APPLICATION OF A MANUAL SCHEDULING TECHNIQUE TO A PARTICULAR MANUFACTURING PROBLEM

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INTRODUCTION

Scheduling is the final stage in production planning, the stage at which all the production activities are coordinated and projected onto a time scale. A typical manufacturing plant may have a number of machines or facilities. At any given time, there could be a number of jobs or commodities that must be processed on the various facilities. Thus it would be necessary to prepare a schedule or a time table that would specify what job a facility should process at any given time. In the ideal situation, all facilities would be kept busy all the time. Also, to deliver the completed jobs at the earliest date, a facility should be available as soon as the job is ready for processing on that facility. Obviously, these two requirements are almost never met. Satisfying one of the requirements does not necessarily satisfy the other requirement. Only in the overall ideal situation would both of the conditions be achieved simultaneously. If there are three machines A, B and C, and only one job which all the three machines have to process; it is quite clear that machines B and C must be kept idle during the time the job is being processed on machine A. Thus it would not be possible to meet the first requirement. Again, if there are three jobs A, B and C, and only one facility on which all the three jobs are to be processed; and if only one job can be processed at any given time; it is quite clear that jobs B and C must wait their turn if job A is being processed, making it rather impossible to meet the second requirement. Thus there is a problem; when and how to assign jobs and machines to obtain an overall optimum? Such a problem is known as an industrial scheduling problem.

Industrial scheduling problems are quite complex and diverse. This is so, because a plant may have hundreds of facilities on which thousands of jobs have to be processed. The number of possible alternatives in this scheduling problem is very large. That alternative which minimizes the total time required to complete all the jobs and hence minimizes the idle time and maximizes the utilization of facilities can be said to be optimal with the total elapsed time as the criterion. Besides these, there could be other criteria for optimizing the scheduling problem. Some of these could be, producing the product with minimum total cost per unit, minimizing the combined set-up cost of machines and inventory carrying cost or minimizing the in-process inventory. An optimal solution can always be obtained by enumeration but if there are just five jobs and five machines and any order is satisfactory, the possible sequences are approximately 25,000,000,000 (i.e. $5!^5$), thus enumeration becomes impractical.

<u>Different types of scheduling:</u>

Industrial scheduling problems can be broadly divided into Project Scheduling and Machine Scheduling. Project scheduling is concerned with the analysis of various phases of a project. Program Evaluation Review Technique (PERT) and Critical Path Method (CPM) are the two well known techniques of project scheduling. Machine scheduling can be subdivided into (i) Flow shop type of scheduling (ii) Job shop type of scheduling and (iii) Intermittent type of scheduling.

In the flow shop type of scheduling, the production is continuous and all the jobs necessarily have the same technological requirements - i.e. they all follow the same route through the machines. A problem of this kind is often referred to as the 'book-binding problem' (Bellman), the 'assembly line balancing problem' (Heller), or the 'flow shop problem' (Ignall). When the route is the same, all jobs flow in the same direction.

In job shop scheduling, the plant or a portion of a plant is viewed as a collection of various facilities. A shop might have ten lathes, six grinders, two drill presses and three milling machines. Some of the jobs may require processing on only lathes and grinders while a few jobs must go through all the four machines by the same or different routes. Here the jobs usually do not flow in the same direction. Also, the jobs are seldom repeated. Job shop scheduling could be treated as a special case of project scheduling with limited facilities, thus PERT and CPM techniques can be applied here too.

The intermittent type of production lies in between the above two. The products are produced in a batch and they may not have the same technological requirements. After one batch is produced, the same facilities may be used for manufacturing some other products. After a set interval of time, the production cycle is repeated. The manufacturing problem to be dealt with, in this report, is of this type.

MANUFACTURING PROBLEM

The manufacturing problem, to be considered here, is to schedule the production of a factory producing incandescent pressure lanterns. Figures 1 and 2. The lanterns are produced in a batch; the facilities being used for other purpose till the time for producing the next batch. Manufacturing these lanterns involves mainly press work. Most of the parts are made from brass sheets and the rest from steel sheets. The facilities are to be scheduled for this production. It is known that the requirements are uniform; and that manufacturing could be done to stock. Also, the available productive hours on each machine, the time it takes to manufacture each part (including set up time), the cost of set up and the technological requirements for each part are known. The problem, then, is to determine order quantities for each part, so that the production requirements are met and the combined cost of set-ups and inventory carrying is minimized. After the quantities are determined, a detailed schedule is to be made.

There are various methods available for solving this type of problem. However, if the requirements are not uniform with time it can be shown (Vazsonyi) that the problem leads to a very large nonlinear, mathematical programming problem. This nonlinear programming problem presents such a formidable proposition that it is not yet practical to develop a general solution. Nevertheless, it is possible to obtain a solution to

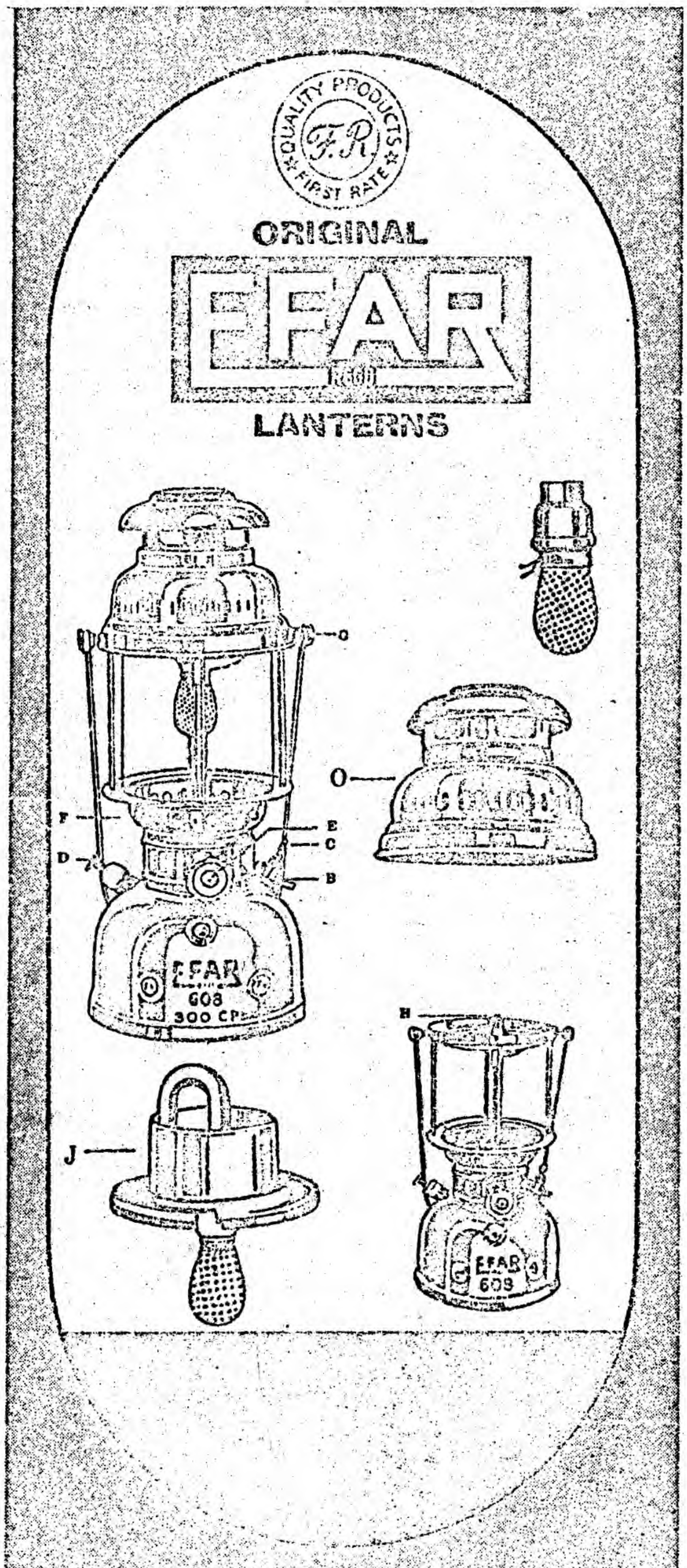


Figure 1. Final Product

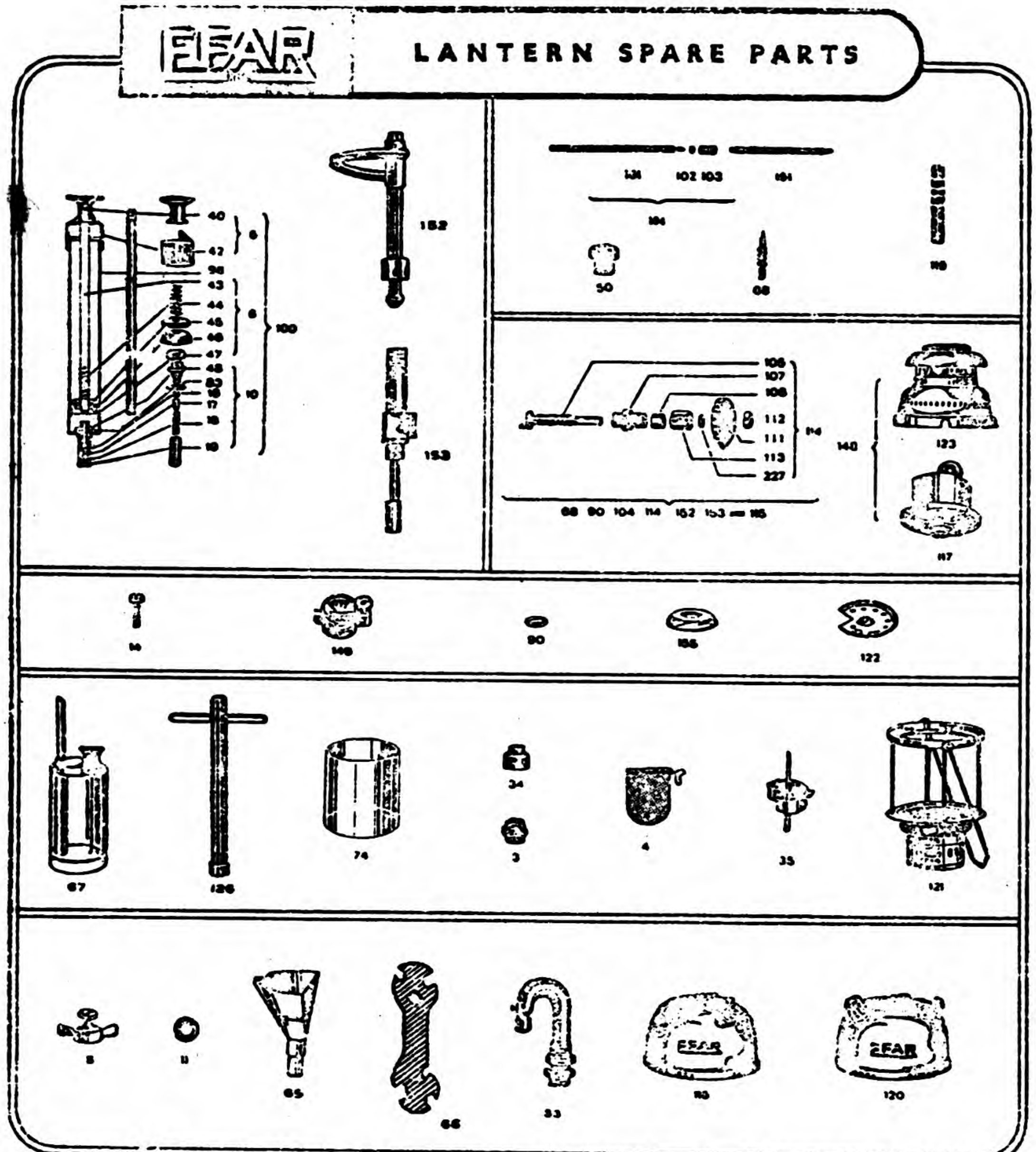


Figure 2. Components of the Final Product

SPARE-PARTS

When ordering spare-parts, please always state the number of the part required and also the candle power of your lantern.

No.	Description
5	Filling-screw-cap complete with washer
6	Pump piston complete
10	Pump valve complete
11	Washer for filling-screw-gauge and filling-screw-cap
14	Screw for center bottom
16	Rubber packing for check valve
17	Check valve cone
18	Spring for check valve
19	Shell for check valve
33	Mixing tube with nuts
34	Gas Chamber
35	Heating cup
40	Pump knob
42	Cap for pump barrel
43	Pump piston rod
44	Spring for pump
45	Pump piston plate
46	Leather washer
47	Pump piston nut
48	Valve screw
50	Nipple
65	Plastic filling funnel with sieve
66	Wrench
67	Filling Can
68	Needle
74	Glass chimney
83	Valve washer
85	Lead washer for gauge
90	Washer for vaporizer
98	Pump barrel empty
100	Pump complete
101	Conducting rod
102	Counter nut for conducting rod
103	Conducting piece
104	Conducting rod complete with nut and piece
105	Excenter
107	Nipple for Excenter
108	Graphite packing
111	Wheel
112	Nut for wheel
113	Sleeve nut for excenter
114	Excenter complete
115	Vaporizer complete with excenter and conducting rod
117	Inner casing complete
118	Container without fittings
119	Key for needle
120	Container complete
121	Frame complete with hail
122	Center bottom plate
123	Hood with top
126	Spanner for Valve
148	Upper part, complete
149	Filling screw gauge
152	Vaporizer upper part
153	Vaporizer lower part
155	Dam plate
227	Disc for wheel

this problem which meets the requirements and stays within available production capacities but which does not necessarily minimize combined inventory and set up costs. Since, in our case, the requirements are uniform, the use of an economic-lot-size formula would minimize the combined set-up and carrying costs.

The word manual in the title of the report means that a computer and/or other algebraic methods will not be used for arriving at the solution; however, mechanical means such as Gantt chart will be used for scheduling the production in detail after the batch size is optimized by the application of economic analysis.

The data for the problem is:

	Monthly requirement	= 1200 units
	Monthly working days	= 24 (i.e. 30 days - 4 Sundays - 4(1/2 Saturdays))
hence,	Monthly working hours	= 24 X 8 = 192 hours.
	Number of set-up men	= 2
	Number of workers	= 30
	Wages for set-up men	= Rs. 9/day = Rs.* 1.125/hr.
	Wages for workers	= Rs. 6/day = Rs. 0.75/hr.
	Inventory carrying cost rate	= 20%+
	Overhead cost (based on running time)	= Rs. 5.75/unit

*Rs., abbreviation for Rupees - Indian currency; present exchange rate at Rs. 7.50 per dollar.

+An estimate of the inventory carrying cost rate was not available from the factory concerned, the figure of 20% was assumed on the basis of the general U. S. literature.

List of facilities (machines) available, components manufactured operation route sheets and machine operation break-down are given in Appendix A.

APPROACH

The theory of multi-product batch size determination proves to be very helpful in cases where the final product is an assembly made of several components, which must also be produced on a batch basis. The components involve different set-up costs, material costs, production rates, etc. If each component were considered on its own, each would have its corresponding optimal batch size, and in most cases, these optimal values would be different for the different components; furthermore, they would be different from the optimal batch size for the final product. Moreover, this approach does not take into account the effects of individual products on each other and on the production schedule. This could easily lead to complications in the production schedules and result in a cumbersome inventory control system.

These difficulties are greatly alleviated by the use of the theory of multi-product batch size determination. The consumption rate, a_c, of the final product is, in fact, the rate at which the components are required for the assembly line, namely,

$$a_c = a_{c_1} = a_{c_2} = a_{c_3} = \ldots = a_{c_i} = \ldots$$

where a_{c_i} is the consumption rate of the ith component in units per unit time (a unit of a component is defined here as the number of pieces required per one final assembly). But as the consumption period Tc is the same for all components, it follows that the quantities are all the same:

$$Q = Q_1 = Q_2 = Q_3 = \ldots = Q_i = \ldots$$

where Q is the batch size of the final product and Q_i is the batch size of component i. The term quantity in this case prescribes the number of units required per Q units of the final product. Thus, if two pieces, say, of component 4 are required for each assembly, and if Q = 1000 units, then Q_4 = 1000 units = 2000 pieces.

The procedure for determining the batch size for the whole production schedule would be as follows:

Since the requirements form a uniform demand, the application of an economic-lot-size formula to each component manufactured would give an optimal batch size by minimizing the combined cost of set-up and inventory, only for that component being considered on its own. The formula for optimal batch size (Eilon, page 232) is,

$$Q_m = \sqrt{\frac{2a_cS}{I(1+\gamma) + 2B}}$$

where,

Q_m = Optimal batch size

a_c = Consumption rate per unit time

S = Set up cost/batch

I = Inventory carrying cost for one piece/unit time

γ = Ratio of consumption rate to production rate

B = Average storage cost/unit of time

Here, the production rate would be very high when compared to the consumption rate, so the ratio $a_c/a_p = \gamma$ is very small, hence can be neglected.

Again, storage costs are fixed (for this particular case) and so do not depend upon the batch size. Thus the storage cost can be ignored also. These assumptions reduce the formula to,

$$Q_m = \sqrt{\frac{2a_cS}{I}} \ .$$

Table 1 (Appendix B) shows the optimal batch size for each component when each is considered on its own. The optimal batch size for the final product is 895 units. In addition to batch size optimization for individual products, it is desirable to seek an optimal solution for the whole production schedule. Of the different optimization criteria available for measuring the effectiveness of the whole production schedule, the two most important and useful criteria are, 'Maximum return' (return is defined as the ratio of profit to cost of production) and 'Maximum rate of return' (rate of return is defined as the ratio of profit to cost of production per unit time). A high rate of return implies that stocks should be kept at a low level and replenished at short intervals of time by small batches. These batches would be smaller than the minimum cost batches. The maximum return criterion gives a larger batch size than the former criterion-and this increased batch size could lead to improved production methods and hence reduction in costs. It is felt that this criterion should be used if the optimal batch size for the whole production schedule comes out to be lower than the total monthly requirements.

Using 'Maximum Return' as the criterion, the optimal batch size for each component is given by (Eilon, page 372),

$$Q_{iM} = g_i Q_{im}$$

where,

$$g_i = \sqrt{\frac{\Sigma S/S_i}{\Sigma K_i \alpha_i^2 / K_i}}$$

where, Q_{iM} = Optimal batch size of ith component when the effects of individual products on each other and on the production schedule is taken into account (by Maximum Return criterion).

Q_{im} = Optimal batch size of ith component when each is considered on its own.

S_i = Set-up cost of ith component

K_i = Carrying cost factor for ith component which in our case is, $I_i/2a_c$

α_i = Ratio of consumption rate of ith component to 1st component = 1 (in our case)

Q_{iM} for all the components is given in Table 2. Obviously for final product $Q_{iM} = Q_{im} = 895$.

Thus each component has two optimal batch sizes, one when each is considered on its own and the second, when the whole production schedule is optimized. It can be seen that these two batch sizes are not compatible, since the schedule optimization sets a rigid relationship between the quantities of the various products included in the schedule, and the quantity ratios are determined by the relative rates of demand and not by the cost parameters that play an important role in optimal batch size determination when each product is analyzed individually. It is also quite clear that neither approach can afford to disregard the other, and in order to reconcile the two, a compromise solution must be worked out in the form of a realistic schedule. This is where the production range becomes useful, since it specifies the allowable deviations from the individual optimums and thereby provides a certain amount of flexibility in the construction of schedule.

The concept of production range could be explained as follows. The total production cost per piece function has a quadratic form; i.e. it is double valued, thus any increase in the total production costs above the total minimum costs corresponds to two batch sizes on either side of Q_m (minimum total costs/piece batch size) as shown in Figure 3. Thus in Figure 3, Q_I and Q_{II} represent two batch sizes, one on either side of Q_m, which could be produced when a certain percentage increase in total production costs above the minimum is allowed. The range between the two limits, Q_I and Q_{II}, is called the production range. The total production costs for any batch size selected anywhere within the production range would not cause an increase in production costs above a predetermined value.

A production range may be likened to dimensional tolerances on engineering components. A certain batch size may be considered the best target that should be aimed at, but in practice it may be impossible to obtain a satisfactory production schedule consisting of ideal batches only. Before determining the production range, it is necessary to define (Eilon, page 243) a nondimensional ratio p as follows:

$$p = \frac{y - c}{y_m - c} = \frac{\text{variable costs/unit}}{\text{minimum variable costs/unit}}$$

where,

y = Total cost/unit

c = Constant cost/unit

y_m = Minimum total cost/unit, i.e. the total cost/unit when the optimum batch size is produced.

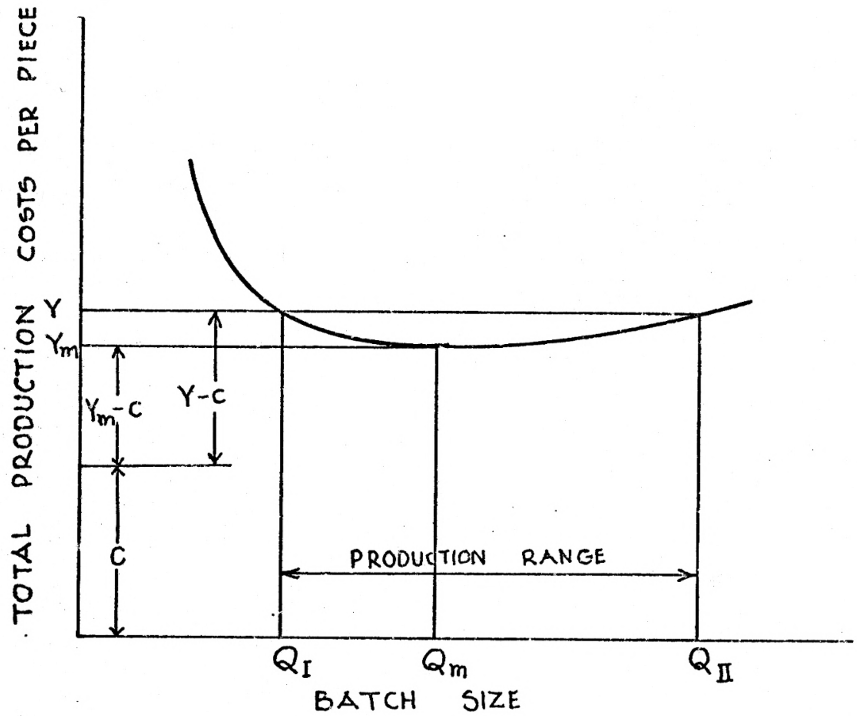


Figure 3. The Production Range

The ratio p is a measure of increase in costs above the minimum. To introduce some flexibility in the selection of batch size, it is necessary to allow a certain increase in costs above the minimum. The value of p is higher than 1 and the extreme values of the production range is given by the following two equations (Eilon, page 244),

$$Q_I = Q_m(p - \sqrt{p^2 - 1})$$

$$Q_{II} = Q_m(p + \sqrt{p^2 - 1})$$

where Q_I and Q_{II} are the lower and higher values of the production range respectively.

A significant feature of the above equations is the amount of flexibility that results, even with a small increase in variable costs; and of course, for a particular percent increase in variable costs the percent increase in total production costs would be even smaller.

It is felt that a 5 percent increase in variable costs above the minimum for each component should give sufficiently wide production range to work with but for some parts, a 10 percent increase in variable costs above the minimum may be necessary to avoid trouble in selecting the batch size. The production range for both percentage increases is shown in Table 3. The production range for the final product is about 654 to 1223 for p = 1.05 and about 515 to 1392 units for p = 1.10.

The next step is to select a quantity Q (batch size), that would fall within the production range of the final product and within the respective ranges of most of the components. The selection of a batch size Q that lies within the limits of the production range of the final product ensures that the costs per unit will remain below a predetermined level, while the uniformity of batch size for all the components greatly simplifies production planning and scheduling procedures.

The selected batch size should be between 654 and 1223 units as that is the production range of the final product for p = 1.05. A look at Table 3 shows that the Q = 900 lies within 5% production range of about 15 components and other two components can also be made in this batch size if their production range is increased to 10%. There are three components for which 900 is too large a batch to be within their production ranges. They can be made in two lots of 450 each every cycle. The reason for their lot size being smaller than other components is that their ratio of set-up cost to constant cost (Table 1) is very low when compared to the other components. A lower ratio gives a lower optimal batch size which results in a lower production range. However, since the batch size is 900 units, there has to be these many units of all components during the final assembly. The idea of making the required quantity in two lots does not look economical, in the sense that set-up cost would be doubled whereas the reasonable saving in interest carrying cost would occur only if the two lots are produced far apart, i.e. one at the beginning of the cycle and the other near the end of the cycle. Because of this, these three components should also be produced in a batch size of 900. It is also found from Table 3 that batch size of 900 is too small for some parts which are made from steel sheets. The reason for their large batch-sizes is obvious. For these components, the ratio of set-up cost to constant cost (Table 1) is very high. The eight components for which batch size of 2700 looks suitable, could be treated with a long cycle approach, i.e. they could be made only once in every three cycles. Thus, there would be 2 cycles - one short and the other long. In the short cycle, only those components which have a batch size of 900 will be manufactured. In the long cycle, besides all the components which are produced in the short cycle (in the batch size of 900), the remaining eight components will be manufactured in the batch size of 2700. The long cycle will come once after every two short cycles.

The next step in the scheduling is to make a time table (schedule) that will show in detail at what time which machine is to be set up for processing a particular operation of a particular component, when the operation will be started and when will it be over. The manual technique commonly used to complete all of the activities within the specified time making the best possible utilization of men and machines is to draw a Gantt chart (Clark). A Gantt chart has proved a valuable tool in scheduling when several parts are produced at the same time. This chart clearly depicts who is responsible for any piece of work, when it is to be completed and how long it will take. Fundamentally, a Gantt chart is an operating chart in that it furnishes information for action. It shows the amount of work scheduled for each machine. The operations of all of the components are plotted on the time scale with respect to the machines on which they are performed. The starting and completion times of each operation are clearly shown.

Although it is not difficult to draw the chart, it does not give an optimum schedule. It is only one of the many feasible solutions. However, with reasonable care in plotting the chart, considerable saving in time can be affected. Benefits are many as mentioned above. The Gantt chart has a limitation in that any error in the calculations and posting are hard to detect and are apt to be cumulative. Once an error is detected, rectification may necessitate the revision of the Gantt Chart.

With reference to the particular manufacturing problem, the following assumptions are made in drawing the Gantt chart:

A. Assumptions regarding the machines:

1. No machine, except furnaces, may process more than one job at any given time. The furnaces, because of their operating characteristics, may process any number of jobs at any given time, the only restriction being their size.
2. Once an operation is started on a machine, it must be performed till it is completed on that machine.

B. Assumptions regarding the jobs:

1. Any particular operation of a job may be processed by two or more similar machines at any given time provided the tooling cost is low (considering the later restriction, only spinning or polishing machines could be used simultaneously to perform the same operation of a job).

2. Consecutive operations of any job may be carried on simultaneously on different machines at any given time, i.e. over-lapping of operations is allowed. The maximum over-lapping would be restricted as follows:

   (i) if the following operation is slower, it will not start earlier than fifteen minutes after the starting of the previous operation and

   (ii) if the following operation is faster, it will not end earlier than fifteen minutes after the ending of the previous operation.

3. Each job must go through a number of machines in a specified order. This is known as 'technological requirement' or the 'routing'.

C. Assumptions regarding the processing times:

1. A known finite time is required to perform an operation. This is known as the processing time.

2. Processing times are deterministic. Thus there are no random or uncertain elements.

3. Processing times are independent. This implies independent of each other, and independent of the order in which the operations are performed.
4. The time required to transport the jobs between machines is assumed to be negligible or is included in the processing times.

D. Other assumptions:

1. The set-up time on each machine is known and the machine can be set up even before the job is ready to be served by that particular facility.
2. The maximum number of set up men available at any time is 2.
3. Furnace capacity would be limited to 600 units for big components such as hood, chimney seat and tank. Since other components are comparatively small, the furnace capacity would not be restricted for them.
4. Any annealing operation would take 4 hours.
5. Parts cannot be put in the furnace in the middle of its working cycle.
6. Total work force would be 30, including 2 set up men and 6 workers for hand operations.

Nomenclature and symbols used in Gantt chart:

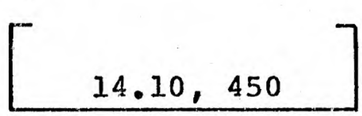
On the Gantt chart a division of space represents both an amount of time and an amount of work to be done in that time. Thus, equal divisions of space on a single horizontal line represents at the same time, equal divisions of time and varying amounts of work scheduled. On the Gantt chart, given in Appendix C, one division of space on the time scale represents eight hours. On the left side of the Gantt chart all the machines plus 6 workers (for operations to be done by hand) are listed.

On the Gantt chart the hour when work is to begin is indicated by a right angle opening to the right, thus -

The hour on which work is to be completed is indicated by an angle opening to the left, thus -

The two angles are joined at the bottom by a straight line to show the amount of work scheduled, thus -

The components are numbered 1 to 32 as shown in Appendix I. The operations under each component are also serially numbered. The component, operation number and the number of units are entered into the Gantt chart, thus -



This would mean 450 units of component number 14 (which is the hood) and operation number 10 (which is 1st spinning) are scheduled in this block. Since this operation is to be done on a spinning machine, it would be shown against that machine. Absence of any figure after the component and operation number indicates that the component would be processed in a batch size of 900.

Any component number with an asterisk would mean that this particular component has been carried over from the previous cycle. This component, because of its long processing time, could not be finished in the cycle in which it was started.

The set-up operation on any machine is shown by the hatched lines between the angles and by the prefix s to the component and operation number.

Difficulties presented by non-uniform batch sizes in drawing the Gantt chart:

At first, an attempt was made to draw the Gantt chart with the short and long cycle approach. A Gantt chart for long cycle was considered first. The following difficulties were encountered due to non-uniform batch sizes:

(1) With batch size of 2700 for eight components, the cycle time becomes quite long and on the chart it becomes difficult to keep track of the different components.

(2) Total processing time on the small ball press and the 40 ton press is very high when compared to the other machines. If the small ball press is worked continuously, even with a high efficiency factor of

90%, it would be busy for about 250 hours in the long cycle. This makes the long cycle awfully long (about 1.33 months) and the distribution of working load on other machines very uneven.

To utilize the time more effectively, the short cycle should start before the long cycle has ended. However, this difference in batch sizes and overlapping of two cycles causes too many complications in the scheduling procedure. This does not mean that scheduling could not be done on the optimal batch sizes but to avoid these scheduling complications, it was decided to give up this long and short cycle approach in favor of all the components having a uniform batch size of 900 units. Since 900 units also lie in the 5% production range of the final product, the total cost per unit should not increase more than 5% above the minimum cost, i.e. when all the components are produced at uniform batch size of 900 than when they are produced at respective optimal batch sizes as found before.

The Gantt chart for the problem is shown in Appendix C. Since the monthly requirement is 1200 units and the batch size is 900, it is clear that new production cycle should start at least after every 3/4th of a month or 144 hours. The two components, chimney seat and hood, have very long processing times. If these two components are always given priority over the remaining components and if all of the operations were placed end to end, i.e. as soon as one operation is over, the next one is started, the chimney seat would take 231 hours and 30 minutes, whereas the hood would take 208 hours and 45 minutes (for 900 units). Somehow, these operations have to be compressed in the total processing times to a maximum limit of 144 hours. This necessitated the overlapping of consecutive operations, i.e. two or more consecutive operations were performed simultaneously instead of waiting for one operation to be over before the next one is started. This worked alright with the chimney seat but even with the maximum of overlapping, the hood could not be processed completely within the stipulated time. Again, some difficulties arose with the component 'tank', too. Though its processing time is only 80 hours and 30 minutes (for 900 units), machines could not be made available at the right time, thus at the end of 144 hours it was still in the processing stage. Moreover, soldering, plating and assembly operations were left unfinished too. However, the required machines were idle in the beginning portion of the cycle. Consequently, this difficulty was overcome by running two cycles concurrently - beginning a portion of the new cycle and completing a later portion of the previous cycle. Thus the first batch of 900 units would come out at the end of the first 288 hours but then each batch would come out every 144 hours.

A graph was drawn (Appendix D) to show the labor force requirement at the beginning of every hour. This shows that the maximum number of workers (including the set-up men) required are twenty three and the minimum eight. The personnel requirements vary quite a few times - the valleys and mountains suggesting that these requirements should be levelled by some means. The theoretical total running time per unit of final product is about 2.2219 hours (two hours thirteen minutes and eighteen seconds) whereas the actual total running time comes to about 2.25 hours. These two figures match well enough, thus 900 units would require 2025 man-hours which can be achieved with fifteen men.

Two other graphs were drawn (Appendix D) to show the relationship between time and the number of workers required for hand operations and set-up men. The requirements for hand operations varied from zero workers to a maximum of six workers and for set-up men from zero to two. The approximate man-hours required are 659 and 160 respectively. For this, a maximum of four workers should be assigned to hand operations instead of the present six. As for the set-up men, though theoretically only one set up man would be sufficient, it appears that more machines would be idle because of unavailability of the set-up men at the required time; if the machines are not ready at the proper time, the result would be more idle time and less production. Hence, it would be desirable to use two set-up men.

This Gantt chart does not have any provision for making up the lost time (and hence lost production) if the schedule breaks down any time. This could happen if any machine breaks down or if the raw material is not available at the required time or there is labor absentism or power failure or any other reason which could result in lost production. The only way to get back on schedule is to make up the lost production by working over time.

Since there is quite a deal of overlapping of operations, considerable material handling would be involved. However, the transportation time is assumed negligible or is supposed to be included in the processing times. Nevertheless, if required, one man would be able to do all the material handling.

This Gantt chart does not present an optimal solution. It only gives one of the feasible solutions. However it could be taken as a first step in scheduling the production of the factory concerned. In conclusion the following modifications could be suggested to improve the scheduling.

(1) At any time not more than fifteen workers should be working. This restriction would level the working force requirement more or less and help achieve the same production with a considerable saving in wages.

(2) Restricting the number of workers employed for hand operations to four would also help toward normalizing the personnel requirement.

(3) At present the total cycle time is 144 hours and two cycles are processed simultaneously. By increasing the total cycle time, the fluctuations in labor requirements can be diminished. However, this approach will increase the number of cycles moving concurrently and hence the in-process inventory.

(4) In the present schedule, very few persons are working toward the tail of the cycle. An attempt should be made to displace the tail to the left. This would complete the cycle sooner than is done now with a resultant saving in production time. Conversely more units could be produced in the same time.

(5) Instead of reducing the work force, another alternative could be to fill up the valleys by scheduling another product at that time.

APPENDIX A

LIST OF MACHINES AND FACILITIES AVAILABLE

Serial Number	Name of Machine	Number Available
1	90 Ton Press	1
2	Furnace	3
3	Spinning Machine	2
4	Trimming Machine	1
5	Big Ball Press	1
6	Stamping Machine	1
7	40 Ton Press	1
8	Production Lathe	1
9	Small Ball Press	1
10	20 Ton Press	1
11	Spot Welding Machine	1
12	15 Ton Press	1
13	Polishing Machine	2
14	Auto-punching Machine	1
15	Grinding Machine	1
16	Small Drilling Machine	1
17	5 Ton Press	1
18	32 Ton Press	1
19	Special Ball Press	1
20	Capstan Lathes	6
21	Wire Straightening Machine	1
22	Shearing Machine	1
23	Special Jig and Fixure	1
24	Special Die	1
25	Soldering Section	
26	Plating Section	
27	Assembly Section	

LIST OF COMPONENTS MANUFACTURED

Serial Number	Name of Component
1	Tank
2	Tank Bottom
3	Pump Barrel
4	Inner Case
5	Air Pocket
6	Air Pocket Chip
7	Chimney Seat
8	Piston Rod
9	Piston Ring
10	Catch Stud
11	Hood Cap
12	Top Ring
13	Guide Rod
14	Hood
15	Holding Disc
16	Iron Disc for Hood
17	Spirit Cup
18	Spirit Chip
19	Catch Screw
20	Valve Seat
21	Center Socket (Upper End)
22	Center Socket (Lower End)
23	Handle
24	Pump Cap
25	Heating Coil Top (Upper End)
26	Heating Coil Top (Lower End)
27	Heating Coil Bottom Pipe
28	Heating Coil
29	Hex Nut
30	Nozzle Holder
31	Filler Mouth
32	Tee Piece

OPERATION ROUTE SHEETS

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time Hr.	Set up Time Min.
	1. Tank				
1	Circle Cutting	90 Ton Press	6	1	30
2	Forming	90 Ton Press	6	1	30
2A	Annealing	Furnace	-	-	-
3	Forming	90 Ton Press	6	1	30
4	Annealing	Furnace	-	-	-
5	Spinning (1st)	Spinning Machine	30	0	45
6	Annealing	Furnace	-	-	-
7	Spinning (2nd)	Spinning Machine	30	0	45
8	Trimming	Trimming Machine	30	0	45
9	Center Punching	Big Ball Press	30	1	00
10	Filler Mouth Punching	Big Ball Press	30	1	00
11	Pump Barrel Punching	Big Ball Press	30	1	00
12	Bidding for Pump Barrel	Big Ball Press	30	1	00
13	Bidding for Filler Mouth	Big Ball Press	30	1	00
13A	Name on tank	Stamping Machine	20	2	30
		Total	278	14	15

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
		2. Tank Bottom		Hr.	Min.
1	Circle Cutting	40 Ton Press	7	1	15
2	Forming	40 Ton Press	7	1	15
3	Trimming	Trimming Machine	30	0	45
		Total	44	3	15
		3. Pump Barrel			
1	Cut to size	Production Lathe	15	0	30
2	Threading	Production Lathe	20	0	30
		Total	35	1	00
		4. Inner Case			
1	Circle Cutting	40 Ton Press	12	1	15
2	Forming	40 Ton Press	7	1	15
3	Forming	40 Ton Press	7	1	15
4	Forming	40 Ton Press	7	1	15
5	Hammering	40 Ton Press	7	1	15
6	Trimming	Small Ball Press	30	0	45
7	Top Cutting leaving center portion as it is	40 Ton Press	10	1	15
8	3 Hole punching on top	40 Ton Press	10	1	15
9	2 Hole punching on top	40 Ton Press	10	1	15

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
10	Half bidding for Mixing Tube	40 Ton Press	8	1	15
11	Full bidding for Mixing Tube	40 Ton Press	8	1	15
12	Air pocket Punching	40 Ton Press	7	1	15
13	Side Notching (1st)	40 Ton Press	7	1	15
14	Side Notching (2nd)	40 Ton Press	7	1	15
		Total	137	17	00

5. Air Pocket

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Hr.	Min.
1	Blanking	20 Ton Press	15	1	30
2	Forming	40 Ton Press	10	1	15
3	Forming	20 Ton Press	15	1	30
4	Hammering	Small Ball Press	45	0	45
5	Cup Bending	Small Ball Press	45	0	45
6	Trimming All Sides	20 Ton Press	15	1	30
7	Hole on top	15 Ton Press	10	1	30
8	Hole in bottom	Small Ball Press	15	0	45
9	Bidding in Bottom Hole	Small Ball Press	15	0	45
10	Air pocket to be welded on inner casing on 4 sides	Spot Welding Machine	90	-	-
		Total	275	10	15

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	6. Air Pocket Chip			Hr.	Min.
1	Blanking	15 Ton Press	10	1	30
2	1st hole	15 Ton Press	8	1	30
3	2nd hole	15 Ton Press	8	1	30
4	3rd hole	15 Ton Press	8	1	30
5	Chip to be spot-welded on Air Pocket	Spot Welding Machine	60	-	-
		Total	94	6	00
	7. Chimney Seat				
1	Circle marking and cutting	By hand	120	-	-
2	Forming (1st)	90 Ton Press	6	1	30
3	Annealing	Furnace	-	-	-
4	Forming (2nd)	90 Ton Press	6	1	30
5	Annealing	Furnace	-	-	-
6	Forming (3rd)	90 Ton Press	6	1	30
7	Annealing	Furnace	-	-	-
8	Forming (4th)	90 Ton Press	6	1	30
9	Annealing	Furnace	-	-	-
10	Spinning (1st)	Spinning Machine	75	0	45

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
11	Annealing	Furnace	-	-	-
12	Spinning (2nd)	Spinning Machine	90	0	45
13	Body Trimming	Trimming Machine	30	0	45
14	Half Bidding	Trimming Machine	50	0	45
15	Full Bidding	Trimming Machine	50	0	45
16	Acid Wash	By Hand	45	-	-
17	Knife Polishing	Polishing Machine	120	0	15
18	Roller on Body	Trimming Machine	30	0	45
19	Bottom Punching	40 Ton Press	10	1	15
20	Bottom Bidding	Small Ball Press	20	0	45
21	4 holes for guide rod	Small Ball Press	25	0	45
22	25 small air holes	Auto-punching Machine	30	0	45
23	Hole for spirit	Small Ball Press	15	0	45
24	9 air holes at bottom	Auto-punching Machine	12	0	45
25	Tee Piece hole	Small Ball Press	20	0	45
26	Tee Piece hole bidding	Small Ball Press	20	0	45

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time Hr.	Set up Time Min.
27	Grinding at bottom	Grinding Machine	25	-	-
28	Filing	By hand	35	-	-
		Total	846	17	15
	8. Piston Rod				
1	Cutting rod to size	Capstan			
2	Threading on one end	Capstan	60	0	45
3	Threading on the other end	Capstan			
		Total	60	0	45
	9. Piston Ring				
1	Sizing				
2	Tapping	Capstan	45	0	45
3	Cutting				
		Total	45	0	45
	10. Catch Stud*				
1	Setting				
2	Cutting				
3	Threading	Capstan	100	1	00
4	Cutting				
5	Die for thread	By hand	40	-	-

*All times for 2 pieces

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
6	Filing	By hand	30	-	-
7	1st Drilling	Small drilling machine	10	0	30
8	2nd Drilling	Small drilling machine	10	0	30
		Total	190	2	00

11. Hood Cap

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
1	Circle marking and cutting	By hand	45	-	-
2	Forming (1st)	90 Ton Press	6	1	30
3	Annealing	Furnace	-	-	-
4	Forming (2nd)	90 Ton Press	6	1	30
5	Annealing	Furnace	-	-	-
6	Spinning	Spinning Machine	30	0	45
7	Trimming	Trimming Machine	25	0	45
8	Bidding	Trimming Machine	20	0	45
9	Acid wash	By hand	20	-	-
10	Knife polishing (Inside and Outside)	Polishing Machine	50	0	15
		Total	202	5	30

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	12. Top Ring			Hr.	Min.
1	Circle Marking and Cutting	By hand	50	-	-
2	Forming	40 Ton Press	10	1	15
3	Center Punching	40 Ton Press	10	1	15
4	Trimming	Trimming Machine	15	0	45
5	4 holes for Guide Rod	15 Ton Press	15	1	30
6	2 holes for Catch Stud	Small Drilling Machine	14	0	30
7	Filing	By hand	35	-	-
8	Acid wash	By hand	30	-	-
9	Knife polishing	Polishing Machine	40	0	15
		Total	219	5	30
	13. Guide Rod*				
1	Sizing	Capstan	192	1	00
2	Cutting				
3	Threading on one end				
4	Threading on the other end				
		Total	192	1	00

*All times for 4 pieces

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	14. Hood			Hr.	Min.
1	Circle Marking and Cutting	By hand	60	-	-
2	Forming (1st)	90 Ton Press	6	1	30
3	Annealing	Furnace	-	-	-
4	Forming (2nd)	90 Ton Press	6	1	30
5	Annealing	Furnace	-	-	-
6	Forming (3rd)	90 Ton Press	6	1	30
7	Annealing	Furnace	-	-	-
8	Forming (4th)	90 Ton Press	6	1	30
9	Annealing	Furnace	-	-	-
10	Spinning (1st)	Spinning Machine	60	0	45
11	Annealing	Furnace	-	-	-
12	Spinning (2nd)	Spinning Machine	60	0	45
13	Annealing	Furnace	-	-	-
14	Spinning (3rd)	Spinning Machine	45	0	45
15	Trimming	Trimming Machine	30	0	45
16	Bidding	Trimming Machine	25	0	45

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
17	1st Notching	Big Ball Press	15	1	00
18	2nd Notching	Big Ball Press	15	1	00
19	Air holes	Auto Punching Machine	55	0	45
20	Ventilator holes	Big Ball Press	35	1	00
21	Bidding on vent holes	Big Ball Press	35	1	00
22	2 Holes on top	Small drilling machine	20	0	30
23	Filing of holes	By hand	20	-	-
24	Acid wash	By hand	60	-	-
25	Knife Polish Inside	Polishing Machine	60	0	15
26	Knife Polish Outside	Polishing Machine	120	0	15
		Total	739	15	30

15. Holding Disc

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Hr.	Min.
1	Blanking	40 Ton Press	10	1	15
2	Forming	40 Ton Press	10	1	15
3	Center punching	40 Ton Press	10	1	15
4	Punching holes	40 Ton Press	10	1	15
		Total	40	5	00

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	16. Iron Disc for Hood			Hr.	Min.
1	Blanking and forming	40 Ton Press	10	1	15
2	Center hole punching	Small Ball Press	15	0	45
		Total	25	2	00
	17. Spirit Cup				
1	Blanking and forming	20 Ton Press	15	1	30
2	Annealing	Furnace	-	-	-
3	Half forming	Small Ball Press	25	0	45
4	Annealing	Furnace	-	-	-
5	Full forming	Small Ball Press	25	0	45
6	Trimming	20 Ton Press	15	1	30
		Total	80	4	30
	18. Spirit Chip				
1	Blanking	Big Ball Press	15	1	00
2	Punching one hole	Big Ball Press	15	1	00
3	Soldering of chip on Spirit Cup	By hand	45	-	-
		Total	75	2	00

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	19. Catch screw*			Hr.	Min.
1	Size	Capstan	180	1	45
2	Drill				
3	Drill				
4	Tapping				
5	Knurling				
6	Groove cutting				
7	Cutting				
8	Tap on bench-vise	By hand	240	-	-
	*All times for 2 pieces	Total	420	1	45
	20. Valve Seat				
1	Size	Capstan	80	1	45
2	Drill				
3	Tapping				
4	Airline				
5	Groove				
6	Polish				
7	Cutting				
		Total	80	1	45

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	21. Center Socket (Upper End)			Hr.	Min.
1	Set	Capstan	75	1	30
2	Blaze				
3	1st cutter				
4	2nd cutter				
5	Die				
6	Cutting				
7	Die on vice	By hand	25	-	--
		Total	100	1	30
	22. Center Socket (Lower End)				
1	Center Point	Capstan	100	1	30
2	Drill				
3	Cutter				
4	Airline				
5	Tapping				
6	Blaze				
		Total	100	1	30

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	23. Handle			Hr.	Min.
1	Straightening	Wire Straightening Machine	5	-	-
2	Cutting	Shearing Machine	5	-	-
3	Polishing	Polishing Machine	15	0	15
4	Side Bending	Jig & Fixture	20	-	-
5	Notching in center	Small Ball Press	30	0	45
6	Bending	Jig & Fixture	20	-	-
		Total	95	1	00
	24. Pump Cap				
1	Blanking and half forming	32 Ton Press	15	1	30
2	Annealing	Furnace	-	-	-
3	Full forming	32 Ton Press	15	1	30
4	Hammering	Small Ball Press	25	0	45
5	Trimming and Threading	Production Lathe	60	0	30
6	Knurling	Production Lathe	30	0	30
7	Center Punching	5 Ton Press	10	1	30
8	Notching on top	15 Ton Press	10	1	30
9	Center Punch Bidding	5 Ton Press	10	1	30
		Total	175	9	15

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
	25. Heating Coil Top (Upper End)			Hr.	Min.
1	Sizing				
2	Groove on Top				
3	Chiseling	Capstan	60	1	15
4	Tapping				
5	Cutting				
6	Filing	By hand	10	-	-
		Total	70	1	15
	26. Heating Coil Top (Lower End)				
1	Sizing				
2	Chiseling	Capstan	40	0	45
3	Drilling				
4	Drilling two holes on side	Small drilling machine	30	0	30
		Total	70	1	15
	27. Heating Coil Bottom Pipe				
1	Sizing	Capstan	25	0	30
2	Cutting				
3	Annealing	Furnace	-	-	-
4	Half Bidding	Big Ball Press	15	1	00

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
5	Annealing	Furnace	-	-	-
6	Full Bidding	Big Ball Press	15	1	00
7	Straightening	Big Ball Press	15	1	00
		Total	70	3	30

28. Heating Coil

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Hr.	Min.
1	Annealing	Furnace	-	-	-
2	Filling Sand				
3	Coiling of pipe	By hand	210	-	-
4	Cutting of Coils				
		Total	210	-	-

29. Hex Nut

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Hr.	Min.
1	Sizing				
2	Chiseling				
3	Drilling	Capstan	75	1	30
4	Tapping				
5	Grooving on top				
6	Cutting				
		Total	75	1	30

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
		30. Nozzle Holder		Hr.	Min.
1	Sizing				
2	Cutter				
3	Drilling				
4	Threading	Capstan	110	1	45
5	Cutter				
6	Drilling				
7	Threading				
8	Surface cleaning	Production Lathe	45	0	30
		Total	155	2	15
		31. Filler Mouth			
1	Blanking	32 Ton Press	10	1	30
2	Half forming	32 Ton Press	10	1	30
3	Annealing	Furnace	-	-	-
4	Full Forming	32 Ton Press	10	1	30
5	Hammering	15 Ton Press	10	1	30
6	Punching on top	15 Ton Press	10	1	30
7	Trimming	Production Lathe	20	0	30

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
8	Threading	Production Lathe	30	0	30
		Total	100	8	30

<u>32. Tee Piece</u>

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time Hr.	Set up Time Min.
1	Melting	Furnace	-	-	-
2	Casting	Special Die	15	-	-
3	Pressing	Special Ball Press	20	1	00
4	Trimming	Special Ball Press	15	1	00
5	Clipping	By hand	25	-	-
6	Annealing	Furnace	-	-	-
7	Hammering	Special Ball Press	15	1	00
8	Clipping	By hand	20	-	-
9	Filing	By hand	15	-	-
10	Sizing and Cutting				
11	Chog Drill	Capstan	90	1	00
12	Drill				
13	Die				

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
14	Filing				
15	Emery Polish				
16	Sizing and Cutting	Capstan	90	1	45
17	Chog Drill				
18	Drill				
19	Tap				
20	Drill				
21	Size Cutter				
22	Drill				
23	Drill	Capstan	120	1	30
24	Scrapping				
25	Filing				
26	Groove				
27	Size Cutter				
28	Cutter Die				
29	Chog Drill	Capstan	120	1	45
30	Drill				

Operation Number	Description of Operation	Name of Machine	Machining Time in Seconds	Set up Time	
				Hr.	Min.
31	Cutting				
32	Filing				
33	Drilling				
34	Tapping	By hand	30	-	-
		Total	575	9	00

Tank Soldering:

Soldering of filler mouth, center socket, pump barrel, tank bottom, bidding, second soldering, scrapping of solder - Average time: 240 Seconds per piece.

Plating:	Time for 10 units
1. Tank, Chromium plating	300 Seconds
2. Chimney seat, Chromium Plating	330 "
3. Hood, Chromium plating	250 "
4. Pump cap, Chromium plating	120 "
5. Holding Disc, Dull plating	180 "
6. Iron plate, Dull plating	150 "
7. Hood cap, Dull plating	130 "
8. Catch stud, Dull plating	90 "
9. Catch screw, Dull plating	90 "
10. Inner case, Dull plating	240 "
	Total 1880 Seconds
Time for one piece	188 Seconds

Assembly of Vapor Part:

The hex screw is inserted into the heating coil bottom which is fitted to the heating coil top. Heating coil is then assembled to the heating coil top, which is then soldered.

Average time 80 Seconds for assembly per piece
40 Seconds for soldering per piece

Assembly of Light:

Assemble chimney carrier on tank with the help of vapor, spirit cup, holding disc and a long screw. Then assemble inner casing along with the mixing tube, nozzle holder, nozzle and mangle. Then assemble hood and handle, test and pack. Average time for one unit 600 Seconds.

MACHINE OPERATION BREAK-DOWN

1. 90 TON PRESS Set-up time per operation - 1 hour 30 minutes

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Tank	1	6	
	2	6	
	3	6	18
Chimney Seat	2	6	
	4	6	
	6	6	
	8	6	24
Hood Cap	2	6	
	4	6	12
Hood	2	6	
	4	6	
	6	6	
	8	6	24
	Total time for the machine		78 seconds

2. FURNACE Set-up time per operation - 0

Time per operation - 4 hours 0 minutes

Tank	2A
	4
	6
Chimney Seat	3
	5
	7

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
	9		
	11		
Hood Cap	3		
	5		
Hood	3		
	5		
	7		
	9		
	11		
	13		
Spirit Cup	2		
	4		
Pump Cap	2		
Heating Coil Bottom Pipe	3		
	5		
Heating Coil	1		
Filler Mouth	3		
Tee-Piece	1		
	6		

3. SPINNING MACHINE Set-up time per operation - 0 hour 45 minutes

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Tank	5	30	
	7	30	60
Chimney Seat	10	75	
	12	90	165

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Hood Cap	6	30	30
Hood	10	60	
	12	60	
	14	45	165
	Total time for the machine		420 seconds

4. TRIMMING MACHINE Set-up time per operation - 0 hour 45 minutes

Tank	8	30	30
Tank Bottom	3	30	30
Chimney Seat	13	30	
	14	50	
	15	50	
	18	30	160
Hood Cap	7	25	
	8	20	45
Top Ring	4	15	15
Hood	15	30	
	16	25	55
	Total time for the machine		335 seconds

5. BIG BALL PRESS Set-up time per operation - 1 hour 0 minutes

Tank	9	30	
	10	30	
	11	30	
	12	30	
	13	30	150

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Hood	17	15	
	18	15	
	20	35	
	21	35	100
Spirit Chip	1	15	
	2	15	30
Heating Coil Bottom Pipe	4	15	
	6	15	
	7	15	45
	Total time for the machine		325 seconds

6. STAMPING MACHINE Set-up time per operation - 2 hour 30 minutes

Tank	13A	20	20
	Total time for the machine		20 seconds

7. 40 TON PRESS Set-up time per operation - 1 hour 15 minutes

Tank Bottom	1	7	
	2	7	14
Inner Case	1	12	
	2	7	
	3	7	
	4	7	
	5	7	
	7	10	
	8	10	
	9	10	
	10	8	

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
	11	8	
	12	7	
	13	7	
	14	7	107
Air-Pocket	2	10	10
Chimney Seat	19	10	10
Top Ring	2	10	
	3	10	20
Holding Disc	1	10	
	2	10	
	3	10	
	4	10	40
Iron Disc for Hood	1	10	10
	Total time for the machine		211 seconds

8. PRODUCTION LATHE — Set-up time per operation - 0 hour 30 minutes

Pump Barrel	1	15	
	2	20	35
Pump Cap	5	60	
	6	30	90
Nozzle Holder	8	45	45
Filler Mouth	7	20	
	8	30	50
	Total time for the machine		220 seconds

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
9. SMALL BALL PRESS	Set-up time per operation - 0 hour 45 minutes		
Inner Case	6	30	30
Air Pocket	4	45	
	5	45	
	8	15	
	9	15	120
Chimney Seat	20	20	
	21	25	
	23	15	
	25	20	
	26	20	100
Iron Disc for Hood	2	15	15
Spirit Cup	3	25	
	5	25	50
Handle	5	30	30
Pump Cap	4	25	25
	Total time for the machine		370 seconds
10. 20 TON PRESS	Set-up time per operation - 1 hour 30 minutes		
Air pocket	1	15	
	3	15	
	6	15	45
Spirit Cup	1	15	
	6	15	30
	Total time for the machine		75 seconds

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
11. SPOT-WELDING MACHINE	Set-up time per operation = 0		
Air Pocket	10	90	90
Air Pocket Chip	5	60	60
	Total time for the machine		150 seconds
12. 15 TON PRESS	Set-up time per operation - 1 hour 30 minutes		
Air Pocket	7	10	10
Air Pocket Chip	1	10	
	2	8	
	3	8	
	4	8	34
Top Ring	5	15	15
Pump Cap	8	10	10
Filler Mouth	5	10	
	6	10	20
	Total time for the machine		89 seconds
13. POLISHING MACHINE	Set-up time per operation - 0 hour 15 minutes		
Chimney Seat	17	120	120
Hood cap	10	50	50
Top Ring	9	40	40
Hood	25	60	
	26	120	180
Handle	3	15	15
	Total time for the machine		405 seconds

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
14. AUTO-PUNCHING MACHINE	Set-up time per operation - 0 hour 45 minutes		
Chimney Seat	22	30	
	24	12	42
Hood	19	55	55
	Total time for the machine		97 seconds
15. GRINDING MACHINE	Set-up time per operation - 0		
Chimney Seat	27	25	25
	Total time for the machine		25 seconds
16. SMALL DRILLING MACHINE	Set-up time per operation - 0 hour 30 minutes		
Catch Stud	7	10	
	8	10	20
Top Ring	6	14	14
Hood	22	20	20
Heating Coil Top (Lower End)	4	30	30
	Total time for the machine		84 seconds
17. 5 TON PRESS	Set-up time per operation - 1 hour 30 minutes		
Pump Cap	7	10	
	9	10	20
	Total time for the machine		20 seconds
18. 32 TON PRESS	Set-up time per operation - 1 hour 30 minutes		
Pump Cap	1	15	
	3	15	30

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Filler Mouth	1	10	
	2	10	
	4	10	30
	Total time for the machine		60 seconds

19. SPECIAL BALL-PRESS Set-up time per operation - 1 hour 0 minute

Tee-Piece	3	20	
	4	15	
	7	15	50
	Total time for the machine		50 seconds

20. CAPSTAN LATHE Set-up time per operation - 0 hour 15 minutes

Piston Rod	1-3	60	60
Piston Ring	1-3	45	45
Catch Stud	1-4	100	100
Guide Rod	1-4	192	192
Catch Screw	1-7	180	180
Valve Seat	1-7	80	80
Center Socket (Upper End)	1-6	75	75
Center Socket (Lower End)	1-6	100	100
Heating Coil Top (Upper End)	1-5	60	60
Heating Coil Top (Lower End)	1-3	40	40
Heating Coil Bottom Pipe	1-2	25	25
Hex Nut	1-6	75	75
Nozzle Holder	1-7	110	110

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Tee-Piece	10-13	90	
	14-20	90	
	21-26	120	
	27-33	120	420
	Total time for the machine		1562 seconds

21. WIRE STRAIGHTENING MACHINE Set-up time per operation - 0

Handle	1	5	5
	Total time for the machine		5 seconds

22. SHEARING MACHINE Set-up time per operation - 0

Handle	2	5	5
	Total time for the machine		5 seconds

23. JIG AND FIXTURE Set-up time per operation - 0

Handle	4	20	
	6	20	40
	Total time for the machine		40 seconds

24. SPECIAL DIE Set-up time per operation - 0

Tee-Piece	2	15	15
	Total time for the machine		15 seconds

25. OPERATIONS DONE BY HAND Set-up time per operation - 0

Chimney Seat	1	120	
	16	45	
	28	35	200

Name of Component	Operation Number	Time Per Operation in Seconds	Total Time Per Component in Seconds
Catch Stud	5	40	
	6	30	70
Hood Cap	1	45	
	9	20	65
Top Ring	1	50	
	7	35	
	8	30	115
Hood	1	60	
	23	20	
	24	60	140
Spirit Chip	3	45	45
Catch Screw	8	240	240
Center Socket (Upper End)	7	25	25
Heating Coil Top (Upper End)	6	10	10
Heating Coil	2-4	210	210
Tee-Piece	5	25	
	8	20	
	9	15	
	34	30	90
	Total time per component		1210 seconds

APPENDIX B

Table 1. Determination of Economic Lot Size

Serial Number	Name of Component	Cost in Rs. Set-up cost, s	Material cost, m	Labor cost, l	Over-head, O, on running time	Constant cost C=m+l+O	S/C	$Q_m = \sqrt{\frac{2a_c S}{I}}$
1	Tank	16.0312	4.9400	0.0579	0.2721	5.2700	3.04	666
2	Tank Bottom	3.6562	3.6240	0.0091	0.0430	3.6761	0.99	381
3	Pump Barrel	1.1250	0.9000	0.0072	0.0341	0.9413	1.19	417
4	Inner Case	19.1250	0.5000	0.0285	0.1343	0.6628	28.97	2052
5	Air Pocket	11.5312	0.0680	0.0573	0.2696	0.3949	29.56	2066
6	Air Pocket Chip	6.7500	0.0210	0.0195	0.0920	0.1325	51.92	2739
7	Chimney Seat	19.4062	2.5870	0.1764	0.8290	3.5924	5.40	880
8	Piston Rod	0.8437	0.2420	0.0124	0.0585	0.3129	2.72	637
9	Piston Ring	0.8437	0.0520	0.0093	0.0440	0.1053	8.43	1082
10	Catch Stud (2)*	2.2500	0.1880	0.0396	0.1861	0.4137	5.48	892
11	Hood Cap	6.1875	1.1620	0.0420	0.1977	1.4017	4.41	803
12	Top Ring	6.1875	1.6640	0.0456	0.2146	1.9242	3.22	685
13	Guide Rod (4)*	1.1250	0.8920	0.0400	0.1882	1.1202	1.00	382
14	Hood	17.4375	3.6750	0.1537	0.7226	4.5513	3.83	748
15	Holding Disc	5.6250	0.1340	0.0083	0.0391	0.1814	31.25	2131
16	Iron Disc for Hood	2.2500	0.0650	0.0051	0.0243	0.0944	25.00	1876
17	Spirit Cup	5.0625	0.1550	0.0322	0.1515	0.3387	22.15	1778
18	Spirit Chip	2.2500						
19	Catch Screw (2)*	1.9687	0.2490	0.0876	0.4117	0.7483	2.66	619
20	Valve Seat	1.9687	0.1620	0.0166	0.0782	0.2568	7.87	1058
21	Center Socket (Upper End)	1.6875	0.3190	0.0416	0.1956	0.5562	6.13	940
22	Center Socket (Lower End)	1.6875						
23	Handle	1.1250	0.1200	0.0198	0.0930	0.2328	4.89	834
24	Pump Cap	10.4062	0.1450	0.0364	0.1713	0.3527	29.73	2076
25	Heating Coil Top	1.4062	0.4420	0.0291	0.1371	0.6082	4.68	820
26	(Upper End)							
26	Heating Coil Top (Lower End)	1.4062						
27	Heating Coil Bottom Pipe	3.9375	0.4980	0.0146	0.0687	0.5813	6.78	994
28	Heating Coil	-	0.6700	0.0438	0.2058	0.9196	-	-
29	Hex Nut	1.6875	0.0780	0.0156	0.0733	0.1669	10.54	1212
30	Nozzle Holder	2.5312	0.3400	0.0323	0.1519	0.5242	4.86	840
31	Filler Mouth	9.5625	0.2100	0.0208	0.0979	0.3287	29.88	2060
32	Tee Piece	10.1250	1.2350	0.1198	0.5632	1.9180	5.30	878
		177.1869	25.3370	1.2221	5.7484	32.3075	5.48	

Q_m for the final product $= \sqrt{\frac{2a_c S}{I}} = \sqrt{\frac{2 \times 40 \times 177.1889}{5.479 \times 10^{-4} \times 32.3075}}$ = 895 Units

*Number in the parenthesis represents number of pieces going into one unit of final product.

Table 2. Determination of optimal batch size considering the whole production schedule.

Serial Number	Name of Components	Q_{mi}	Set up Cost, s_i	$K_i = \frac{Ii}{2a_{ci}}$	$g_i = \sqrt{\frac{\Sigma S/S_i}{\Sigma K/K_i}}$	$Qi_M = g_i Q_{mi}$
1	Tank	666	16.0312	0.3609	1.343	895
2	Tank Bottom	381	3.6562	0.2517	2.350	894
3	Pump Barrel	417	1.1250	0.0644	2.146	895
4	Inner Case	2052	19.1250	0.0453	0.435	893
5	Air Pocket	2066	11.5312	0.0270	0.432	893
6	Air Pocket Chip	2739	6.7500	0.0090	0.325	890
7	Chimney Seat	880	19.4062	0.2460	1.007	886
8	Piston Rod	637	0.8437	0.0214	1.428	910
9	Piston Ring	1082	0.8437	0.0072	0.828	896
10	Catch Stud (2)*	892	2.2500	0.0283	1.003	895
11	Hood Cap	803	6.1875	0.0959	1.115	895
12	Top Ring	685	6.1875	0.1317	1.306	894
13	Guide Rod (4)*	382	1.1250	0.0767	2.342	895
14	Hood	748	17.4375	0.3117	1.197	895
15	Holding Disc	2131	5.6250	0.0124	0.419	893
16	Iron Disc for Hood	1876	2.2500	0.0064	0.476	893
17 18	Spirit Cup Spirit Chip	1788	7.3125	0.0231	0.503	894
19	Catch Screw (2)*	619	1.9687	0.0512	1.446	895
20	Valve Seat	1058	1.9687	0.0175	0.845	894
21 22	Center Socket (Upper End) Center Socket (Lower End)	940	3.3750	0.0380	0.950	893
23	Handle	834	1.1250	0.0159	1.066	889
24	Pump Cap	2076	10.4062	0.0241	0.430	893
25 26	Heating Coil Top (Upper End) Heating Coil Top (Lower End)	820	2.8124	0.0416	1.089	893
27	Heating Coil Bottom Pipe	994	3.9375	0.0398	0.900	895
28	Heating Coil	-	-	0.0629	-	-
29	Hex Nut	1212	1.6875	0.0114	0.737	893
30	Nozzle Holder	840	2.5312	0.0359	1.066	895
31	Filler Mouth	2060	9.5625	0.0225	0.434	894
32	Tee Piece	878	10.1250	0.1313	1.020	896
			177.1250	2.2112		

*Number in the parenthesis represents number of pieces going into one unit of final product.

Table 3. Determination of Production Range

Serial Number	Name of Component	Q_m	P = 1.05: $Q_1=Q_m X.773$	P = 1.05: $Q_2=Q_m X1.37$	P = 1.10: $Q_1=Q_m X.642$	P = 1.10: $Q_2=Q_m X1.558$	Q_{iM}	Within 5% Range	Within 10% Range
1	Tank	666	486	913	428	1038	895	900	
2	Tank Bottom	381	278	521	244	593	894	450	
3	Pump Barrel	417	304	571	268	650	895	450	
4	Inner Case	2052	1498	2811	1317	3197	893	2700	
5	Air Pocket	2066	1508	2831	1326	3219	893	2700	
6	Air Pocket Chip	2739	1999	3752	1758	4267	890	2700	
7	Chimney Seat	880	642	1206	565	1371	886	900	
8	Piston Rod	637	465	873	409	993	910		900
9	Piston Ring	1082	790	1482	695	1686	896	900	
10	Catch Stud (2)*	892	652	1223	573	1391	895	900	
11	Hood Cap	803	586	1100	515	1251	895	900	
12	Top Ring	685	499	938	440	1067	894	900	
13	Guide Rod (4)*	382	279	524	245	596	895	450	
14	Hood	748	546	1025	480	1165	895	900	
15	Holding Disc	2131	1556	2919	1368	3320	893	2700	
16	Iron Disc for Hood	1876	1369	2570	1204	2923	893		2700
17	Spirit Cup	1778	1298	2436	1141	2770	894		2700
18	Spirit Chip								
19	Catch Screw (2)*	619	452	848	397	964	895		900
20.	Valve Seat	1058	772	1449	679	1648	894	900	
21	Centre Socket (Upper End)	940	686	1288	604	1465	893	900	
22	Centre Socket (Lower End)								
23	Handle	834	609	1143	535	1299	889	900	
24	Pump Cap	2076	1515	2844	1333	3234	893	2700	
25	Heating Coil Top (Upper End)	820	599	1123	526	1278	893	900	
26	Heating Coil Top (Lower End)								
27	Heating Coil Bottom Pipe	994	726	1362	638	1549	895	900	
28	Heating Coil	-	-	-	-	-	-	---	
29	Hex Nut	1212	885	1660	778	1888	893	900	
30	Nozzle Holder	840	613	1151	539	1309	895	900	
31	Filler Mouth	2060	1504	2822	1323	3209	894	2700	
32	Tee Piece	878	641	1203	564	1368	896	900	
FINAL PRODUCT		895	654	1223	575	1392	895	900	

* Number in the parenthesis represents number of pieces going into one unit of final product.

APPENDIX C

Gantt Chart for the Problem

GANTT CHART FOR A STANDARD LOT SIZE OF 900 UNITS

APPENDIX D

Graph Showing Labor Force Requirement


LEGEND
TOTAL LABOR FORCE REQUIREMENT
NUMBER OF WORKERS FOR HAND OPERATIONS
NUMBER OF SET-UP MEN
NUMBER OF WORKERS
TIME IN HOURS

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APPLICATION OF A MANUAL SCHEDULING TECHNIQUE TO A PARTICULAR MANUFACTURING PROBLEM

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ABSTRACT

This report deals with the scheduling problem of a particular type of industry involved in an intermittent type of production. The problem was to determine the optimal batch size (based on minimum total combined set-up and inventory carrying cost) of the final product, with the data collected from a factory and then to prepare a schedule which shows all the phases of production in detail.

Since the final product is an assembly made of several components, the theory of multi-product batch size determination was utilized in arriving at the optimal batch sizes of the components and of the final product. After allowing a certain percentage increase above the minimum total production costs, a batch size of 900 was selected which fell within the production range of the most of the components and of the final product. A Gantt chart was drawn next to represent all the production activities in detail. Some difficulties had to be overcome in drawing the Gantt chart.

This Gantt chart gives only one of the many feasible solutions and may not be an optimum. A graph was drawn to show that the hour-to-hour labor force requirement fluctuated a great deal - suggesting that this requirement be levelled before this schedule could be put to practice. However, it could be taken as the first step in scheduling the production of the factory concerned. Some modifications could be suggested to improve upon and make it more realistic.