized, i.e., how these resources are scheduled. The main routings of list of the operations required to meet the production demand with the standard man and machining times of each production part associated with each operation. However the existence of inventories in this system, of course, has another impact on aggregate production planning. For example, the parts of which the raw materials can not be obtained from local or foreign suppliers, are not taken into the production program.

The minimum economic lot size to be produced of each subcomponent which is determined by the production department is an another impact on Aggregate Production Planning. The parts of which the demands are less than the minimum economic lot size of produced parts are not taken into the production program.

The production capacity (Man, Machine, and Equipment), and requirements of the Parts Production Plant are the main inputs to the aggregate production planning. The following information flow figure shows this relationships.



The engineering and Manufacturing Information, which is prepared by the engineering and design department, consists of the following necessary data on each part.

1- Necessary operations and manufacturing list

2- Processing time of operations on machines

3- Set-up time of machines for different operations

4- Raw materials requirements.

The Production Planning Department determines the number of man and machining hours required to meet the demand (Customer and Machine Assembly Plant demand) in light of the above informations. This process in known as "Planning Capacity Requirements" where o tentative plan to show the required capacity is included. This is then compared with the available capacity in order to determine whether or not the production demand can be met. In this plant, the problem of capacity during the aggregate production planning has not arisen, since there has always been idle capacity in all machines except for one or two. So in the beginning of each production period, the required capacity is always available. When the capacity requirement exceeds the available capacity, there are basically three alternative solutions.

1- Baying new machinery and/or hiring personnel
2- Use of overtime
3- Use of subcontractor.

In the aggregate production planning, the number of man are generally calculated according to the number of machines; e.g. one operator for each machine is always provided in each shift. Man and machine capacities are also allocated with a margin of tolerance of 10 percent.

In aggregate production planning the following procedure is followed for the allocation of each machine:

1- Estimate the necessary operation time (T_1) of the machine required to meet the demand in the production year. This is always estimated by adding the operation times of the parts which will be manufactured on machine.
2- Find the available working hours (T_2) in the production year.
3- Find the available machine hours (T_3), by using the following formula

$$T_3 = N_1 \cdot T_2$$

where N_1 : Number of machines of the same type available in the plant for the year.

4- Decide on the number of shifts (N_2) per day to meet the required operation time of the machine (T_1) so that the following relationship is satisfied:

$T_1 \leq N_2 \cdot T_2 \quad , \quad N_2 = 1,2,3$

If the above relationship can not be met with the available capacity, then either buy a new machine or use a sub-contractor. However, the latter rarely occurs.

5- Find the required number of men for the machine (N_3) by using the following formula

$N_3 = N_1 \cdot N_2$

6- Find the available operation hours (T_3) according to the following formula

$T_3 = N_3 \cdot T_2$.

The above procedure is applied to all machines which exist in the system, to find the total available and utilized man and machine times.

3.3. SCHEDULING

This is the activity that determines the overall production plan on the basis of months over the production year. After the total production amount of each part has been determined, and capacities have been pretty well fixed, scheduling activity assigns production capacity to individual products.

The demand which comes directly from customer and from the machine assembly plant determines which parts should be produced when, and all scheduling is done accordingly. After this step, all of the scheduling decisions are taken by the Production Planning Department to minimize deviation from due dates, but because of inefficient use of the available capacity, this objective can not always be achieved. This occurs due to lack of scheduling policy, and therefore most of the jobs are completed before or after their due-dates.

In this plant, if the available man and machine capacities are less than the work scheduled for a given week or month, either the workers do overtime or some of the current month's work is "pushed ahead" to the following weeks or months. If the available man and machine capacities are for more than the work scheduled, some work is "pulled back" from the following months in order to fill up the idle capacity. Since scheduling is not done very well, the actual load in the plant does not fit the available capacity exactly, and therefore some "push ahead" and "pull back" inevitably occur.

3.4. INVENTORY

When the inventory system of this plant was analyzed, it was found that the stock turnover of this plant is very low, i.e., the value of stock in hand is very high when compared with sales. The reason for this low turnover is analyzed by classifying the system into three main groups:

1- Raw material inventory

2- Work-in-process inventory

3- Factory overhead inventory.

Raw materials inventory covers 40% of the total inventory. The raw materials demand of this plant is satisfied in relatively larger quantities than needed, especially to avoid raw materials shortages, and also to obtain quantity price discounts, and to keep shipping costs low. The quantity and timing of the purchasing of raw materials is not based on a certain inventory model, but it is usually done quarterly. The main reason for keeping large raw materials stocks and not using an inventory model is the present situation of the raw material suppliers in Turkey, i.e., capacities of suppliers being unstable.

The second and most valuable part of the inventory system is the work-in-process inventory which covers 48% of the total inventory (It has a value of more than 80 million TL). The work-in-process inventory being very high is due to unscheduled production program of finished products, which results in idle inventories between machines, and/or idle machines while other machines are working with full capacity. The effect of the Quality Control Department is another reason for the high level of work-in-process inventory, i.e., some accepted subcomponents of the finished products may be idle due to some rejected subcomponents of the same finished products. Fortunately in the long run, positive effects of intensive quality control offset their negative effects, which results in producing high quality goods.

The remaining 12% of the total inventory covers the factory overhead inventory, which also contains indirect materials inventory of the whole plant. The demand of this inventory is satisfied in the same way as the raw material inventory requirements.

The finished goods inventory of this plant is not mentioned here, because the level of this inventory is not high with respects to the others.

3.5. MAINTENANCE

There are two types of maintenance programs which are in application in this plant.

1- The maintenance program which is applied to every machine once year, in which all the machines are dissambled, tested, replaced if necessary, and reassembled.

2- The maintenance program which is prepared by the manufacturing department is generally done quarterly, and and consists of lubrication of the parts, whereas machine tool alignment is not taken into program.

Unexpected breakdowns occur very rarely due to the systems being new.

4. DEFINITION OF THE PROBLEM

The main problem of the plant under study is high work-in-process inventory, the reasons for which have been explained in previous section. Therefore the main objective of this thesis is to minimize the work-in-process inventory by finding an optimum sequencing of jobs, which will be processed in a multi-machine system. The sequencing of jobs will be done according to the SPT-T (Shortest-Processing Time Scheduling Rule with Truncation Process) rule, and the results thus obtained will be analyzed.

The main components of this system are jobs, operations and machines. The characteristics of these components will be the main input for finding an optimal sequencing of jobs according to the SPT-T rule. These are:

- due-date of jobs
- processing times of operations
- set-up times of machines
- number and order of operations in each job.

In addition to high work-in-process inventory there are others problems existing in the production system. These are

1- Too many semifinished parts waiting in the production line,
2- Ineffective use of machine capacities
3- Low stock turnover
4- Too many tardy jobs.

The solution to high work-in-process inventory and the above problems will be taken as a criteria of performance of the SPT-T rule in this plant.

4.1. DEFINITION OF JOB

The optimal quantities of each part in each manufacturing run, determines the "job" of the system. Each job consists of a set of g_i operations. These are described by g_i pairs of values

$$\begin{matrix} m_{i1} & P_{i1} \\ m_{i2} & P_{i2} \\ \vdots & \vdots \\ m_{ig_i} & P_{ig_i} \end{matrix}$$

where m_{ij} is the identification number of the machine that is required to perform the j^{th} operation of the i^{th} job, and P_{ij} is the processing time, e.g. the amount of time that will be required for machine m_{ij} to perform the operation.

As previously defined, the demand is deterministic at a constant rate. Therefore there are known and constant demands $D_1, D_2, \ldots D_{12}$ that occur over the months throughout the year, and a single lot may be procured in each period. Let Q_i denote the optimal quantity of job i in each manufacturing run over the year. There is a fixed set-up cost for each Q_i, and there is also an inventory carrying cost for each unit of stock. But no shortage is allowed as a policy of the firm, because the due-date of each part is previously set by the customers or by the Machine Assembly Plant. Now the problem is to determine the lot sizes, Q_1 ...... Q_N, which minimizes the sum of procurement costs, and inventory carrying costs over the period. So under this circumstance, the behaviour of this production-inventory system conforms to the model given in Figure 4.1.

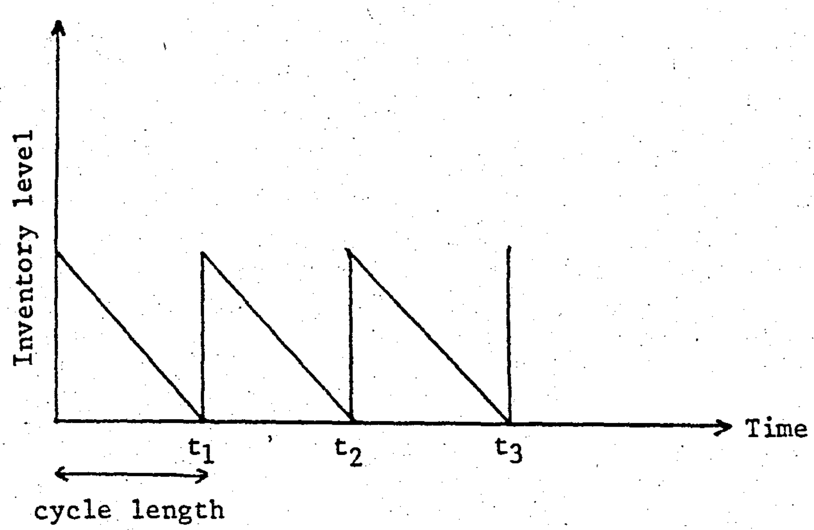


Figure 4.1. Infinite production rate, no backlogging

Now, it is obvious that the Economic Order Quantity (EOQ) is the best adaptive formula for this model to find the optimal value of Q_1, Q_2, ... Q_N. Therefore optimal lot size of each job will be calculated according to the EOQ formula given below.

$$Q_i = \sqrt{\frac{2A_iD_i}{h_i}}$$

where

Q_i : optimal lot size of job i. $i = 1, 2, \ldots\ldots N$

A_i : set-up cost of job i.

D_i : yearly demand of job i.

h_i : inventory carrying cost per unit per year.

Number of manufacturing runs (N_i) of job i in year will be calculated according to the following formula:

$$N_i = \frac{D_i}{Q_i}$$

5. RELATIONSHIP BETWEEN INVENTORY LEVEL AND SCHEDULING RULE

The primary objective of the production manager is to meet production targets both in volume and time, while controlling production cost and inventories at the same time. By holding large inventories he generally can meet both volume and time targets. Maintaining large inventories, however, is costly. Inventory holding cost can be excessive and a decline in demands can easily result in large obsolescence costs. Cost control thus suggest maintaining minimum or low inventories.

This problem of the production manager can be fortunately solved by a better scheduling procedure. One of the primary effects of scheduling on inventory is the reduction of work-in-process inventories, which can be achieved by maintaining a shorter cycle time through the line. The level of costly raw material inventories can also be reduced by the reduction of work-in-process inventories and cycle-time without cutting production targets. The effect of scheduling rules on work-in-process is well treated in Conway(1) and therefore will be omitted here.

6. SCHEDULING RULES

According to Oral and Malouin(2), Scheduling is the task of ordering of the operations of jobs on each machine in such a way that a predetermined criterion of performance is optimized. In general, the optimal ordering of operations on each machine for a given criterion of performance may not be any longer the best ordering for another criterion of performance. This means that the criterion of performance should be determined before the selection of the scheduling dispatching rule or rules. However, this approach may not always yield simple scheduling dispatching rules, if one can obtain such a rule at all. On the other hand, there are some known simple and applicable scheduling dispatching rules which are optimal with respect to certain criteria of performance. Some of these rules describing the following measures of shop performance. These are

1- Number of jobs in the shop
2- Job flow time
3- Mean completion time of jobs
4- Mean waiting time of jobs
5- Shop utilization
6- Number of tardy jobs in the shop
7- Average tardiness of jobs
8- Maximum tardiness of jobs.

It is difficult to find the effectiveness of scheduling rules in relation to a given criterion. However in this section SPT, S/OPN rules and SPT-T rule which is the combination of these two rules will be explained and analyzed with respect to desired criteria of performance, namely minimization of work-in-process inventory.

6.1. SHORTEST PROCESSING TIME SCHEDULING

Scheduling according to processing time, SPT, creates a priority rule in which the job with the shortest processing time is scheduled first.

It is proven that this rule is one of the best for minimization of (1)

1- Number of jobs in the shop
2- Average tardiness of jobs
3- Mean completion time of jobs
4- Mean waiting time of jobs in the shop
5- Number of tardy jobs.

The main disadvantage of this rule is that it generally produces a great tardiness in a job with a very long processing time, since it always gives high priority to the job with the shorter processing times. This is due to the fact that this rule never takes the due-dates of jobs into consideration.

6.2. S/OPN TYPE SCHEDULING RULE

The least-slack-time-per-operation-remaining, abbreviated S/OPN. This rule gives the highest priority to the job which has the least-slack-time-per-operation remaining, where slack time of a job at time t is calculated according to the following formula:

$$Q_i = \frac{d_i - t - P_i}{n_i}.$$

where

- Q_i : the slack time per operation remaining for job i
- t : Present time
- P_i : Remaining processing time of job i
- n_i : number of remaining operation of job i.

<u>Example 6.1.</u>

Let consider two jobs X and Y in a single machining shop, composed of both four operations.

Job X = (x_1, x_2, x_3, x_4), and

Job Y = (y_1, y_2, y_3, y_4)

Assume that both jobs enter the shop at t=0, and let processing time of $P_{x_1}=3$, $P_{x_2}=2$, $P_{x_3}=2$, $P_{x_4}=3$, and $P_{y_1}=3$, $P_{y_2}=1$, $P_{y_3}=4$, $P_{y_4}=4$ units of time. Assuming the due-dates of the jobs to be $d_x=16$ and $d_y=17$, then the slack-time-per-operation-remaining of X is given as follows.

$$Q_x = \frac{16-10}{4} = \frac{6}{4}$$

and the slack-time-per-operation remaining of job Y is,

$$Q_y = \frac{17-12}{4} = \frac{5}{4}$$

Therfore, according to S/OPN rule, the first operation of job Y, y_1, is scheduled first and the operation will take 3 units of time.

At t=3, the situation is as follows:

Job X has waited for 3 units of time and hence the new slack time of this job is decreased by 3

$$Q_x = \frac{13-10}{4} = \frac{3}{4}$$

Job Y has three more operations to be processed and hence the number of remaining operations is decreased to 3.

$$Q_y = \frac{14-9}{3} = \frac{5}{3}$$

Since 3/4 is less than 5/3, operation X_1 is scheduled next, and the machine is occupied for three units of time.

Applying the same procedure to the remaining operations, the scheduling is completed, and the sequencing of jobs and tardiness will be as follows

1- $y_1-x_1-y_2-x_2-y_3-x_3-y_4-x_4$ with tardiness $T_x=6$ and $T_y=2$

2- $y_1-x_1-y_2-x_2-y_3-x_3-x_4-y_4$ with tardiness $T_x=2$ and $T_y=6$

6.3. SHORTEST-PROCESSING TIME SCHEDULING RULE WITH TRUNCATION PROCESS

The examination of above two rules indicate that both the processing times and the due-dates of the jobs should be taken into the consideration. The question, whether one can somehow combine simple and useful ordering rules into a new ordering rule, applicable yet in practice, which will optimize or sufficiently nearly optimize a desired criterion of performance is answered by Oral and Malouin(2). Their rules, SPT and S/OPN, are converted into a new one called the Shortest Processing Time Scheduling Rule with Truncation Process (SPT-T).

The reason for introducing SPT-T rule is the simple fact that, SPT scheduling rule is preferable to the S/OPN in terms of the percentage of jobs that are tardy and mean tardiness, whilst in the case of variance and higher moments of tardiness, the reverse is true. With these observations it gives a better result to combine these two types of rules a way to retain advantages of both, but avoid their disadvantages.

6.3.1. Dispatching Rule

SPT-T rule introduces the concept of truncation process, with parameter r, the truncated processing time. It has been previously indicated that, when using the SPT rule, ε_i, the processing time of the next immediate operation of job i is the deciding factor for assigning priorities to jobs. As for the S/OPN rule, Q_i, the slack-time-per-operation-remaining for job i is the deciding factor. The combination of these two rules implies that during the scheduling process, sometimes processing time ε_i, and the rest of the times the slack-time-per-operation-remaining Q_i, will be the deciding factor, but the percentage use of these two rules can be controlled by changing the value of the parameter of the SPT-T rule according to the characteristics of the job-shop, such as the number of jobs in the job-shop. The parameter r, $-\infty<r<\infty$, enters the discussion here, and takes a value according to the characteristics of the shop, and determines whether SPT rule or S/OPN rule is used when assigning priorities to jobs. The SPT-T dispatching rule is defined in symbols as follows:

$$\underset{i}{\mathrm{Min}}^{(K)} \min\{\varepsilon_i+r, Q_i\}, \text{ for } i \in I$$

where

ε_i : the processing time of the next immediate operation of job i

Q_i : the slack time per operation remaining for job i

r : a parameter, $-\infty<r<\infty$

I : the set of the jobs waiting at a machine center.

According to this SPT-T rule, all the next immediate available operations of jobs with their processing times and the slack time per operation remaining of each job waiting at a given machine center are listed. Then K^{th} priority is given to the job with K^{th} minimum of $\min\{\varepsilon_i+r, Q_i\}$ K=1,2, ... n, where n is the number of jobs in I. In the case of tie when comparing jobs, the first-come-first-served rule is used, i.e, the job which has waited longest is scheduled first. This priority assignment is repeated at the completion of each single operation.

Example 6.2.

Let us consider again two jobs X and Y in a single machining shop composed of two and three operations respectively

Job X = (x_1, x_2); $P_{x_1}=3$, $P_{x_2}=2$, $d_x=7$

Job Y = (y_1, y_2, y_3); $P_{y_1}=2$, $P_{y_2}=4$, $P_{y_3}=1$, $d_y=12$

and let take r=0

at t=0,

$$\text{Min }\{\min(3,1),\ \min(2,\ \tfrac{5}{3})\} = 1$$

schedule x_1 for 3 unit of time

at t=3,

$$\text{Min }\{\min(2,2),\ \min(2,\ 2/3)\} = 2/3$$

schedule y_1 for 2 unit of time

at t=5,

$$\text{Min }\{\min(2,0),\ \min(4,1)\} = 0$$

schedule x_2 for 2 unit of time

The remaining operations y_2 and y_3 will schedule respectively, and the sequencing of jobs will be as

$$x_1 - y_1 - x_2 - y_2 - y_3$$

The tardiness of jobs associated with the schedule above are the following

$$T_x = 0$$

$$T_y = 0$$

6.3.2. Criterion of Performance

Oral and Malouin(2) conclude that 90-95% use of r-truncated processing time when assigning priorities, produce the best results for job-shop scheduling with respect to

- percentage of tardy jobs
- average tardiness
- variance of tardiness
- skewness of tardiness
- kurthosis of tardiness
- maximum tardiness.

7. SCHEDULING SIMULATION MODEL

A simulation model has been designed for the purpose of studying the effects of the scheduling rule SPT-T in solving the problems, which have been explained in previous chapters. In this simulation model the actual production amount of Parts Production Plant in 1981 has been used as real data.

The main characteristic of the system which has been simulated are as follows

1- The system has 70 different types of jobs where each job is a simple sequence of operations, including assembly
2- There are 29 machine centers. Each machine centers can have more than one machine of the same type. Therefore the total number of machines in the system becomes 48 when the above condition is taken into consideration. Moreover;
   a) each machine center is continously available for assignment
   b) only one machine center is capable of performing a given operation
   c) set-up time for operations is assumed
   d) no preemption is allowed
   c) instantaneous transfer to the next machine center is assumed.

In the simulation model five tables are needed to describe the state of the parts production plant. Therefore a brief description of the characteristic of each table is given as follows:

i- Job table: This table defines the order of operations and the processing time of these operations for each job,

ii- Event table: This table keeps tracks of what should happen at future time period. In other words, it retains the forecasts of primary events,

iii- Machine table: To insure that jobs from queues are put on idle machines, and that the proper job is removed from a machine and placed in the next queue, it is necessary to maintain records on the status of each processing station. This data is also needed to obtain summary information about each machine's processing record (e.g. machine utulization),

iv- Queues: The focus of this study is on how to remove jobs from queues (i.e. waiting lines) when a machine is idle. It is necessary to keep track of the specific jobs in each queue and their priority,

v- Output table: As the simulation operates it is necessary to accumulate the data that can produce the required statistics. In this case the output table accumulates the following statistics.

a) machine utilization

b) queue position

c) manufacturing run of job

d) average tardiness.

This simulation model consits of one main program and 10 subroutines, flowchart, details, and result of which are given in this section.

7.1. SIMULATION PROGRAM

1- MAIN Program: The necessary data related to the system is read into the program and the shop is assigned to the initial condition.

The main function of this program is to find the type and time of the event that should happen at the future time period.

2- Subroutine CREATE: Generation of job arrival in predetermined time interval is done in this program. Also the due-date and next arrival time of related job is calculated in this program. Finally arrived job is transferred to the machine on which job will be processed.

3- Subroutine INQUE: This program stores the jobs, waiting in the machine's queues, according to their priority. Processing of job starts immediately if the machine is idle.

4- Subroutine QUTQUE: This subroutine takes jobs out of queue for processing and updates the position of the jobs which are left in the queue.

5- Subroutine ENTER: This subroutine finds the number of idle machines of the same type and assigns a jobs to these machines according to the priority of jobs, if there exists a job in the queue of that type of machine. The completion time of the assigned job is automatically calculated also by this subroutine.

6- Subroutine SELECT: This subroutine prevents the unnecessary records in the machine and event table, by storing the machine number which has the lowest completion time in comparison to the other machines of the same type. Assignment of the machine to the idle condition is also done in this program.

7- Subroutine ASSMBL: This subroutine is used for the assembled jobs to control whether their subcomponents are ready to be assembled. If they are all ready then the assembled job arrival is generated.

8- Subroutine PRIOR: This subroutine calculates the priority of the job according to the SPT-T rule.

9- Subroutine LEAVE: The event of job completion is done in this subroutine. Therefore the necessary updating of machine and job record is also done in this subroutine. Controlling assembly structure of job is another function of this subroutine.

This subroutine also controls the operation order of the jobs according to the following criteria.

a) If there is still remaining operation to be done on the job, then the job is sent to the next operation.

b) If there is no remaining operation to be done on the job then the manufacturing run of the job is finished and the job leaves the shop. This case is printed in the output.

10- Subroutine STAT: This subroutine is used to collect statistics for queues and machines.

11- Subroutine REPORT: This subroutine is used to obtain the following periodic reports which cover the time from the beginning of the simulation till the reporting time.

a) Machine queue report: This report covers the maximum and average number of jobs waiting in queues.

b) Machine utilization report: This report covers the average and the maximum utilization of the machines of the same type.

c) Job status report: This report gives the number of started and finished jobs.

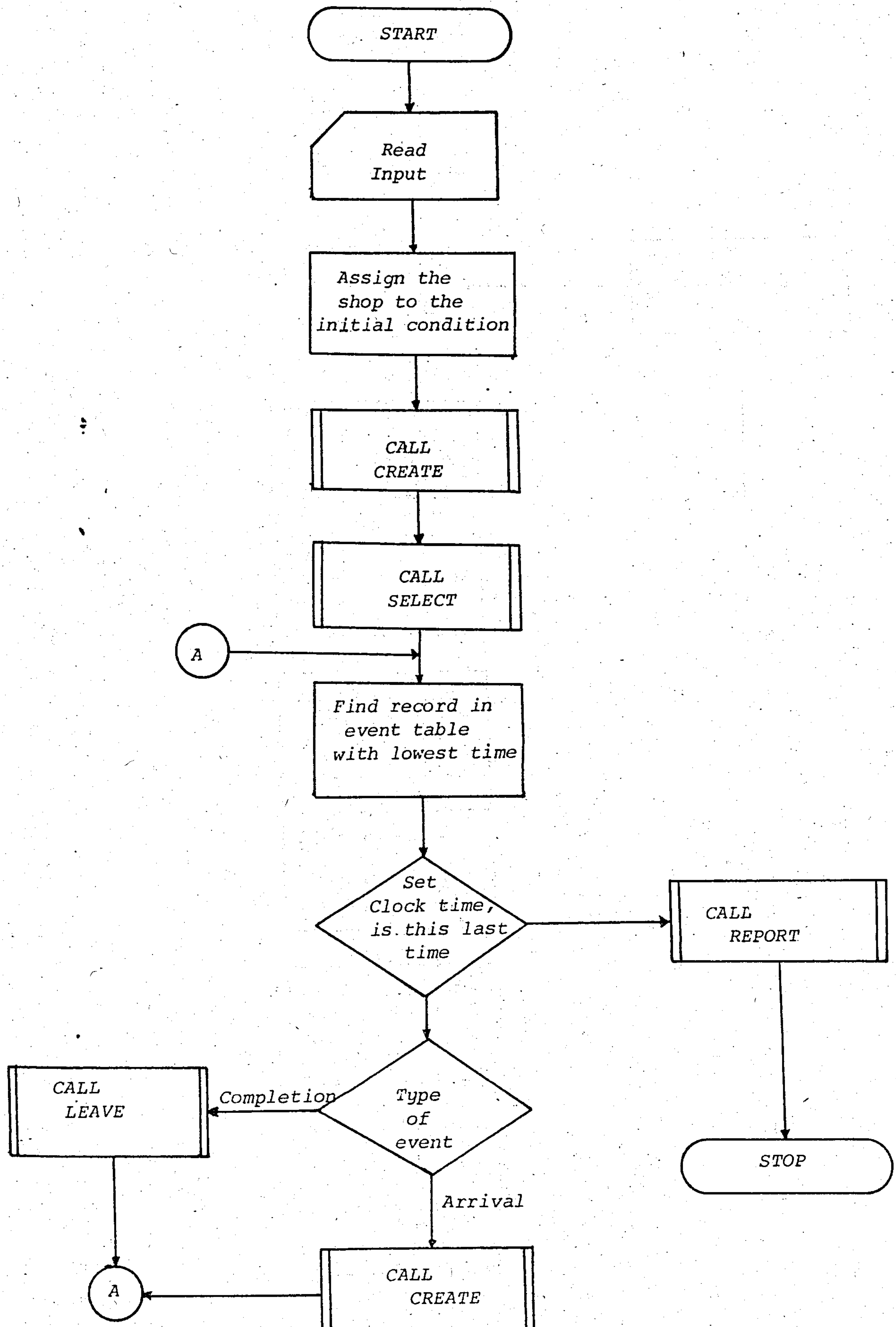
d) Average tardiness report: This report covers the average tardiness of jobs being simulated.

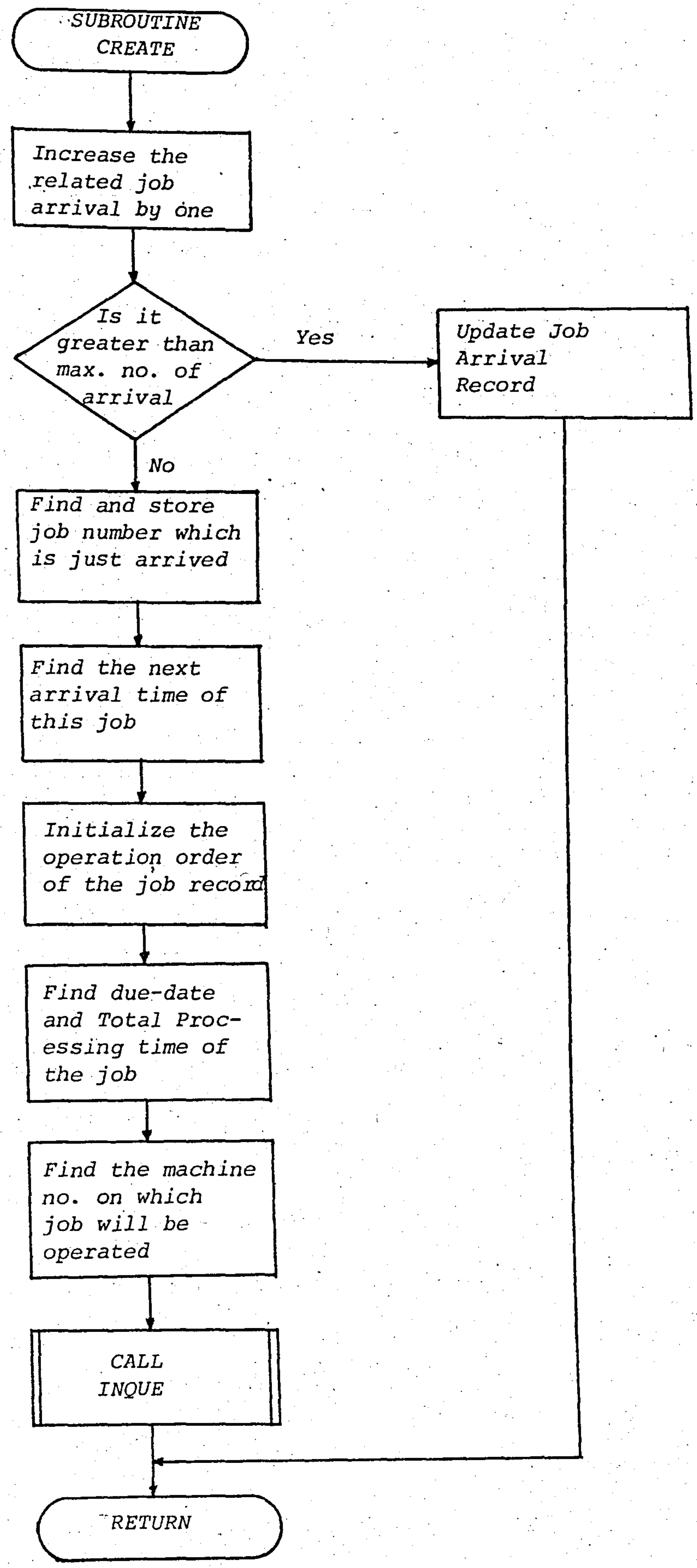
e) Job priority report: This report gives the number of jobs which takes either according to SPT or according to S/OPN rule.

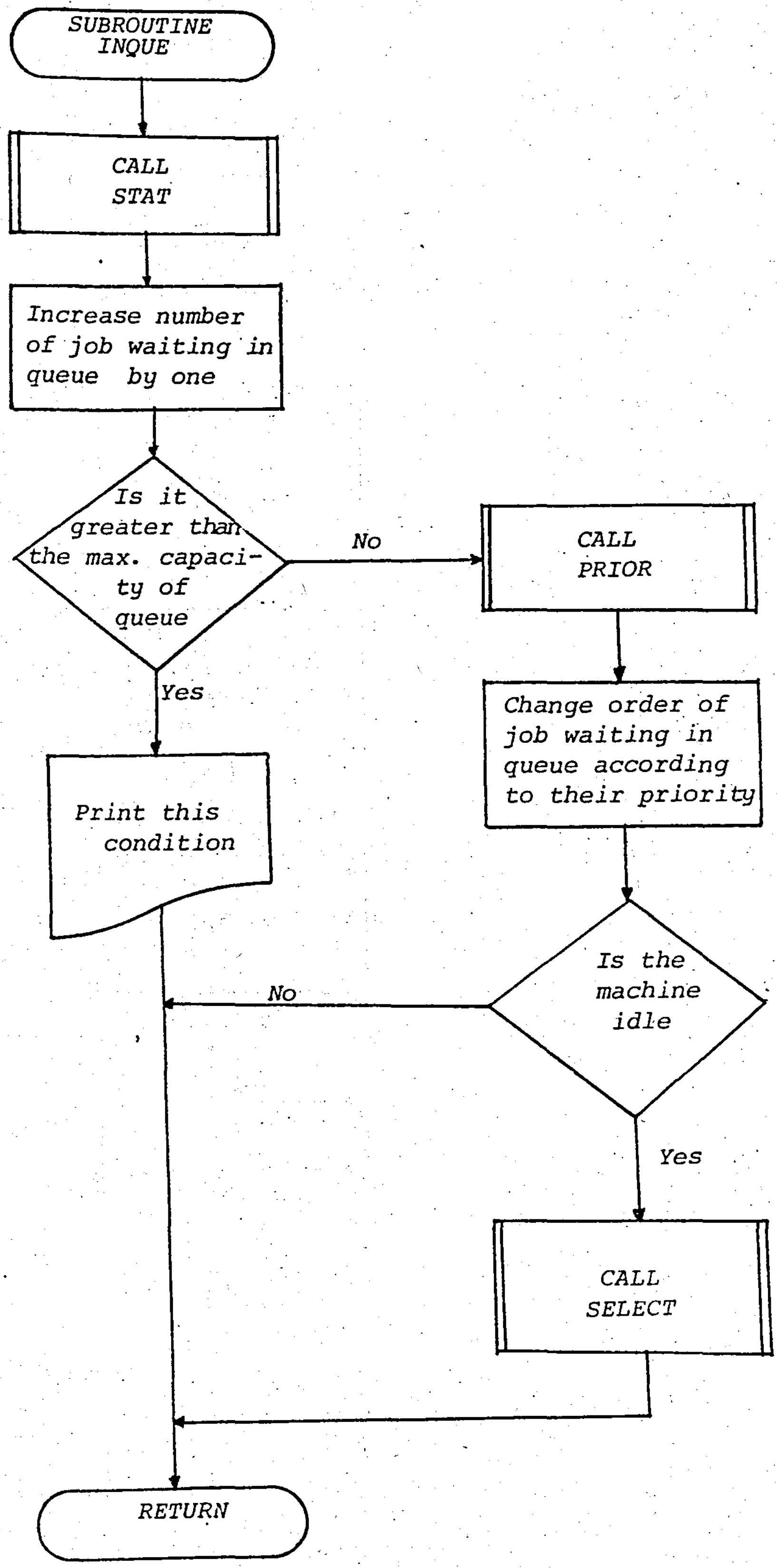
7.2. FLOW-CHART OF THE MODEL

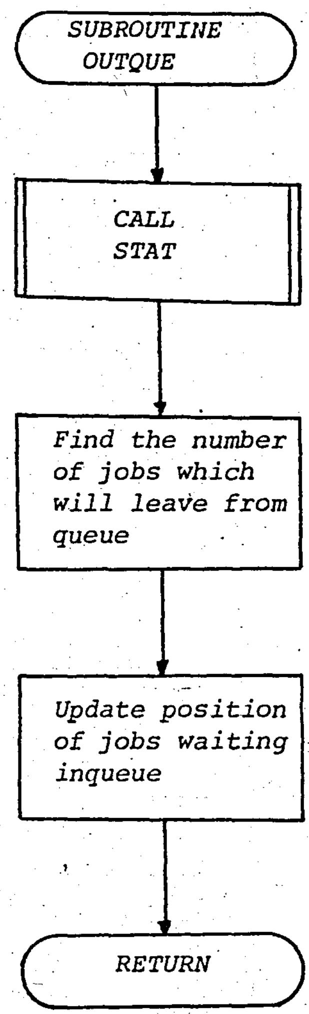
The flow-chart of the simulation model which is explained above is indicated in Figure 7.1.

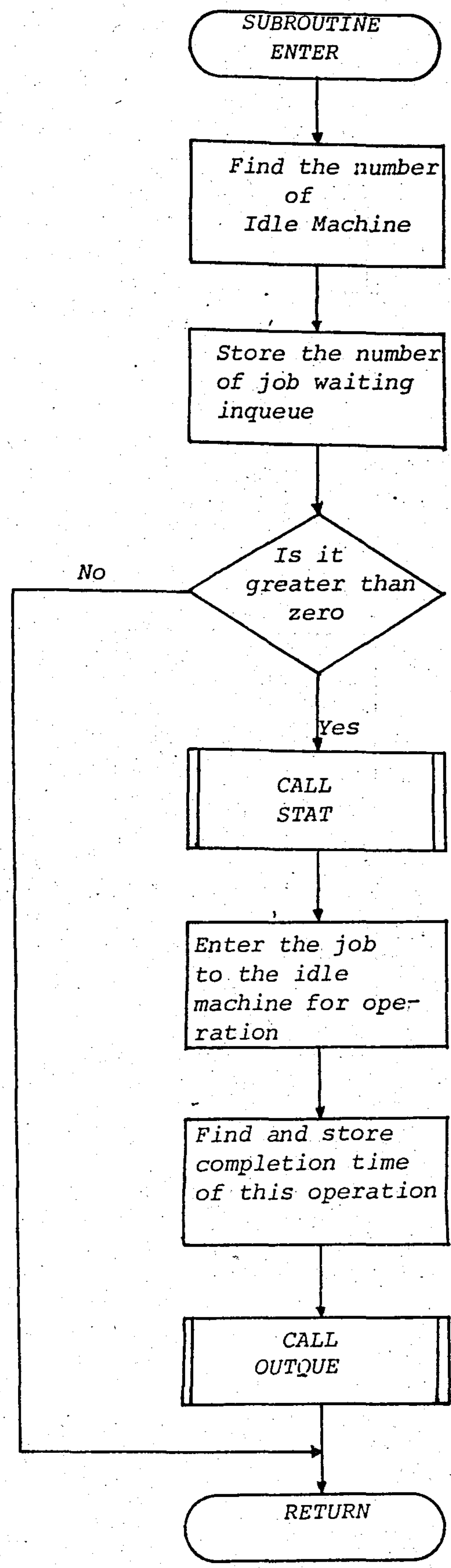
Figure 7.1. Flow-Chart of the Simulation Model

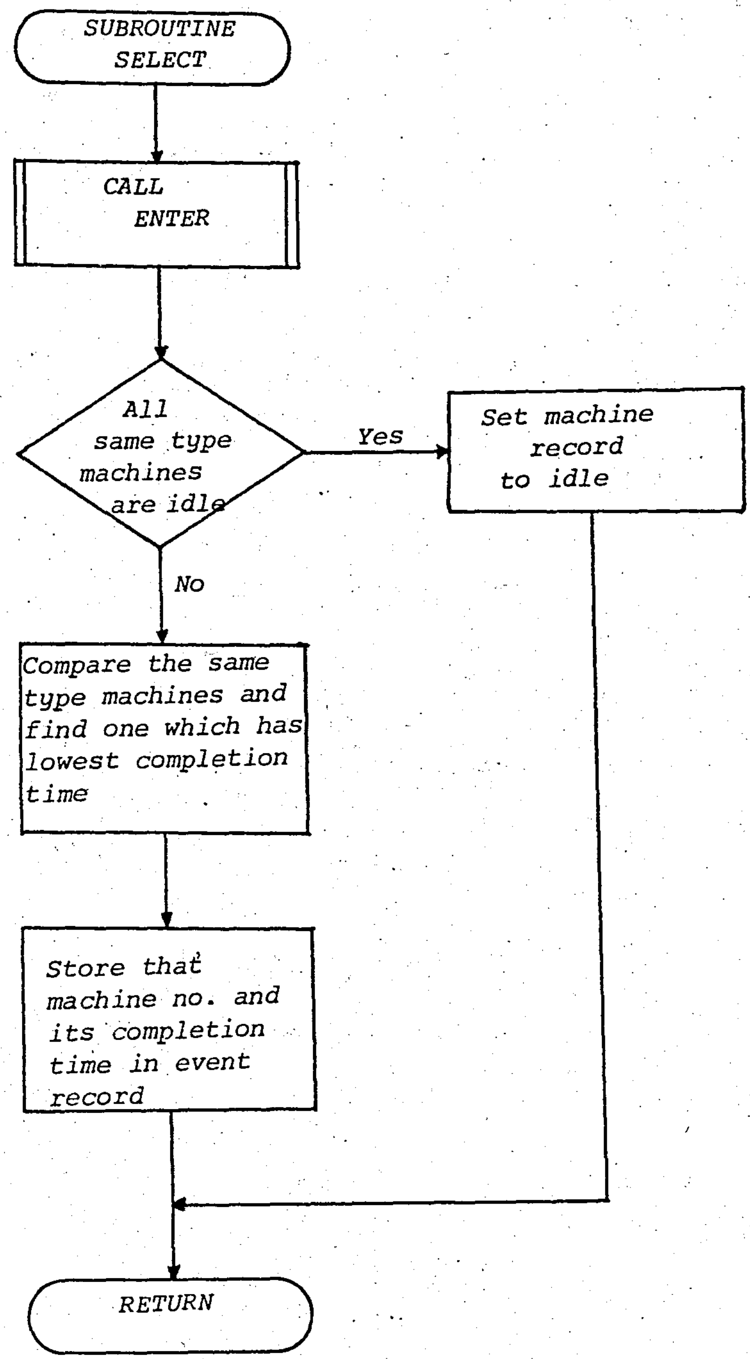


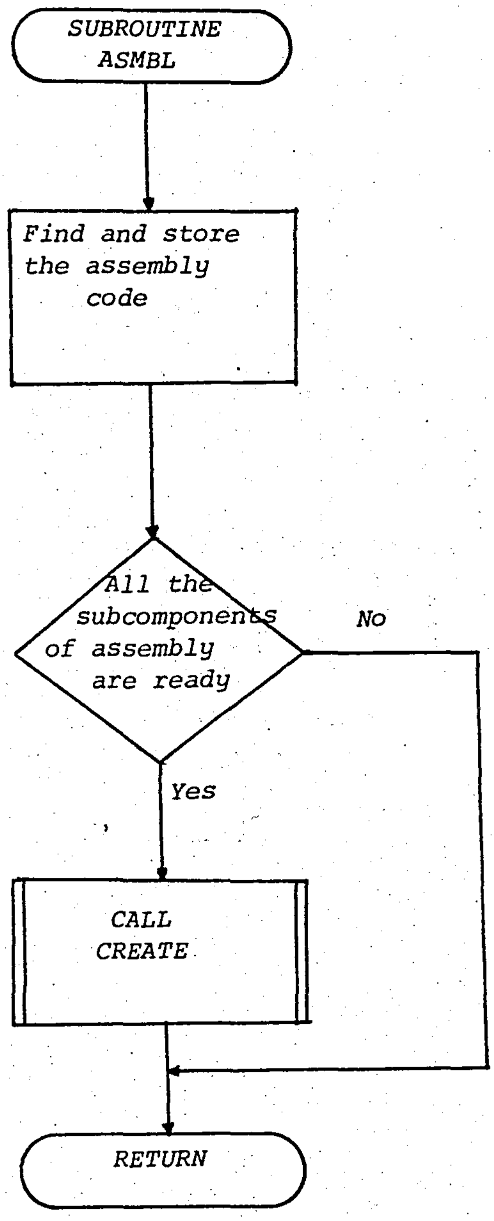

SUBROUTINE CREATE
Increase the related job arrival by one
Is it greater than max. no. of arrival
Yes
Update Job Arrival Record
No
Find and store job number which is just arrived
Find the next arrival time of this job
Initialize the operation order of the job record
Find due-date and Total Processing time of the job
Find the machine no. on which job will be operated
CALL INQUE
RETURN

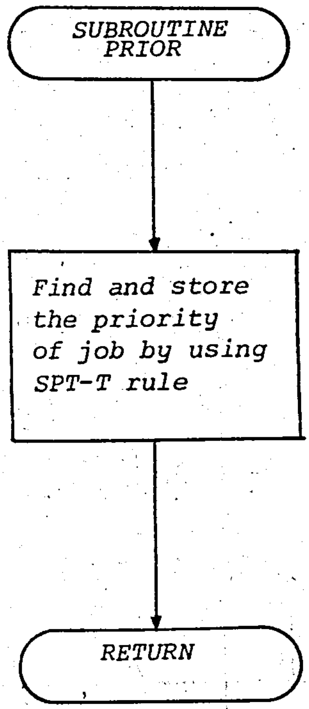

SUBROUTINE INQUE
CALL STAT
Increase number of job waiting in queue by one
Is it greater than the max. capacity of queue
No
Yes
CALL PRIOR
Change order of job waiting in queue according to their priority
Print this condition
Is the machine idle
No
Yes
CALL SELECT
RETURN

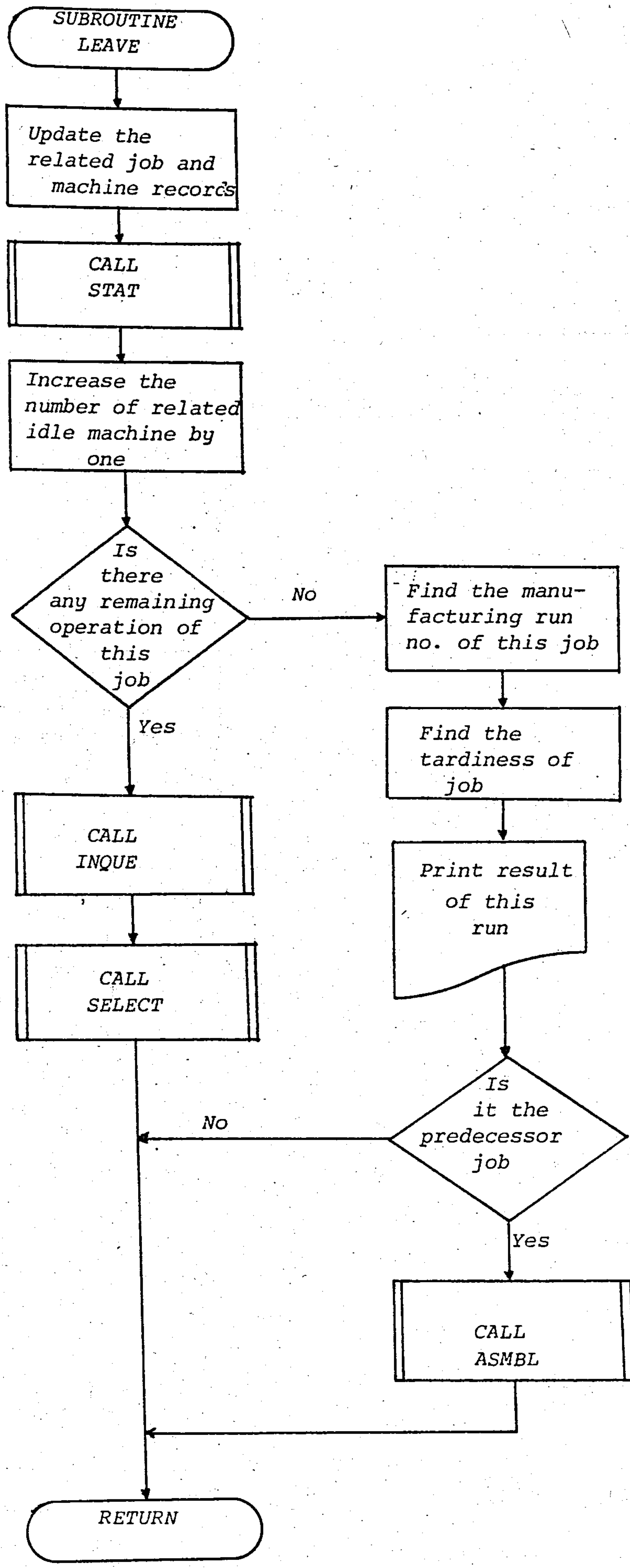

SUBROUTINE OUTQUE
CALL STAT
Find the number of jobs which will leave from queue
Update position of jobs waiting inqueue
RETURN


SUBROUTINE ENTER
Find the number of Idle Machine
Store the number of job waiting inqueue
Is it greater than zero
No
Yes
CALL STAT
Enter the job to the idle machine for operation
Find and store completion time of this operation
CALL OUTQUE
RETURN

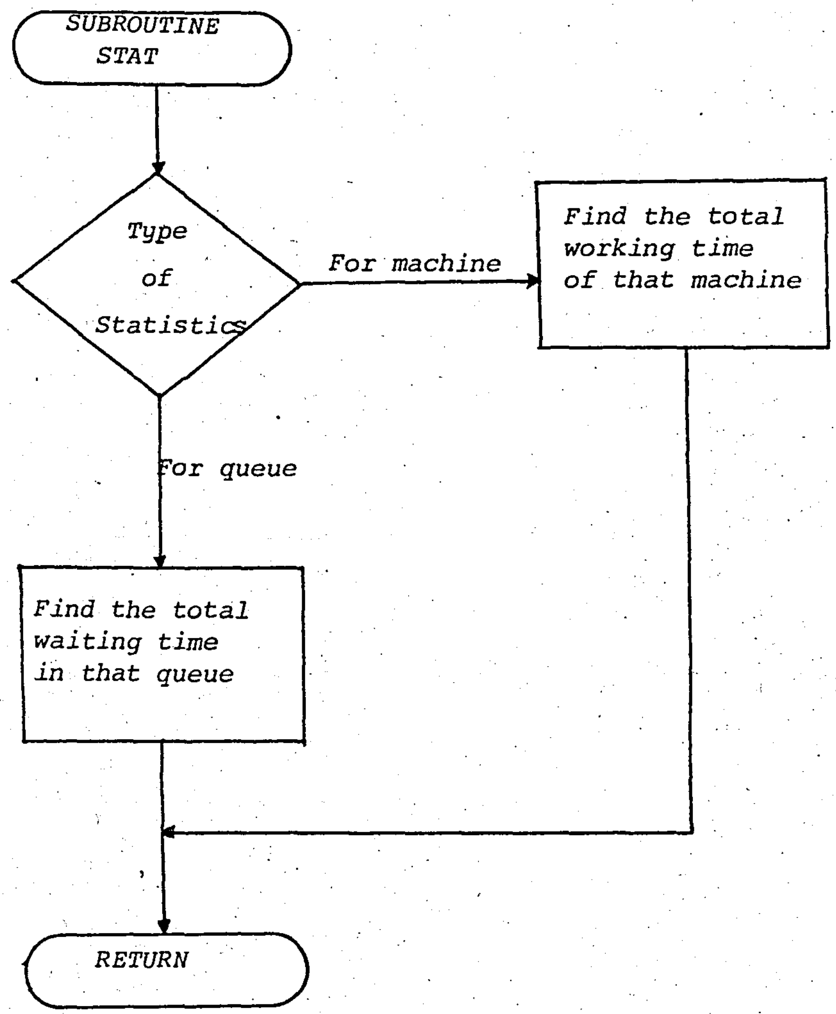

SUBROUTINE SELECT
CALL ENTER
All same type machines are idle
Yes
No
Set machine record to idle
Compare the same type machines and find one which has lowest completion time
Store that machine no. and its completion time in event record
RETURN

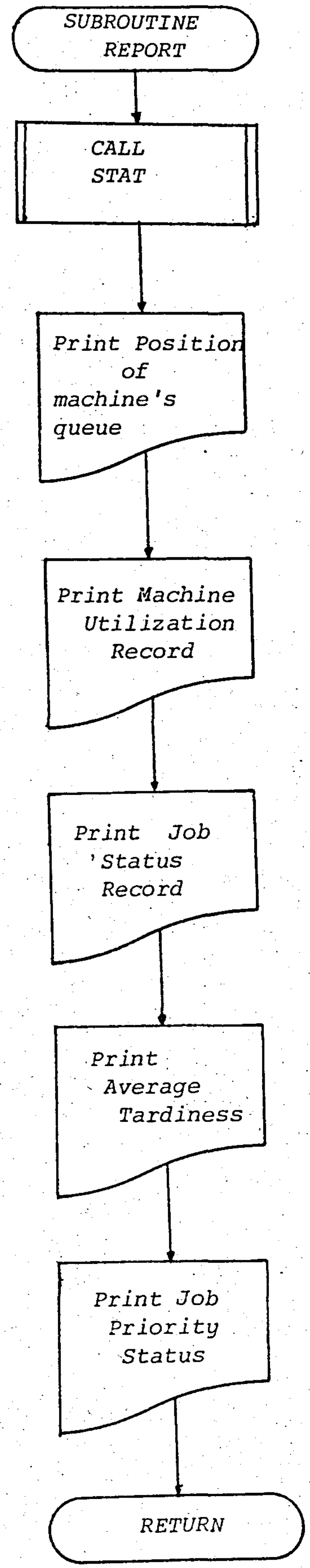

SUBROUTINE ASMBL
Find and store the assembly code
All the subcomponents of assembly are ready
No
Yes
CALL CREATE
RETURN


SUBROUTINE PRIOR
Find and store the priority of job by using SPT-T rule
RETURN



SUBROUTINE LEAVE
Update the related job and machine records
CALL STAT
Increase the number of related idle machine by one
Is there any remaining operation of this job
No
Yes
Find the manufacturing run no. of this job
Find the tardiness of job
Print result of this run
CALL INQUE
CALL SELECT
Is it the predecessor job
No
Yes
CALL ASMBL
RETURN


SUBROUTINE STAT
Type of Statistics
For machine
Find the total working time of that machine
For queue
Find the total waiting time in that queue
RETURN


SUBROUTINE REPORT
CALL STAT
Print Position of machine's queue
Print Machine Utilization Record
Print Job Status Record
Print Average Tardiness
Print Job Priority Status
RETURN

7.3. RESULTS AND POSSIBLE IMPROVEMENTS

The simulation model has been run for a period of one year utilizing the actual data obtained from the Parts Production Plant. The following results of the simulation runs indicates the possibility of four major improvements.

i- to decrease the level of work-in-process inventory,
ii- to better utilize the machining and equipment,
iii- to avoid slow moving items,
iv- to better plan the production capacity.

These possible improvements will be now discussed in more detail.

7.3.1. Work-in-process Inventory

As explained in previous chapters, the system has a high level of work-in-process inventory. As a result of the application of SPT-T rule to the system, the work-in-process has decreased more than 50%. The comparison of the simulation model with the actual system in the plant is given in Table 7.1.

The work-in-process inventory is reduced with the aid of the simulation model since shop orders are released to the floor just before the production starts and finished with minimum delay. This condition achieved by assigning priorities to the jobs according to the SPT-T rule.

Reduction of work-in-process inventories will allow a shorter cycle-time through the line. This will enable more stability in delivery schedules and shorter delivery commitments to sales departments. With reduced work-in-process inventory and stabilized line the level of costly finished-goods inventories can be decreased. Finished-goods inventory is also reduced by preventing the early completion of shop orders that otherwise would be part of finished goods inventory.

The reduction of work-in-process inventory leads to reduction of raw material inventory for raw materials are not allowed to enter the shop unless they are required due to the fact job arrival times are predetermined. Raw material inventory is also reduced by controlling the quantity released to the shop since optimal production quantity of each part (i.e. economic lot size of each part) is predetermined.

TABLE 7.1

AVERAGE WORK-IN-PROCESS INVENTORY OF THE SYSTEM

Time Period (Month)	W.I.P. in Actual Case(TL)	W.I.P. in Simulation Model(TL)
1	60.120.000	38.418.000
2	61.600.000	35.923.000
3	62.000.000	41.648.000
4	63.690.000	47.014.000
5	82.726.000	55.998.000
6	82.764.000	52.565.000
7	100.864.000	65.470.000
8	115.028.000	52.947.000
9	104.494.000	56.044.000
10	98.675.000	33.446.000
11	95.425.000	37.159.000
12	92.325.000	16.553.000
Average W.I.P.	84.975.916	44.432.083

7.3.2. Tardiness

The previous analysis on the system has shown that there exists too many tardy jobs. Therefore, tardiness has been taken as one of the criteria of performance of the suggested scheduling rule. The results of the simulation model has proved that effective use of the SPT-T rule has also decreased the number of tardy jobs and average tardiness of the system (See Table 7.2).

The frequency distributions of tardiness before and after the simulation model are given in Figure 7.2 and 7.3 respectively.

TABLE 7.2

AVERAGE TARDINESS OF THE SYSTEM

At time Period	Actual Case		Simulation Model	
	Tardiness(Hr)	Number of Tardy Job	Tardiness(Hr)	Number of Tardy Job
1	93	3	3.61	4
2	113	9	13.79	17
3	115	22	29.54	40
4	149	46	45.12	66
5	194	86	69.50	94
6	267	159	89.74	120
7	357	246	113.74	147
8	470	280	136.34	167
9	496	328	168.25	185
10	543	381	177.68	199
11	595	437	182.92	205
12	648	483	194.12	211

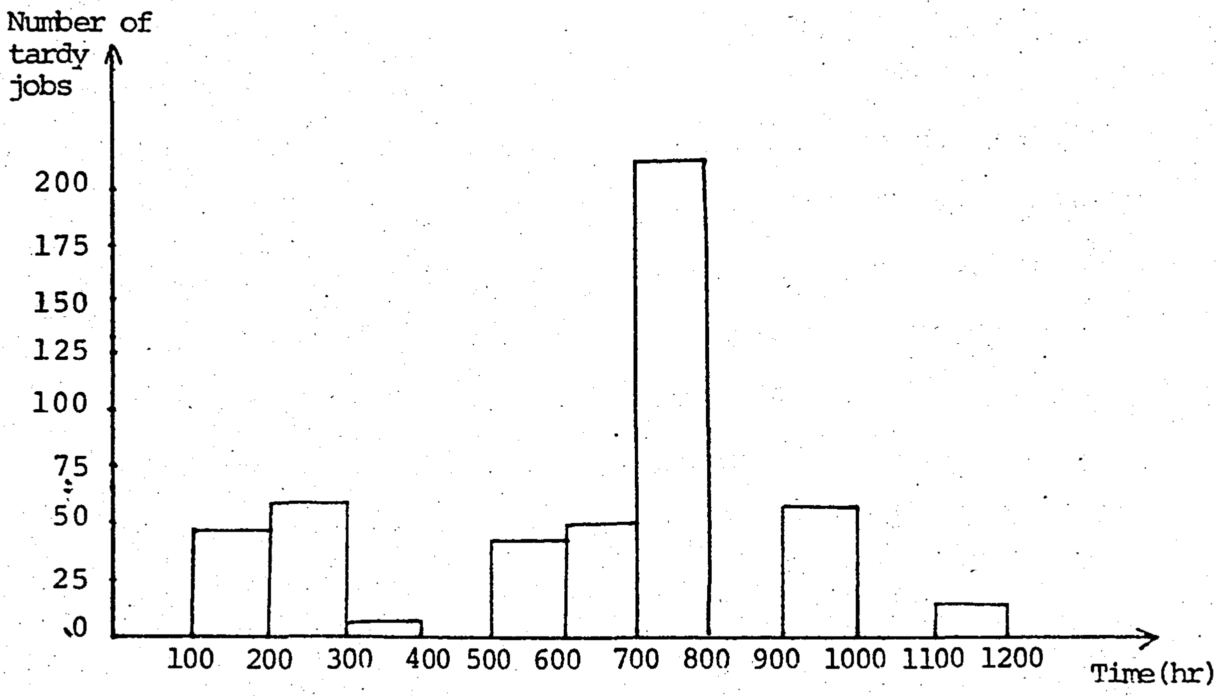


Figure 7.2- Frequency distribution of tardy jobs in actual case

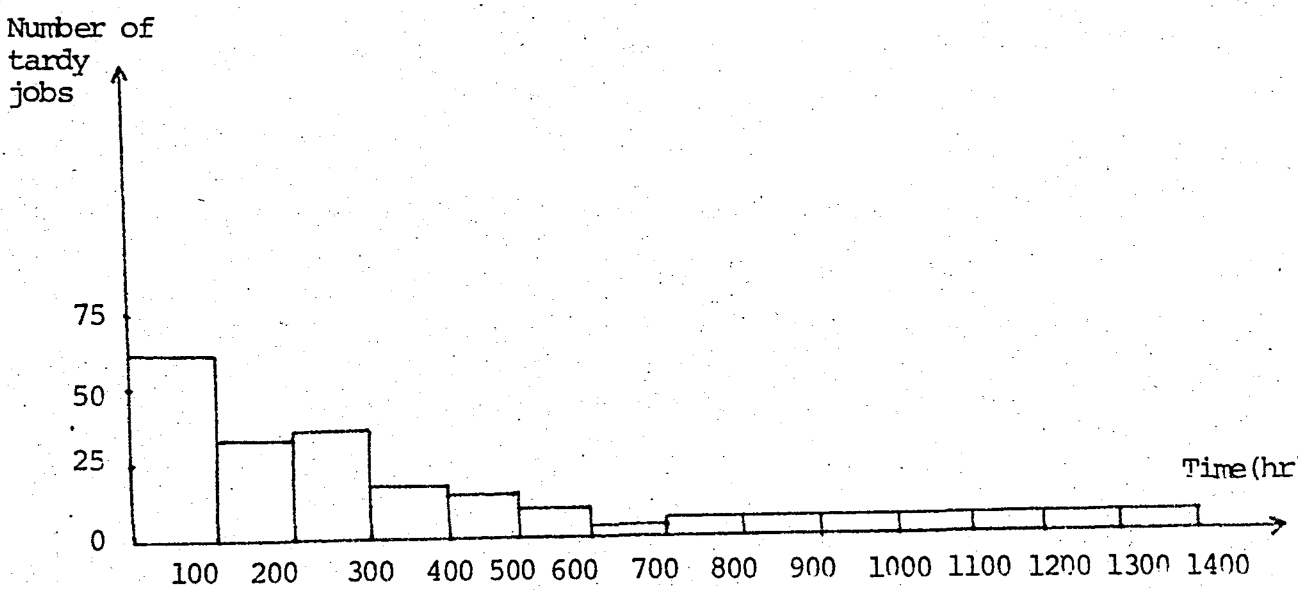


Figure 7.3- Frequency distribution of tardy jobs in simulation model

7.3.3. Overtime

Reduced overtime is another benefit of the SPT-T rule in the system. In the actual case the Parts Production. Plant is usually working 3 shifts and sometimes in 2 shifts, but in the simulation model the same production amount is produced by using 2 shifts all the time. Reduced working hours achieved by the usage of job priority which also prevents the ineffective utilization of man and machine capacities. This result obtained in terms of money saving is 10 million TL per year for the company.

7.3.4. Shop Utilization

The reduction in overtime, work-in-process inventory and the tardiness of jobs result in overall effective shop utilization in comparison to the actual case in the Parts Production Plant.

The simulation model shows that, on the average 50% of the available capacity is sufficient to make the parts of the year in question. Table 7.3 gives the average machine utilization of this system in system in the simulation model. In the actual case same production quantities is produced by using almost 100% of the capacity. With the actual performance one may get the impression that the capacity is fully utilized and therefore if it is desired to produce more than the expansion is necessary. This study shows the contrary. No

TABLE 7.3

AVERAGE MACHINE UTILIZATION

Machine Code	Average Utilization(%)	Machine Code	Average Utilization(%)
1	59	15	49
2	29	16	23
3	14	17	13
4	20	18	17
5	88	19	22
6	21	20	33
7	43	21	25
8	100	22	26
9	43	23	24
10	69	24	9
11	57	25	14
12	23	26	65
13	69	27	57
14	40	28	13
		29	26

expansion is needed to produce more but a better utilization is the answer. This shows the positive effects of the suggested model (SPT-T rule) on shop utilization.

7.3.5. Investments

Although the simulation model shows that the average utilization of the capacity is low, there are some machines which are rather overloaded where as some are underutilized. The overloaded machines have a great effect on high level of work-in-process and tardiness. Therefore the simulation model can be used as an indicator for the investment plan related with the Parts Production Plant, e.g. machine number 5 and 8 have proved to be overloaded in the run made with the actual data. Another run of the program has been made with an increase in the capacities of machine number 5 and 8 which has resulted in apparent decrease of the average tardiness of the jobs and the level of work-in-process inventory. The case above has been discussed with the plant manager and it has been justified that the machines shown to be overloaded in the simulation model are also overloaded in practice. In fact, extra machine, performing the same operations are bought to overcome this problem. Therefore the simulation model is valid approach for the future investment plan of the system.

8. IMPLEMENTATION PROCEDURE

The scheduling and control of work actually on the shop floor is a complex and demanding task. In most large shops there are hundreds of job orders in process at any given time. Thus there is not only the problem of the limited capacity, but also the problem of shop floor control.

Many management problems are caused by a lack of up-to-date information on the status of jobs in the shop. Often even the location of a job is not known, let alone whether it is ahead or behind schedule and what work remains to be done. Therefore in this section the implementation procedure of the SPT-T rule will be explained to provide a well designed dispatching and shop control system (See Figure 8.1), and it will be seen how a well designed dispatching and shop floor control system can help to organize and rationalize the flow of jobs through the shop, and to ensure that the right jobs are being worked on at all times. It will be also seen how a well designed dispatching and shop control system can greatly assist management in the continuous decision-making process that is required to keep a shop running i.e. in controlling the level of work-in-process inventory, tracking down trouble some jobs, and spotting difficult situations before they develop.

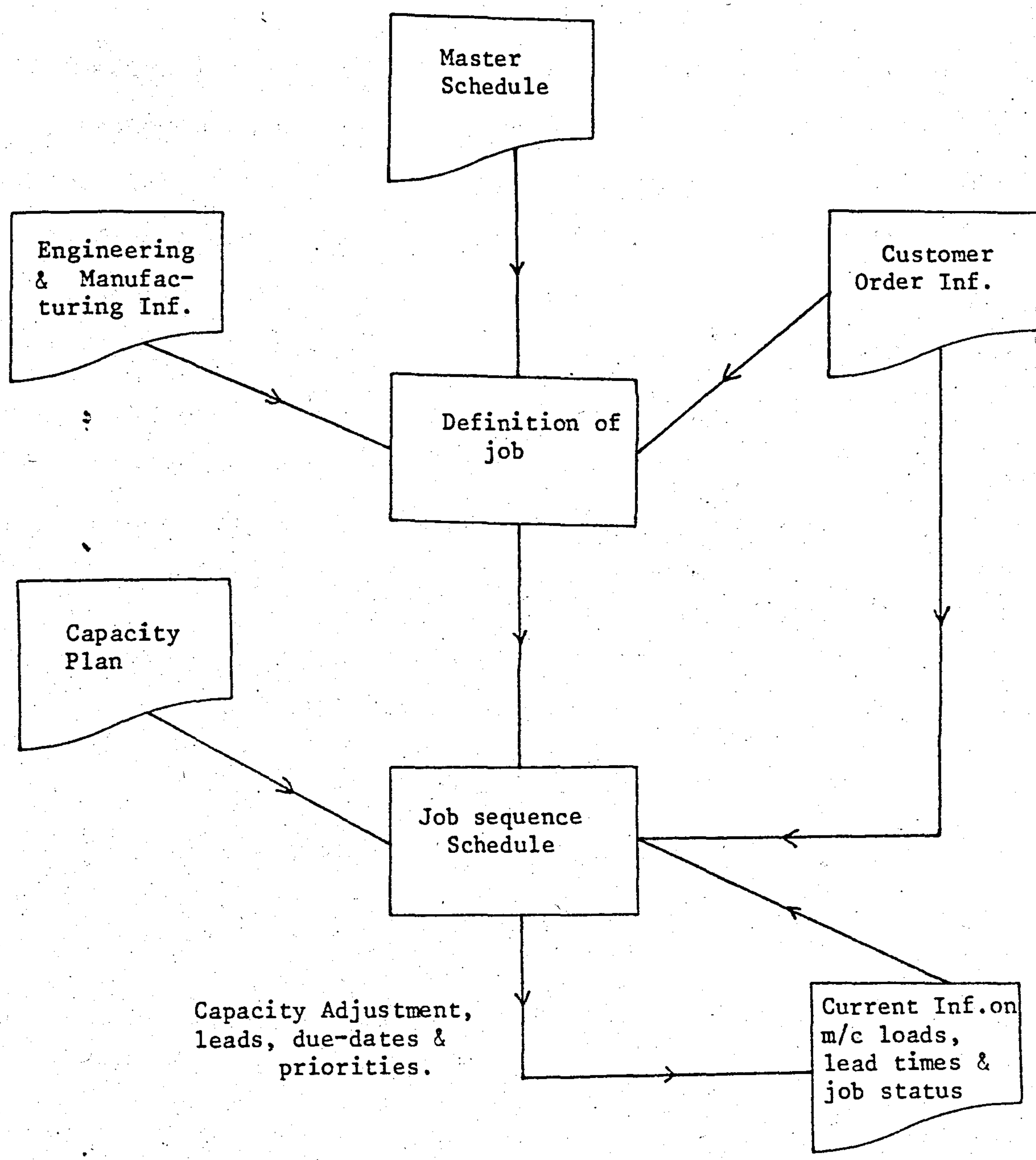


Figure 8.1. Information flow for short-term scheduling

8.1. DEFINITION OF JOB

Definition of job is the most important stage of this implementation because all decisions related with scheduling will be done under the basis of job. It has been previously defined that, the optimal quantities of each part in each manufacturing run will determine the "job" of the system; and it will be calculated according to the EOQ formula. Their due dates and number of manufacturing run in year will be also obtained by the use of the same formula. The details of this activity is explained in Section 4.1, therefore only the main formulas of this activity will be given here. These are;

1- Optimal lot size of jobi

$$Q = \sqrt{\frac{2A_i D_i}{h_i}}$$

2- Number of manufacturing run of jobi in year

$$N_i = \frac{D_i}{Q_i}$$

3- Due-date of jobi

$$T_i = \frac{1}{N_i}$$

The cycle length of job corresponds its due-date, because it has been previously indicated that the demand is deterministic and uniformly distributed over the months throughout the year. Job arrival will be generated at the beginning of the cycle length of job.

8.2. FLOW SHOP CONTROL SYSTEM

Priority shop scheduling requires valuable information because all decisions related with job priority are done according to the informations related with current position of the shop. Therefore the design and control of these informations are very important as well as the selection of scheduling rule.

There will be two types of information for each scheduled job. The first one will contain the fixed information of job (See Figure 8.2) and it will be used over the whole production year. The informations on this card will be prepared by the Production Planning Department at the beginning of production year.

The second one will contain some informations from the first one and some information from the current position of shop (See Figure 8.3) such as the first, second and fifth columns of Figure 8.3 completely depend on the information of Figure 8.2 and they do not change, but the remaining column of the Figure 8.3 must be updated at the end of each operation especially slack time will be. Therefore the informations on Work Order Card (Fig.8.3) will be continously updated to keep the priorities and job status current. With current information on job stutus and priorities available in readable form dispatchers or foremen can be provided with lists showing the current location and priority of all jobs in the shop.

Job No ________________ Demand ________________

Job Name ________________ Lot size ________________

Oper.No.	Machine No.	Processing Time	Set - up Time

Figure 8.2- Job Information Card.

Job No ________________ Date ________________

W/O No ________________

Production Amount ______ Latest Start Time ____________

Total Proc.Time ________ Date to be Finished __________

Oper.No.	M/C No.	Date Started	Date Finished	Processing &Set-up time	Slack Time	Priority

Figure 8.3- Work Order Card.

If these lists are sorted by machine or work center (each machine can be thought as a work center), the man on the shoop floor has not only a picture of all jobs in each machine queue, but also information that will enable him to make good decisions on which job to run next by using the SPT-T rule which is explained in Chapter 6.

Figure 8.3 also contain the latest start date of job which is calculated by subtracting the total processing time of job from its due-date. This information will used when it comes to be critical means, current date is equal to the latest start date. In this case this job will take high priority in each machine but this will occur rarely, in situations such as missing materials tools documents or machine breakdown.

9. CONCLUSION

The application of SPT-T rule to the Parts Production Plant of Çimsataş would provided not only a cost advantage due to decrease in the level of work-in-process inventory and efficient shop utilization but a systematic and a better approach for job shop scheduling as well. The high level of work-in-process inventory observed has been decreased by 50% which amounts to 30 million TL. per year. The total saving implied by the suggested model is 40 million TL. per year when overtime has been reduced from 3 shifts to 2 shifts. In addition to the cost advantage there are also intangible benefits that would have been realized. These are as follows.

i- A better shop control system can be established by the use of SPT-T rule, that is, controlling the level of work in process inventory, tracking down troublesome jobs, and finding out difficulties before they develop. This shows that SPT-T rule is a practical and flexible method to be applied to such a system.

ii- Average number of tardy jobs has been decreased by 55% and the average tardiness by 70% due to sequencing the jobs by using the SPT-T rule.

iii- It is possible to identify the machines which are bottlenecks in production system and hence to indicate technological needs for investment planning.

In this study, the value of the parameter r for SPT-T rule has been assumed to be zero. It is, however, possible to run the simulations for different values of r until an appropriate value of it is founded. Under the prevailing conditions, at the plant this has been observed to be rather difficult since it would have been complicated the implementation. This feature of the scheduling rule has been left to a later planning period as a strategic decision in order to first implement the very basic scheduling rule at the plant.

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APPENDIX A

USER'S MANUAL

APPENDIX A. USER'S MANUAL

In this section input and output variables of the simulation model will be explained.

INPUT VARIABLES

NJ : Number of job in the shop

NM : Number of machine in the shop

SMTM : Simulation time

MQ : Maximum queue capacity

INC : Periodic report time

NA : Number of assembly job in the shop

TOJ : Total number of operation array of each job

PT : Processing time matrix of jobs

OO : Operation order matrix of jobs

MC : Array of available machine capacities

DD : Due-dates array of jobs

NMR : Number of manufacturing run array of each job

RPT : Total processing time array of each job.

JA : Array of number of subcomponents existing in each assembly structure

AS : Assembly structure matrix

ST : Job number matrix of subcomponents existing in each assembly structure

OUTPUT VARIABLES

MS	:	Machine statistics matrix
QQ	:	Queue statistics matrix
MM	:	Machine matrix which contain job number
Q	:	A queue matrix in which jobs are waiting according to a given priority rule
RM	:	A matrix which contains completion time of operations in each corresponding machines
JOB	:	An array in which the job numbers corresponding to each batch is stored
MIN	:	An array which contains the priority given to each batch
OR	:	An array which contains the operation rank number
DDT	:	Due-date array of each batch
RPTT	:	Remaining processing time array of each batch
BF	:	Array of manufacturing run finished
BFF	:	Array of subcomponents finished
LL1	:	Number of jobs that took priority according to the S/OPN rule
LL2	:	Number of jobs that took priority according to the SPT rule
RT	:	Ready time array of each batch

APPENDIX B

COMPUTER PROGRAM

```
MAIN
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),OO(29,4),MM(29,30),PM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MO,LL1,LL2
      COMMON /YSF/ RI(429)
      READ*,NJ,NM,SMTM,MO,INC,NA
      READ*,(TOJ(I),I=1,NJ)
      READ*,((PT(I,J),J=1,TOJ(I)),I=1,NJ)
      READ*,((OO(I,J),J=1,TOJ(I)),I=1,NJ)
      READ*,(MC(J),J=1,NM)
      READ*,(DD(I),I=1,NJ)
      READ*,(NMR(I),I=1,NJ)
      READ*,(RPT(I),I=1,NJ)
      READ*,(JA(I),I=1,NA)
      READ*,((AS(I,J),J=1,2),I=1,NJ)
      READ*,((ST(I,J),J=1,JA(I)),I=1,NA)
      BN,TARD,CLOCK,LL1,LL2=0
      REPT=INC
      KKK=1
      CFEC=NJ+NM
      DO 1 I=1,NJ
      II=I+NM
      FEC(II,5)=I
      IF(AS(I,2).NE.0)GO TO 9
      FEC(II,1)=SMTM+1
      GO TO 1
    9 CALL CREATE(BN,II,CLOCK,SMTM,0,$1)
    1 CONTINUE
      DO 2 I=1,NM
      FEC(I,2)=2
      FEC(I,5)=I
      MS(I,1)=MC(I)
      CALL SELECT(I,CLOCK)
    2 CONTINUE
    3 MINT=SMTM
      DO 4 J=1,CFEC
      IF(FEC(J,1).EQ.-1) GOTO 4
      IF(MINT.LE.FEC(J,1)) GOTO 4
      MINT=FEC(J,1)
      I=J
    4 CONTINUE
      CLOCK=MINT
      IF(CLOCK.GE.SMTM) GOTO 8
      IF(CLOCK.LT.REPT) GOTO 5
      CALL REPORT(CLOCK,TARD,NM,NJ,KKK)
      REPT=REPT+INC
    5 IF(FEC(I,2)-1)7,7,6
    6 CALL LEAVE(I,CLOCK,TARD,SMTM,KKK,NM,$3)
    7 CALL CREATE(BN,I,CLOCK,SMTM,0,$3)
    8 CALL REPORT(CLOCK,TARD,NM,NJ,KKK)
      STOP
      END
YSF.CREATE/
```

```
PORT
      SUBROUTINE REPORT(CLOCK,TARD,NM,NJ,KKK)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),QQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MO,LL1,LL2
      REAL AVQ,AVM,AVTARD
      PRINT 1,CLOCK
    1 FORMAT(1H1,///,20X,,CUMULATIVE STATISTICAL REPORT AT TIME,,3X,I5)
      DO 15 I=1,NM
      CALL STAT(QQ,I,MC,0,CLOCK)
      CALL STAT(MS,I,MC,1,CLOCK)
   15 CONTINUE
      BFT=0
      DO 2 I=1,NJ
      BFT=BFT+BF(I)
    2 CONTINUE
      PRINT 3
    3 FORMAT(///,10X,,QUEUE,,3X,,AV.CONT.,,3X,,MAX.CONT,,/)
      DO 5 I=1,NM
      AVQ=FLOAT(QQ(I,3))/FLOAT(CLOCK)
      PRINT 4,I,AVQ,QQ(I,4)
    4 FORMAT(/11X,I3,5X,F6.2,6X,I3)
    5 CONTINUE
      PRINT 6
    6 FORMAT(////,10X,,MACH.,,3X,,NUMBER OF,,3X,,AVERAGE,,3X,,MAXIMUM,,/
     *,10X,,CODE,,3X,,MACH.AVAIL,,2X,,UTILIZED,,2X,,UTILIZED,,/)
      DO 8 I=1,NM
      AVM=FLOAT(MS(I,3))/FLOAT(CLOCK)
      PRINT 7,I,MC(I),AVM,MS(I,4)
    7 FORMAT(/,11X,I3,7X,I2,7X,F5.2,7X,I2)
    8 CONTINUE
      PRINT 9
    9 FORMAT(////,10X,,JOB.NO,,3X,,MAN.RUN.STA.,,3X,,MAN.RUN.FIN,,/)
      DO 11 I=1,NJ
      II=I+NM
      PRINT 10,I,FEC(II,3),BF(I)
   10 FORMAT(/,12X,I2,9X,I3,12X,I3)
   11 CONTINUE
      AVTARD=FLOAT(TARD)/FLOAT(BFT)
      PRINT 12,AVTARD
   12 FORMAT(///,10X,,AVERAGE TARDINESS,,F7.2)
      PRINT 13,LL1,LL2
   13 FORMAT(//,10X,,NUMBER OF JOBS THAT TOOK PRIORITY ACCORDING TO THE
     *S/OPN RULE = ,,I5,/,10X,,NUMBER OF JOBS THAT TOOK PRIORITY ACCORDI
     *NG TO THE SPT RULE = ,,I5)
      KKK=1
      RETURN
      END
F.MAIN/
```

```
ECT
      SUBROUTINE SELECT(M,CLOCK)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),OQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      CALL ENTER(M,CLOCK,$1)
      IF(MS(M,1).EQ.MC(M))GOTO 3
    1 LMIN=9999
      DO 2 J=1,MC(M)
      IF(LMIN.LE.RM(M,J))GOTO 2
      IF(RM(M,J).EQ.0)GOTO 2
      LMIN=RM(M,J)
      MN=J
    2 CONTINUE
      FEC(M,1)=LMIN
      FEC(M,3)=MN
      FEC(M,4)=MM(M,MN)
      GOTO 4
    3 FEC(M,1)=-1
      FEC(M,3)=0
      FEC(M,4)=0
    4 RETURN
      END
.REPORT/

QUE
      SUBROUTINE OUTQUE(L,M,CLOCK)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),OQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      CALL STAT(OQ,M,MC,0,CLOCK)
      N,OQ(M,1)=OQ(M,1)-L
      DO 1 J=1,N
      Q(M,J)=Q(M,J+L)
    1 CONTINUE
      DO 2 J=N+1,N+L
      Q(M,J)=0
    2 CONTINUE
      RETURN
      END
.SELECT/
```

```
TER
      SUBROUTINE ENTER(M,CLOCK,*)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),QQ(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),QQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      L=MS(M,1)
      IF(L.GT.QQ(M,1))L=QQ(M,1)
      IF(L.EQ.0)RETURN
      J=1
      DO 3 K=1,L
      JJ=1
      CALL STAT(MS,M,MC,1,CLOCK)
      MS(M,1)=MS(M,1)-1
    1 IF(MM(M,J).NE.0)GOTO 2
      N,MM(M,J)=Q(M,K)
      RM(M,J)=CLOCK+PT(JOB(N),OR(N))
      IF(MIN(N).EQ.PT(JOB(N),OR(N)))GO TO 4
      LL1=LL1+1
      GO TO 5
    4 LL2=LL2+1
    5 JJ=0
    2 J=J+1
      IF(JJ.EQ.1)GOTO 1
    3 CONTINUE
      CALL OUTQUE(L,M,CLOCK)
      RETURN 1
      END
F.ASMBL/

MBL
      SUBROUTINE ASMBL(J,L,NM,CLOCK,SMTM,*)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),QQ(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),QQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      LL=L
      N=AS(J,1)
      IJ=JA(N)
      DO 1 K=1,IJ
      IF(BFF(ST(N,K)).EQ.0)RETURN 1
    1 CONTINUE
      DO 2 K=1,IJ
      BFF(ST(N,K))=BFF(ST(N,K))-1
    2 CONTINUE
      II=AS(J,2)+NM
      CALL CREATE(LL,II,CLOCK,SMTM,1,$3)
    3 RETURN 1
      END
F.OUTQUE/
```

```
\T
      SUBROUTINE STAT(S,N,MC,K,CLOCK)
      IMPLICIT INTEGER (A-Z)
      DIMENSION S(29,4),MC(29)
      MK=S(N,1)
      IF(K.EQ.1)MK=MC(N)-S(N,1)
      TT=CLOCK-S(N,2)
      S(N,2)=CLOCK
      S(N,3)=S(N,3)+MK*TT
      IF(MK.GT.S(N,4))S(N,4)=MK
      RETURN
      END
F.DATA2/
```

```
IOR
      SUBROUTINE PRIOR(BN,CLOCK)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),OQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MO
      MIN(BN)=PT(JOB(BN),OR(BN))
      MINV=(DDT(BN)-RPTT(BN)-CLOCK)/(TOJ(JOB(BN))-OR(BN)+1)
      IF(MIN(BN).GT.MINV)MIN(BN)=MINV
      RETURN
      END
F.ENTER/
```

```
EATE
      SUBROUTINE CREATE(BN,II,CLOCK,SMTM,K,*)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),OQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MO,LL1,LL2
      COMMON /YSF/ RT(429)
      FEC(II,3)=FEC(II,3)+1
      IF(FEC(II,3).LE.NMR(FEC(II,5))) GO TO 5
      FEC(II,3)=FEC(II,3)-1
      FEC(II,1)=SMTM+1
      RETURN 1
    5 IF(K.EQ.1) GO TO 6
      BN=BN+1
      FEC(II,1)=CLOCK+DD(FEC(II,5))
    6 JOB(BN)=FEC(II,5)
      RT(BN)=CLOCK
      OR(BN)=1
      DDT(BN)=DD(JOB(BN))+CLOCK
      RPTT(BN)=RPT(JOB(BN))
      M=OO(JOB(BN),OR(BN))
      CALL INQUE(M,BN,CLOCK)
      RETURN 1
      END
F.DATA1/
```

```
QUE
      SUBROUTINE INQUE(M,BN,CLOCK)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),QQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      NNN=M
      CALL STAT(QQ,M,MC,0,CLOCK)
      L,QQ(M,1)=QQ(M,1)+1
      IF(L.LT.MQ)GOTO 2
      PRINT 1,M
    1 FORMAT(///,10X,,MAX.ALLOWED NO OF MEMBERS IN QUEUE,,2X,I2,2X,,IS E
     *XCEEDED,)
      RETURN
    2 Q(M,L)=BN
      CALL PRIOR(BN,CLOCK)
      IF(L.EQ.1)GOTO 5
      DO 4 J=1,L-1
      K1=Q(M,J)
      CALL PRIOR(K1,CLOCK)
      IF(MIN(K1).LE.MIN(BN))GOTO 4
      DO 3 JJ=L,J+1,-1
      Q(M,JJ)=Q(M,JJ-1)
    3 CONTINUE
      Q(M,J)=BN
      GOTO 5
    4 CONTINUE
    5 IF(MS(M,1).GT.0.AND.MS(M,1).LT.MC(M))GO TO 6
      IF(FEC(M,1).NE.-1)RETURN
    6 CALL SELECT(M,CLOCK)
      RETURN
      END
F.LEAVE/


AVE
      SUBROUTINE LEAVE(I,CLOCK,TARD,SMTM,KKK,NM,*)
      IMPLICIT INTEGER (A-Z)
      COMMON TOJ(70),PT(70,20),OO(70,20),MC(29),DD(70),NMR(70),RPT(70),
     *FEC(99,5),MS(29,4),QQ(29,4),MM(29,30),RM(29,30),Q(29,30),JOB(429),
     *MIN(429),OR(429),DDT(429),RPTT(429),BF(70),BFF(70),AS(70,2),
     *ST(15,5),JA(15),MQ,LL1,LL2
      COMMON /YSF/ RT(429)
      L=FEC(I,4)
      LM,M=FEC(I,5)
      J=JOB(L)
      K=FEC(I,3)
      MM(M,K)=0
      RM(M,K)=0
      CALL STAT(MS,M,MC,1,CLOCK)
      MS(M,1)=MS(M,1)+1
      RPTT(L)=RPTT(L)-PT(J,OR(L))
      OR(L)=OR(L)+1
      IF(OR(L).LE.TOJ(J))GOTO 2
      BF(J)=BF(J)+1
      BFF(J)=BFF(J)+1
      T=CLOCK-DDT(L)
      IF(T.LT.0)T=0
      TARD=TARD+T
      IF(KKK.NE.1)GO TO 3
      PRINT 4
    4 FORMAT(1H1,///,15X,,JOB,,2X,,MAN.RUN,,2X,,READY,,2X,,COMPLETION,,
     *2X,,TARDINESS,,/,15X,,NO.,,4X,,NO.,,4X,,TIME,,6X,,TIME,)
      KKK=0
    3 PRINT 1,J,BF(J),RT(L),CLOCK,T
    1 FORMAT(/,15X,I3,5X,I2,4X,I5,5X,I4,8X,I4)
      IF(AS(J,2))6,6,7
    7 CALL ASMBL(J,L,NM,CLOCK,SMTM,$6)
    2 M=OO(J,OR(L))
      CALL INQUE(M,L,CLOCK)
    6 CALL SELECT(LM,CLOCK)
      RETURN 1
      END
```

```
N*YSF(1),DATA1
70,29,3780,30,1890,13
7,6,6,7,8,9,9,9,7,7,7,7,7,7,7,7,5,5,6,6,18,18,20,20,5,5
5,5,5,5,5,5,5,8,8,6,6,6,6,7,7
4,4,4,4,4,4,4,4,4,2,2,2,2,2
2,2,2,2,2,2,2,2,4,3,3,4,10,9,7
18,10,14,10,4,8,13
42,23,20,8,15,30
65,38,31,9,22,51
107,55,62,40,22,33,69
231,44,14,11,6,12,13,19
59,26,56,15,11,9,14,15,25
56,25,50,11,8,5,13,13,26
96,46,96,18,13,9,19,19,45
38,19,18,34,18,57,40
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58,62,66,59,63,67
SAHIN*YSF.INQUE/
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APPENDIX C

A SAMPLE OUTPUT

JOB NO.	MAN.RUN NO.	READY TIME	COMPLETION TIME	TARDINESS
53	1	0	13	0
55	1	0	17	0
61	1	0	18	0
63	1	0	24	0
65	1	0	24	0
67	1	0	29	0
60	1	0	38	0
64	1	0	39	0
66	1	0	46	0
51	1	0	51	0
52	1	0	65	0
48	1	0	76	0
1	1	0	77	0
46	1	0	78	0
11	1	0	90	0
17	1	0	92	0
62	1	0	93	0
31	1	76	104	0
54	1	0	105	0
47	1	0	108	0
58	1	0	110	0
50	1	0	133	0
66	2	110	139	0
62	2	110	148	0
29	1	78	154	0
52	2	115	188	0
10	1	0	202	0
33	1	133	208	0
30	1	108	210	0
15	1	0	210	0
42	1	0	235	0
69	1	0	240	0
2	1	0	241	0
47	2	115	241	11
51	2	150	246	0
46	2	150	253	0

58	2	110	255	35
66	3	220	255	0
54	2	170	264	0
49	1	0	283	113
13	1	0	283	0
62	3	220	284	0
21	1	0	301	0
43	1	0	305	0
52	3	230	316	0
67	2	300	324	0
29	2	253	327	0
12	1	0	327	0
7	1	0	332	0
63	2	300	335	0
47	3	230	349	4
14	1	0	353	0
66	4	330	359	0
30	2	241	361	0
16	1	0	370	0
51	3	300	373	0
6	1	0	377	0
8	1	0	380	0
25	1	235	382	0
46	3	300	383	0
38	1	110	389	74
62	4	330	395	0
45	1	0	397	187
9	1	0	411	0
70	1	0	420	0
49	2	170	442	102
32	1	283	452	49
59	1	0	456	156
52	4	345	469	9
42	2	250	471	0
3	1	0	483	0
55	2	420	486	0
30	3	340	499	29
66	5	440	502	0

15	2	290	504	0
54	3	340	533	23
46	4	450	545	0
47	4	345	552	22
44	1	0	553	0
4	1	0	564	0
58	3	220	566	236
66	6	550	579	0
14	2	378	605	0
32	2	442	608	46
12	2	343	613	0
29	3	383	617	41
51	4	450	620	20
65	2	600	624	0
67	3	600	629	0
47	5	460	630	55
52	5	460	634	59
53	2	600	647	0
40	1	0	659	29
58	4	330	676	236
22	1	0	678	0
30	4	552	684	11
61	2	600	685	0
64	2	650	689	0
46	5	600	690	0
66	7	660	696	0
13	2	472	697	0
1	2	630	707	0
28	1	397	708	101
70	2	540	712	0
23	1	0	715	0
62	5	440	729	179
54	4	510	740	60
42	3	500	744	0
5	1	0	749	0
25	2	471	751	110
52	6	575	758	68
51	5	600	766	16

43	2	320	771	131
9	2	540	786	0
30	5	634	792	37
66	8	770	803	0
26	1	305	816	201
15	3	580	816	0
29	4	620	819	6
50	2	420	825	0
51	6	750	827	0
58	5	440	829	279
49	3	340	841	331
63	3	600	848	0
47	6	575	849	159
55	3	840	867	0
46	6	750	873	0
52	7	690	875	70
54	5	680	890	40
59	2	300	899	299
29	5	766	902	0
66	9	880	909	0
67	4	900	924	0
62	6	550	930	270
52	8	805	938	18
25	3	744	939	25
45	2	210	946	526
47	7	690	953	148
62	7	660	955	185
47	8	805	956	36
62	8	770	960	80
60	2	650	962	0
42	4	750	973	0
57	1	0	977	377
12	3	686	977	0
24	1	0	979	0
63	4	900	980	0
8	2	630	991	0
30	6	849	1002	32
46	7	900	1002	0

48	2	600	1004	0
45	3	420	1009	379
32	3	841	1012	51
66	10	990	1019	0
62	9	880	1033	43
14	3	756	1048	0
4	2	630	1052	0
51	7	900	1066	16
38	2	255	1068	608
47	9	920	1074	39
15	4	870	1079	0
50	3	840	1083	0
49	4	510	1085	405
54	6	850	1093	73
52	9	920	1114	79
62	10	990	1115	15
11	2	945	1125	0
66	11	1100	1129	0
58	6	550	1130	470
25	4	973	1132	0
30	7	953	1141	67
46	8	1050	1141	0
10	2	945	1142	0
7	2	945	1152	0
30	8	956	1162	85
20	1	0	1163	218
29	6	873	1179	113
19	1	0	1194	249
47	10	1035	1194	44
3	2	945	1203	0
13	3	944	1203	0
6	2	945	1206	0
28	2	946	1215	59
42	5	1000	1239	0
66	12	1210	1239	0
70	3	1080	1242	0
30	9	1114	1259	24
69	2	945	1267	0

53	3	1200	1272	0
32	4	1085	1272	67
12	4	1029	1282	0
58	7	660	1283	513
28	3	1009	1304	85
51	8	1050	1319	119
9	3	1080	1322	0
49	5	680	1323	473
43	3	640	1335	375
1	3	1260	1337	0
54	7	1020	1338	148
46	9	1200	1364	14
52	10	1035	1367	217
38	3	566	1374	603
29	7	1066	1376	117
31	2	1004	1386	0
2	2	1260	1398	0
26	2	771	1415	334
45	4	630	1416	576
52	11	1150	1434	169
14	4	1134	1452	0
49	6	850	1456	436
27	1	553	1468	255
58	8	770	1479	599
62	11	1100	1481	271
32	5	1323	1485	42
30	10	1367	1498	10
15	5	1160	1498	48
45	5	840	1503	453
33	2	825	1515	165
35	1	0	1523	263
42	6	1250	1533	33
51	9	1200	1536	186
47	11	1150	1546	281
54	8	1190	1569	209
46	10	1350	1581	81
52	12	1265	1584	204
43	4	960	1585	305

58	9	880	1589	599
49	7	1020	1591	401
25	5	1230	1617	208
29	8	1310	1619	107
55	4	1260	1626	0
47	12	1265	1641	261
4	3	1260	1647	0
46	11	1500	1649	0
15	6	1450	1656	0
38	4	676	1680	799
45	6	1050	1686	426
8	3	1260	1687	0
32	6	1456	1694	118
12	5	1372	1707	0
30	11	1546	1716	49
47	13	1380	1731	236
33	3	1083	1739	131
26	3	1335	1739	94
13	4	1416	1739	0
62	12	1210	1742	422
42	7	1500	1744	0
48	3	1200	1758	0
47	14	1495	1759	149
51	10	1350	1766	266
38	5	820	1772	738
14	5	1512	1791	0
54	9	1360	1793	263
50	4	1260	1793	113
28	4	1416	1813	187
52	13	1380	1814	319
70	4	1620	1834	0
56	1	0	1844	1194
9	4	1620	1844	0
51	11	1500	1852	202
32	7	1591	1852	141
22	2	1260	1853	0

CUMULATIVE STATISTICAL REPORT AT TIME 1890

QUEUE	AV.CONT.	MAX.CONT
1	.27	4
2	.37	9
3	.01	4
4	.00	1
5	18.58	29
6	.01	4
7	.27	3
8	13.69	22
9	.39	7
10	.85	4
11	.14	2
12	.00	1
13	6.18	13
14	.06	3
15	.12	3
16	.01	1
17	.00	1
18	.06	2
19	.00	1
20	.04	1
21	.07	2
22	.02	1
23	.03	2
24	.00	1
25	.00	1
26	.68	4
27	.29	3
28	.00	1
29	.06	2

MACH. CODE	NUMBER OF MACH.AVAIL	AVERAGE UTILIZED	MAXIMUM UTILIZED
1	1	.63	1

2	3	.87	3
3	3	.55	3
4	2	.43	2
5	5	5.00	5
6	3	.56	3
7	1	.43	1
8	1	1.00	1
9	1	.45	1
10	1	.92	1
11	1	.35	1
12	1	.08	1
13	2	1.98	2
14	3	1.38	3
15	2	1.08	2
16	1	.19	1
17	1	.08	1
18	1	.19	1
19	2	.45	2
20	1	.33	1
21	1	.23	1
22	1	.28	1
23	1	.13	1
24	1	.07	1
25	4	.35	3
26	1	.76	1
27	1	.60	1
28	1	.10	1
29	1	.31	1

JOB.NO	MAN.RUN.STA.	MAN.RUN.FIN
1	3	3
2	2	2
3	2	2
4	3	3
5	3	1
6	2	2
7	2	2

8	3	3
9	4	4
10	2	2
11	2	2
12	6	5
13	5	4
14	5	5
15	7	6
16	1	1
17	1	1
18	2	0
19	2	1
20	2	1
21	1	1
22	2	2
23	1	1
24	1	1
25	7	5
26	4	3
27	1	1
28	6	4
29	11	8
30	13	11
31	3	2
32	7	7
33	4	3
34	1	0
35	2	1
36	1	0
37	1	0
38	9	5
39	2	0
40	3	1
41	3	0
42	8	7
43	6	4
44	3	1
45	9	6

46	11	11
47	16	14
48	3	3
49	12	7
50	4	4
51	11	11
52	16	13
53	3	3
54	12	9
55	4	4
56	2	1
57	2	1
58	12	9
59	4	2
60	2	2
61	2	2
62	12	12
63	4	4
64	2	2
65	2	2
66	12	12
67	4	4
68	3	0
69	2	2
70	4	4

AVERAGE TARDINESS 89.74

NUMBER OF JOBS THAT TOOK PRIORITY ACCORDING TO THE S/OPN RULE = 676
NUMBER OF JOBS THAT TOOK PRIORITY ACCORDING TO THE SPT RULE = 611

JOB NO.	MAN.RUN NO.	READY TIME	COMPLETION TIME	TARDINESS
52	14	1495	1900	290
54	10	1530	1906	206
49	8	1190	1912	552
28	5	1503	1922	209
49	9	1360	1938	408
25	6	1533	1940	237
29	9	1536	1944	215
52	15	1610	1948	223
47	15	1610	1952	227
1	4	1890	1967	0
43	5	1280	1969	369
12	6	1715	1977	0
59	3	600	1998	1098
15	7	1740	1999	0
30	12	1641	2008	246
30	13	1814	2029	94
45	7	1260	2032	562
11	3	1890	2045	0
49	10	1530	2059	359
42	8	1750	2069	69
54	11	1700	2074	204
52	16	1725	2077	237
13	5	1883	2077	0
10	3	1890	2094	0
16	2	1890	2103	0
3	3	1890	2106	0
58	10	990	2108	1008
29	10	1766	2112	153
26	4	1585	2121	226
28	6	1686	2134	238
69	3	1890	2170	0
47	16	1725	2170	330
45	8	1470	2175	495
59	4	900	2178	978
32	8	1913	2187	155
44	2	600	2196	996

21	2	1890	2213	0
34	1	0	2219	329
41	1	0	2219	1589
32	9	1938	2222	164
7	3	1890	2229	0
30	14	1900	2251	230
57	2	600	2256	1056
14	6	1890	2279	11
30	15	1952	2286	213
4	4	1890	2303	0
39	1	455	2306	1205
15	8	2030	2307	0
6	3	1890	2320	0
43	6	1600	2330	410
12	7	2058	2346	0
70	5	2160	2349	0
30	16	2170	2358	67
32	10	2050	2361	182
18	1	0	2370	1110
31	3	1758	2371	0
33	4	1793	2378	60
8	4	1890	2380	0
44	3	1200	2384	584
29	11	1852	2421	376
5	2	756	2422	910
54	12	1870	2432	392
25	7	1744	2460	546
58	11	1100	2470	1260
9	5	2160	2474	0
54	13	2040	2475	265
14	7	2268	2496	0
13	6	2360	2535	0
42	9	2000	2551	301
15	9	2320	2554	0
68	1	0	2565	1935
25	8	2060	2572	333
58	12	1210	2590	1260
42	11	1700	2600	730

1	5	2520	2616	0
40	2	630	2627	1367
20	2	945	2638	748
2	3	2520	2658	0
12	8	2401	2682	0
68	2	630	2687	1427
28	7	2032	2689	447
45	9	1680	2695	805
38	6	1130	2714	1379
5	3	1512	2724	456
32	11	2600	2759	39
28	8	2175	2768	393
19	2	945	2768	878
49	12	1870	2794	754
26	5	1960	2798	519
49	13	2040	2818	608
38	7	1283	2842	1354
17	2	1890	2845	0
15	10	2610	2845	0
39	2	890	2852	1308
25	9	2551	2870	149
23	2	1890	2893	0
27	2	2196	2895	39
4	5	2520	2907	0
38	8	1470	2934	1250
9	6	2700	2937	0
8	5	2520	2947	0
18	2	1260	2953	433
32	12	2794	2957	43
70	6	2700	2963	0
11	4	2835	2974	0
35	2	1260	2982	462
32	13	2818	2983	45
14	8	2646	3016	0
12	9	2744	3018	0
28	9	2695	3022	117
27	3	2384	3026	0
38	9	1582	3027	1233

10	4	2835	3035	0
26	6	2330	3039	309
13	7	2832	3067	0
7	4	2835	3071	0
68	3	1260	3093	1203
3	4	2835	3093	0
6	4	2835	3096	0
15	11	2900	3103	0
38	10	2103	3106	793
69	4	2835	3157	0
19	3	1890	3171	1336
56	2	650	3185	1885
34	2	1890	3195	0
1	6	3150	3227	0
5	4	2268	3234	210
14	9	3024	3263	0
35	3	2520	3327	0
20	3	1890	3327	492
12	10	3087	3331	0
5	5	3024	3392	0
15	12	3190	3393	0
68	4	1890	3396	876
37	1	977	3402	1135
22	3	2520	3433	0
70	7	3240	3442	0
9	7	3240	3477	0
68	5	2520	3503	353
13	8	3304	3509	0
8	6	3150	3511	0
41	2	630	3560	2300
4	6	3150	3572	0
38	11	2470	3592	917
39	3	1998	3618	975
24	2	1890	3624	0
14	10	3402	3627	0
36	1	1844	3674	1220
12	11	3430	3687	0
20	4	2835	3695	0

40	3	1260	3698	1808
15	13	3480	3703	0
18	3	2520	3739	0

CUMULATIVE STATISTICAL REPORT AT TIME 3780

QUEUE	AV.CONT.	MAX.CONT
1	.20	4
2	.33	9
3	.00	4
4	.00	1
5	14.19	29
6	.00	4
7	.26	3
8	14.62	22
9	.30	7
10	.64	4
11	.75	5
12	.04	1
13	4.09	13
14	.09	3
15	.12	3
16	.01	1
17	.00	1
18	.03	2
19	.00	1
20	.06	1
21	.04	2
22	.02	1
23	.03	2
24	.00	1
25	.00	1
26	.61	4
27	.25	3
28	.00	1
29	.03	2

MACH. CODE	NUMBER OF MACH.AVAIL	AVERAGE UTILIZED	MAXIMUM UTILIZED
1	1	.59	1

2	3	.36	3
3	3	.43	3
4	2	.40	2
5	5	4.41	5
6	3	.62	3
7	1	.43	1
8	1	1.00	1
9	1	.43	1
10	1	.69	1
11	1	.57	1
12	1	.23	1
13	2	1.38	2
14	3	1.20	3
15	2	.93	2
16	1	.23	1
17	1	.13	1
18	1	.17	1
19	2	.44	2
20	1	.33	1
21	1	.25	1
22	1	.26	1
23	1	.24	1
24	1	.99	1
25	4	.58	3
26	1	.65	1
27	1	.57	1
28	1	.13	1
29	1	.26	1

JOB.NO	MAN.RUN.STA.	MAN.RUN.FIN
1	6	6
2	3	3
3	4	4
4	6	6
5	5	5
6	4	4
7	4	4

8	6	6
9	7	7
10	4	4
11	4	4
12	11	11
13	8	8
14	10	10
15	13	13
16	2	2
17	2	2
18	3	3
19	4	3
20	4	4
21	2	2
22	3	3
23	2	2
24	2	2
25	9	9
26	6	6
27	3	3
28	9	9
29	11	11
30	16	16
31	3	3
32	13	13
33	4	4
34	2	2
35	3	3
36	2	1
37	2	1
38	12	11
39	4	3
40	6	3
41	6	2
42	9	9
43	6	6
44	3	3
45	9	9

46	11	11
47	16	16
48	3	3
49	13	13
50	4	4
51	11	11
52	16	16
53	3	3
54	13	13
55	4	4
56	2	2
57	2	2
58	12	12
59	4	4
60	2	2
61	2	2
62	12	12
63	4	4
64	2	2
65	2	2
66	12	12
67	4	4
68	6	5
69	4	4
70	7	7

AVERAGE TARDINESS 194.13

NUMBER OF JOBS THAT TOOK PRIORITY ACCORDING TO THE S/OPN RULE = 1164
NUMBER OF JOBS THAT TOOK PRIORITY ACCORDING TO THE SPT RULE = 1019
PRINT$

APPENDIX D

BROCHURE OF COMPANY

Çimsataş
Çukurova İnşaat Makinaları
Sanayi ve Ticaret A.Ş.

ÇİMSATAŞ

İnşaat Makineleri Üretiminde Öncü Kuruluş - Leading Manufacturer of Construction Equipment in Turk

ÇİMSATAŞ Entegre Tesisleri:
- İnşaat Makineleri ve Ağır İş Kamyonları Üretim Tesisleri,
- İnşaat Makineleri ve Parça Üretim Tesisleri,
- Dövme Tesisleri,
- Döküm Tesisleri,
- Kalite Kontrol Laboratuar Üniteleri
- Takım Aparat ve Kalıp Üretim Tesisleri,
- Mühendislik ve Dizayn Büroları,

ve diğer üniteleriyle, alanında öncü kuruluştur.

ÇİMSATAŞ: CATERPILLAR TRACTOR CO. ve MACK TRUCKS Inc. gibi dev teknojilerle işbirliği yaparak en modern yöntemlerle ürettiği inşaat makineleri ve kamyonlarla bölge ülkelerinin altyapı sorunlarının çözümüne katkıda bulunmaktadır.

ÇİMSATAŞ is a leading industrial company in Turkey with its own Foundry, Forgi
Plant and Construction Machinery Production Plant.

ÇİMSATAŞ is producing construction machines and their parts under the license
CATERPILLAR TRACTOR CO.Dump Trucks and Highway Tractors production w
be made under the license of MACK TRUCKS INC. Technical know-how for forgi
plant has been obtained from FORGES STEPHANOISES OF France
These investments help to build the total infrastructure of the country.

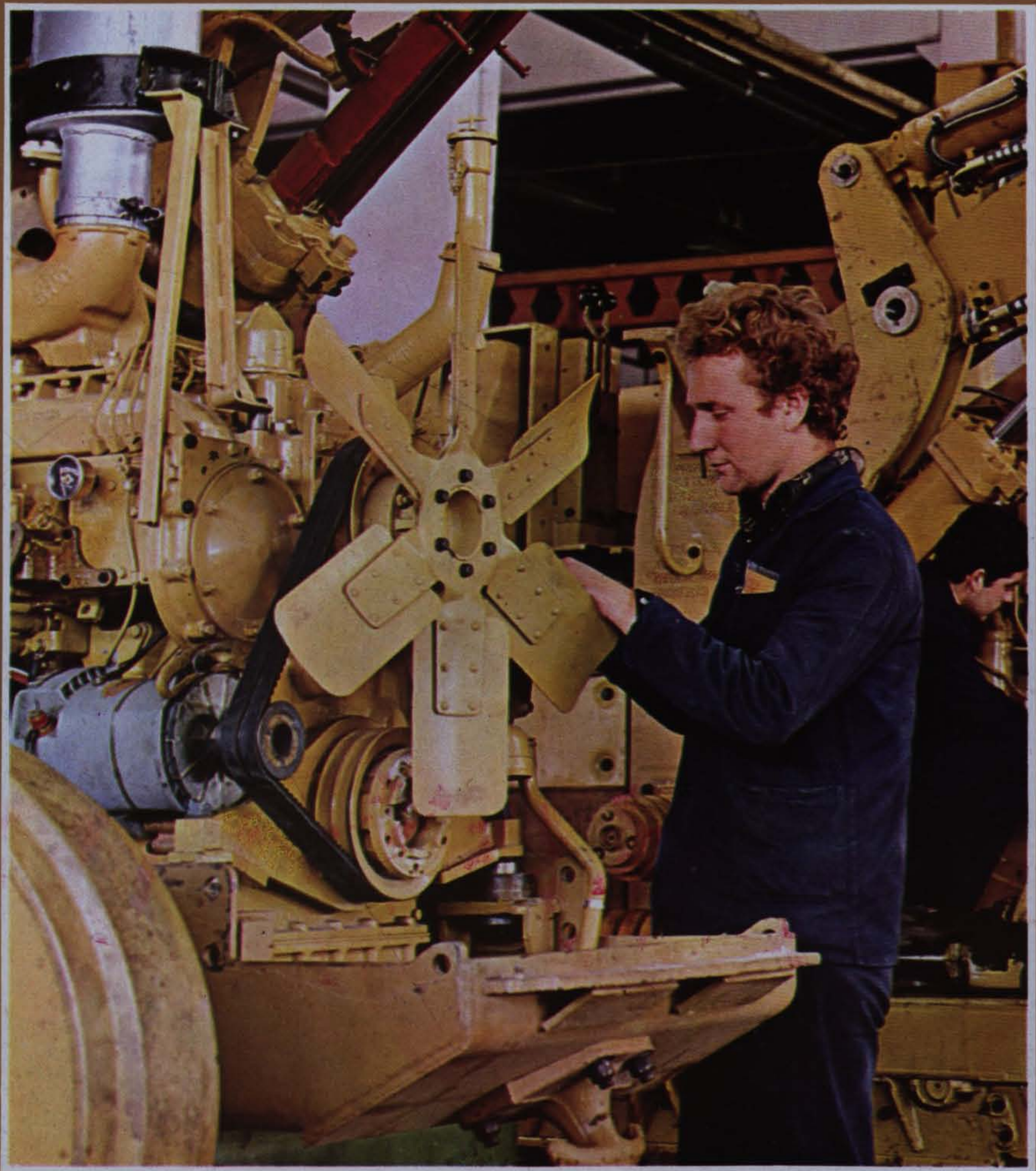
İNŞAAT MAKİNELERİ VE AĞIR İŞ KAMYONLARI ÜRETİM TESİSLERİ

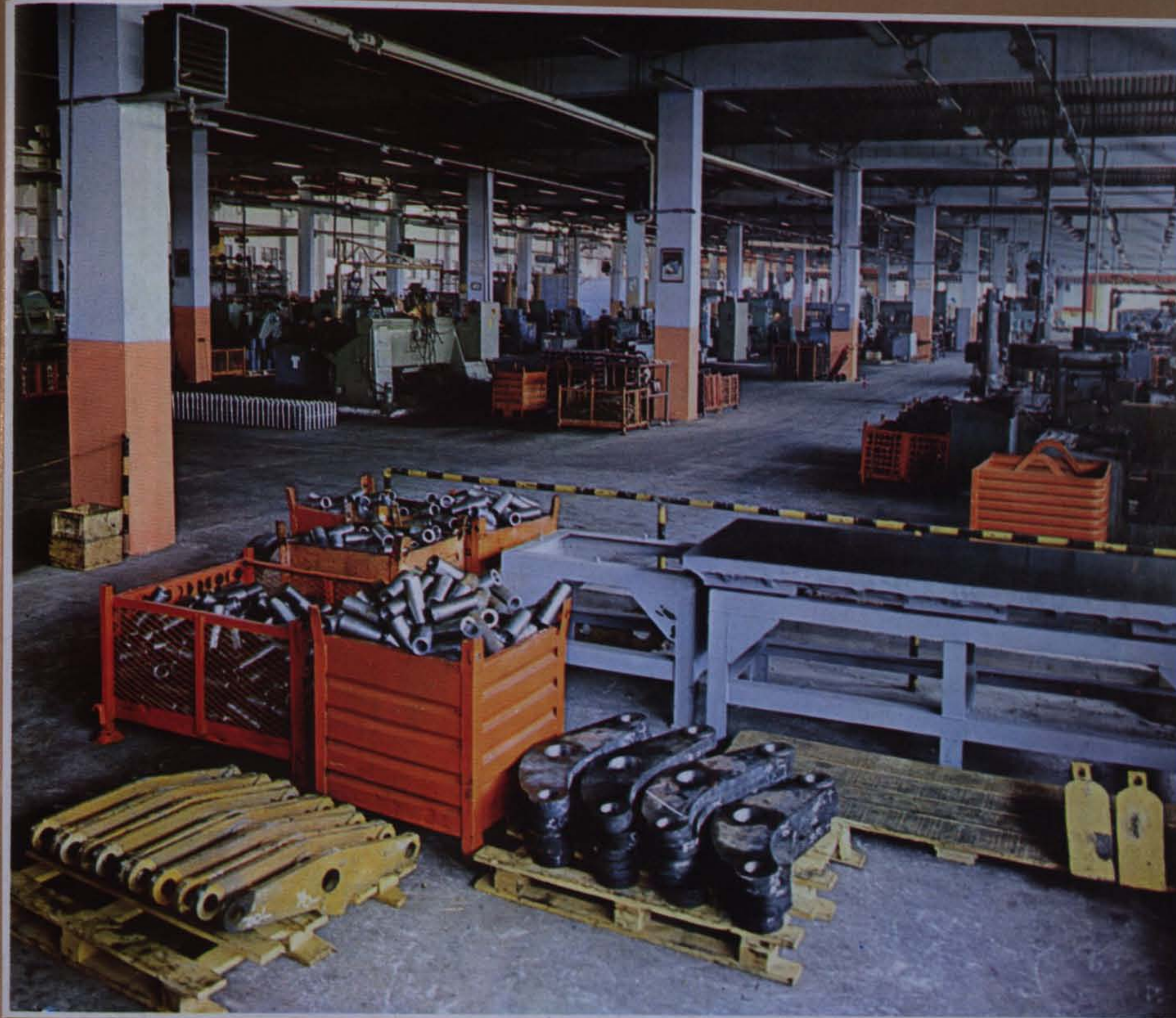
En büyük ve modern teknolojik imkânlarla, inşaat makinelerinin ve ağır iş kamvonlarının üretilmesi için kurulan bu tesislerde, paletli ve lastik tekerlekli yükleyici ve paletli dozerlerin üretimi için CATERPILLAR lisansı; damperli kamyon ve treyler çekicileri üretim için MACK TRUCKS Inc. lisansı kullanılmaktadır.

ÇİMSATAŞ İnşaat Makineleri ve Ağır İş Kamyonları Üretim Tesisleri'nin planlanmasında, bölge ülkelerinin de ağır iş makineleri ihtiyacının karşılanması amaçlanmıştır. 1981 yılında üretilmesine başlanan ÇİMSATAŞ "955L" tipi yükleyiciler bugün çeşitli ülkelerde başarıyla görev yapmaktadırlar.

CONSTRUCTION MACHINES AND DUMP TRUCKS PRODUCTION PLANT

Production of wheel and track type loaders and dozers are made under the license of CATERPILLAR TRACTOR CO.Production started in 1981 with 955 L Traxcavators. 953 Traxcavators are scheduled to be produced in 1982.
Production of dump trucks and highway tractors will be made under the license of MACK TRUCKS INC.
This plant is capable of supplying the neighbouring countries with its products.



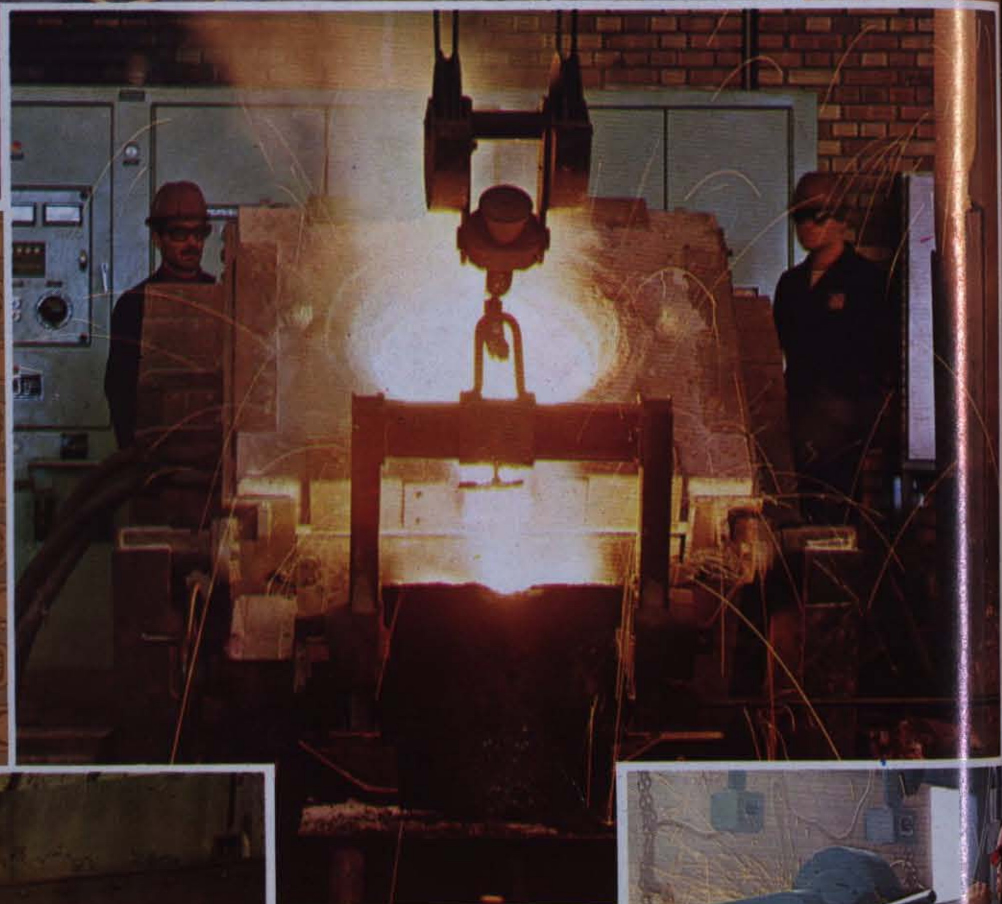


İNŞAAT MAKİNELERİ PARÇA ÜRETİM TESİSLERİ

ÇİMSATAŞ'ın bu modern tesislerinde, yürüyüş takımları ve ilgili parçalar üretilmesinin yanı sıra, otomotiv endüstrisinin talaşlı imalat ve ısıl işlem sorunlarının çözülmesi planlanmıştır. Döküm ve dövme tesislerinden gelen her türlü parçaları işleyebilecek nitelikte torna, freze, kesme, özel işlem tezgâhları ile, işlenen ürünlerin normalizasyon, sertlik alma, her türlü su verme işlemlerini yapabilecek çeşitli ısıl işlem fırınları ile donatılmıştır.

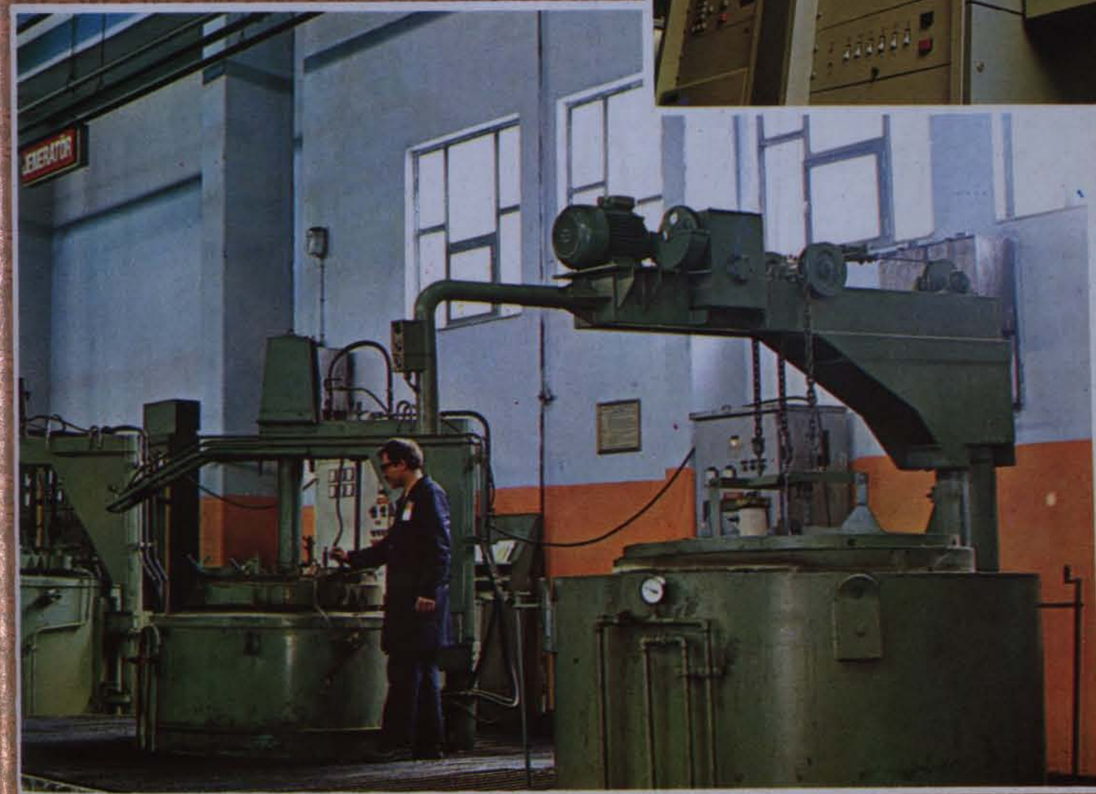
PARTS PRODUCTION PLANT

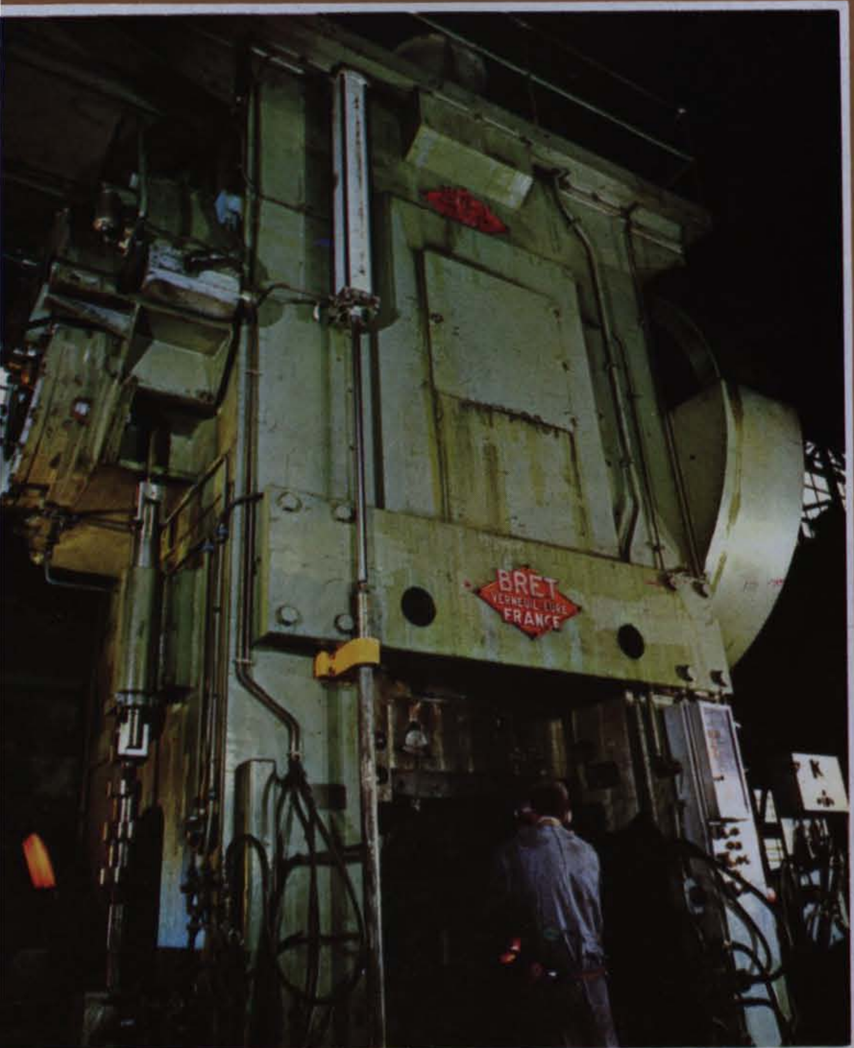
This technologically modern plant produces undercarriage components and various parts for the automotive industry.
Rough forgings and castings go through the machinery operation on various special turning, milling and cutting machines.
All kinds of heat treating (hardening, tempering, stress relieving) operations are also made in this plant.
Through the use of the most sophisticated machining and heat treating equipment ÇİMSATAŞ has the total capacity for your parts production needs.







DÖVME TESİSLERİ

ÇİMSATAŞ ürünü iş makineleri ve kamyonların kaliteli dövme malzeme ihtiyacının karşılanması ve dış piyasaya sipariş üzerine dövme parça temini amaçlarıyla, Fransız FORGES STEPHANOISES firması know-how'ı ile kurulmuştur. Üretim tamamen mekanik maksi preslerle gerçekleştirilmekte, kütük ısıtma operasyonu endüksiyonla ısıtma tezgâhlarında yapılmaktadır. İş makinelerinin yürüyüş takımları parçaları, otomotiv endüstrisinin ihtiyacı olan her türlü dövme parçalar üretimiyle ilk aşamada 12.500 ton/yıl kapasite amaçlanmıştır.

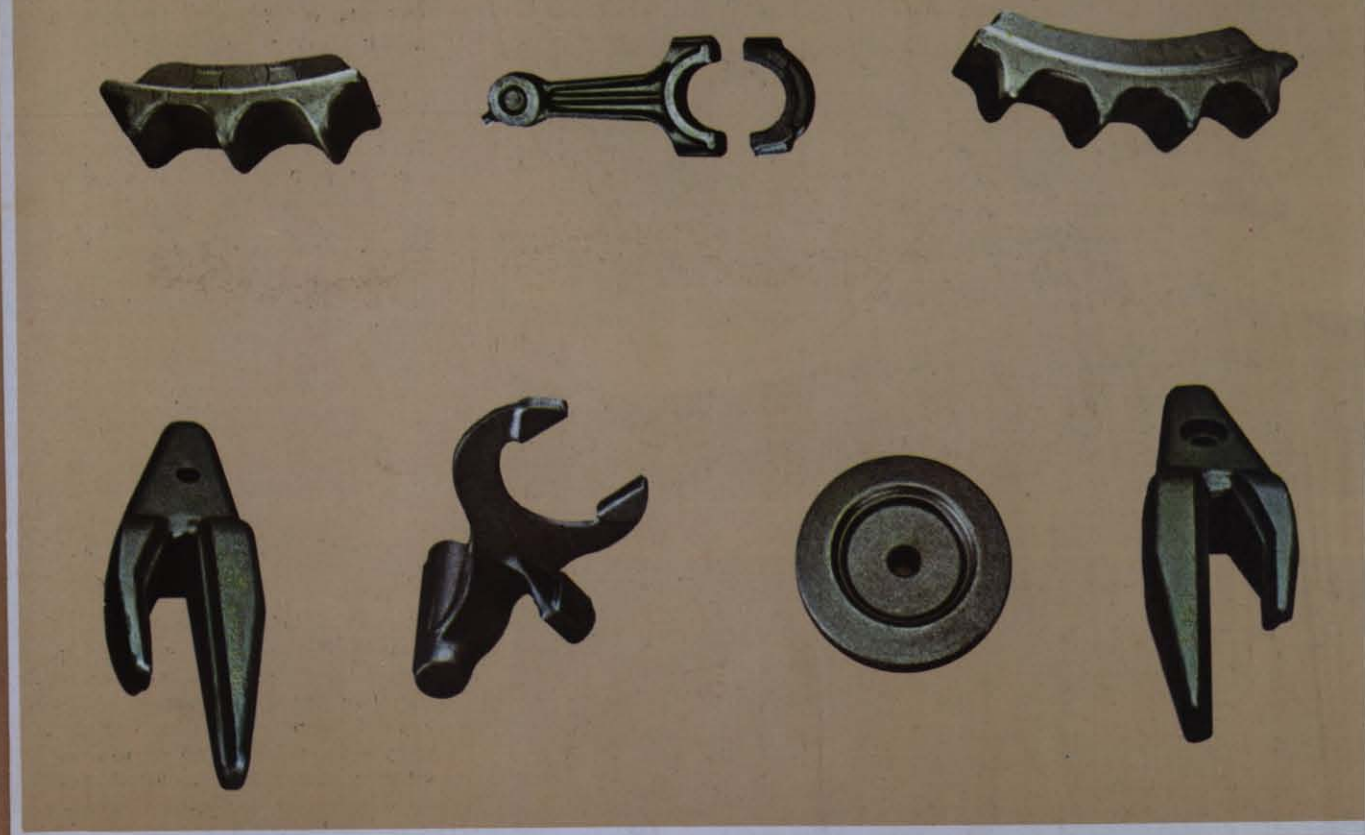
FORGING PLANT

This plant supplies rough forgings to the Parts Production Plant mainly for the production of undercarriage parts.

Rough forging requirements of various other automotive industries are also met by this plant. Forgings are produced with the know-how of Forges Stephanoises, France.

Production is made completely on 4500 tons and 2500 tons mechanical maxi presses where billets are heated by induction heating equipment. The annual forging production capacity of 12500 tons will be increased in the future in order to be able to meet increasing demand in high quality rough forgings for the automotive industry.

DÖVME PARÇA ÖRNEKLERİ/ SOME FORGED PARTS



DÖKÜM TESİSLERİ

Alaşımlı, alaşımsız çelik, sfero ve kaliteli üretimi alanında hizmet vermektedir. 800 kg/net. parça döküm kapasitesi ve 2.500 ton/yıl. üretim kapasitesiyle, ÇİMSATAŞ Entegre Tesisleri'nin kalite döküm ihtiyacını karşıladığı gibi otomot ve parça üretim endüstrisinden gelecek piyasa siparişlerini de karşılayabilecek durumdadır.

FOUNDRY

The ÇİMSATAŞ Foundry has the capa 800 kg/net piece casting and 2500 tons annum. It can produce quality castings alloy steels,low alloy, sphero and gray i

The ÇİMSATAŞ Foundry has the cap meet both in house casting requiremen and the increasing high quality casting demand of industry.

Üretimi planlanan mamullerin işlem ve metod hazırlama, takım ve fikstür dizayn, ilk imalat ve gelişme-yatırım çalışmaları bu bürolarda gerçekleştirilmektedir.

ENGINEERING DESIGN OFFICE

The efficient production methods for all units are prepared in this office.

Designing of Tools and Fixtures, developin prototype production and realization of expansion projects are among the responsibilities of the Engineering and Design office.

TAKIM APARAT VE KALIP ÜRETİM TESİSLERİ

ÇİMSATAŞ kalıp tesisleri en modern teknoloji ürünü kalıp işleme tezgâhları ile donatılmıştır. Burada en karmaşık şekilli parçaların bile dövme kalıpları son model kopya freze, pantograf freze ve elektro erozyon tezgâhlarında dövme usul ve tekniklerine uygun olarak üretilmektedir. Bu arada, gerek mekanik işlem ve gerekse ısıl işlem için ihtiyaç duyulan çeşitli kalıp ve fikstürler de , parçaların imal şekillerine uygun özellik ve hassasiyette hazırlanmaktadır.

TOOLS, FIXTURES AND DIES PRODUCTION DEPARTMENT

The most state of the art machinery and equipment are operating in this department of ÇİMSATAŞ.Dies of the most complicated forged components are produced in this department with the use of precise copy milling, pantograf milling and spark erosio machines.

Various dies and fixtures for machining an heat treat operations are produced in this department with highest precision.

LİTE KONTROL VE LABORATUAR SİSLERİ

ISATAŞ Kimya Laboratuarında yaş temle her türlü çelik, pik, sfero ve non- analizler yapılmakta olup, en gelişmiş yasal analiz cihazı olan "emisyon spek- metre" yoluyla yukarıda belirtilen zemeler içerisindeki 20 elemanın anında analizleri gerçekleştirilmektedir. Fizik Metalurji Laboratuarlarında ise, üretilen çaların akma, çekme, çentik kavemetleri gibi mekanik testleri, mikro , sertlik, çatlak kontrol gibi fiziksel ler devamlı yapılmaktadır. Üretilen in mamuller "ÇİMSATAŞ RANTİSİ" altındadır.

QUALITY CONTROL LABORATORIES

ÇİMSATAŞ 'Q.C.' labs have a wide range of facilities for chemical analysis, testing and determining mechanical properties of alloy steels, sphero, gray iron and non-ferrous materials.
Chemical contents of ferrous and non-ferrous materials are determined through wet methods as well as by use of the most sophisticated equipments like emission spectrometer, up to 20 elements.

The parts produced in ÇİMSATAŞ are tested against their mechanical properties such as tensile/impact strength, elongation. Facilites are also available for microstructural analysis, non-destructive testing and hardness measurements.
All the parts are guaranteed for quality by Çimsataş.

ÇİMSATAŞ

Çukurova İnşaat Makinaları Sanayi ve Ticaret A.Ş.

ÇİMSATAŞ ÇUKUROVA İNŞAAT MAKİNALARI SANAYİ VE TİCARET A.Ş. BİR ÇUKUROVA HOLDİNG KURULUŞUDUR.

ÇİMSATAŞ ÇUKUROVA İNŞAAT MAKİNALARI SANAYİ VE TİCARET A.Ş. IS A ÇUKUROVA HOLDING COMPANY.

ÇİMSATAŞ ÇUKUROVA İNŞAAT MAKİNALARI SANAYİ VE TİCARET A.Ş.

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İstanbul Bürosu : Telephone: 90-11-462813/90-11-474168/90-11-484258
Telex: 23 585 CKE TR / 22 693 CADA TR / 23345 CCE TR