CHAPTER II

LEAD TIME ESTIMATION

2.1 INTEGRATED MANUFACTURING LAYOUT

The main objective of production scheduling in mass production systems is to maximise the machine utilisation.

Eventhough this performance measure can be very useful in machine shops this scheduling approach cannot improve the performance of other related areas of production where there is inordinate delay in processing the make-to-order jobs for limited quantities.

Conventional production layouts are well managed with hierarchical controls as shown in Fig. 2.1. This hierarchy is well suited for mass production system where specialised skill is the performance measure at the shopfloor level. The main handicap of a specialised shopfloor decision maker would be his incapability in the planning and coordination function which is always exercised by higher level strategic decision maker. Make to order jobs need more planning and coordination between shopfloor decision makers of various stages. In order to achieve this the manufacturing unit is to be restructured into integrated cellular layout as shown in Fig. 2.2.

The layout consists of self contained cells as follows: (1) demand cell, (2) design cell, (3) Process planning cell, (4) manufacturing cell and (5) delivery cell.

2.2 PROCESS PLANNING AND PROCESSING TIMES

The higher level decision makers of operations planning have to decide the questions of when, who and where in a production environment based on a specified due date and available resources.
Therefore higher level macro process plans are required to act as a link between marketing and manufacturing. How the processes can be completed at each stage has to be precisely decided. The primary objective is to define all the feasible processes of all stages and optimally select them from the available resources with their constraints. Estimated processing times are included as part of the process plans.

In the present work, a module called MAcro Process Planner (MAPP) in the prototype Knowledge Based Expert System (KBES) has been designed to generate macro level process plans for make-to-order demands in a job shop manufacturing system. The flow chart for the program is shown in Fig. 2.3 and the further details of the programme are elaborated with reference to the following outputs being generated:

(1) The demand schedule indicates the marketing activities such as identification of demand and submission of quotations.

(2) The design schedule gives guidelines for designing the job as per the specifications.

(3) The process schedule selects the processing times for all the stages from demand identification to job delivery.

(4) The delivery schedule selects the plans for delivery of the job as per quotations submitted.

(5) The operations schedules are prepared for all the stages to plan all the details of activities for the job completion.

(6) The inspection schedules are prepared for all the stages to plan in-built quality assurance mechanisms for all operations.
The maintenance schedules are prepared for all the stages to plan in-built preventive maintenance measures for all the stages to have a safe and reliable manufacturing system.

Processing time for each stage has been obtained as a part of the output of the program in the process schedule. For convenience a day is taken as the standard time unit throughout the present work. Assuming that the manufacturing organisations are working only single shift with 8 hours per shift, one hour of processing time have been considered as 0.125 time unit. A part of an hour has been considered as one hour.

2.3 MANUFACTURING LEAD TIME

For managing the manufacturing operations of mass production systems, one of the main objectives was to minimise the mean processing times of all operations. This type of system performance measures were very useful for improving the efficiency of the individual operations, but they have been proved to be ineffective when the performance measures are based on total completion time for fulfilling the requirements of demands for make-to-order jobs.

Lead time is a performance measure defined as the time calculated from allotment of the job in a manufacturing unit to the completion of delivery of the job as per ordered specifications. In an ideal manufacturing system isolated from environmental distractions the lead time can be equal to processing time as estimated in the process plan. But in reality jobs consume more time in the manufacturing unit than the estimated processing time. Researchers have attempted to identify the problems for this gap between lead times and processing times.
and as the solutions proposed were only of marginal utility most of the production managers manage their manufacturing operations by living with this problem.

Manufacturing lead times in intermittent job shop systems are often very long. Yet the actual processing times on all the machines on which the job has to be processed are usually quite small. The manufacturing lead times are dominated by the transit times between operations. This is demonstrated by the speed with which urgent orders can be expedited through the system when required.

It is observed that an increased rate of incoming customer orders inflates lead times and the planning values for lead times are updated to reflect the latest situation in the shop. Hence longer lead times are quoted and the customers react by releasing more orders to cover the requirements during the increased lead times. This will further inflate the lead time, which will necessitate to increase the shop capacity. This will make a reduction in lead time and then customers release fewer orders. Then the capacity is to be decreased and the cycle starts again. This vicious cycle is termed as 'lead time syndrome'. A manufacturing system incapable of responding quickly and precisely to actual processing times will have to waste time and other resources for managing this lead time syndrome.

In the past efforts were made to identify the factors and procedures influencing manufacturing lead time in order to formulate systematic methods for lead time estimation.

At the long term planning level lead times are in aggregate determined by factors like product structure, the production
process and the layout of the production facilities. Therefore the lead time estimation was treated as a forecasting problem with an emphasis on accurate forecasting and then developing a planning routine to minimise the impact of forecast errors.

Additional slack time in the lead time is commonly recommended as an improvement measure for the reasons of (i) to catch up the operations which falls behind (ii) to allow for regular preventive maintenance and (iii) to allow for improvement of operations. This approach will necessitate additional capacity investments.

Another method [57] applied to calculate lead times on the basis of the jobs processing time, multiplied by some empirical factors. Jobs are given flow allowances that are proportional to the total work required. The method relies on an information base consisting of the parameters describing the individual jobs to which a manufacturing lead time is assigned. In the present work an approach based on this method has been considered for formulating an optimisation problem in order to minimise the lead time based on the processing time multiplied by some empirical factors. The details of the empirical factors are elaborated in the following sections.

2.4 SET UP FACTOR

The time spend for arranging the set up of a process will increase the completion time of job in a job shop manufacturing system. One of the main objectives of automation was to reduce set up time and to have economic and faster mass production systems. The main disadvantage of automation with special purpose machines (SPM) is the rigidity of this non flexible manufacturing
systems. The rigidity became a capacity constraint when the facilities became technologically obsolete for developing new jobs at a competitive lead time. Therefore the mechanised rigid automation systems were replaced by advanced manufacturing technologies to increase the flexibility in the manufacturing systems. This type of systems were found more useful for job shop manufacturing especially for make-to-order demands.

In the regular performance measures of processing time based schedules the set up time was neglected. It is difficult to estimate the set up time for each operation separately. However in a manufacturing system with fast processing facilities the total time for completion time of the job will be lesser than compared to a shop with slow processing systems. Keeping this fact in view a relationship for set up factor is established to estimate the lead time as a multiple of the processing time. The set up factor is a ratio of the number of set up available in the system and the maximum number of types of products that can be produced in the system. The relationship is given below:

\[
\text{Set up factor } (P) = \frac{(P_1)^c}{P_2}
\]

Where \( P_1 \) is the number of types of products produceable in a cell and \( P_2 \) is the number of set up available in the system. 'c' is an exponent to indicate the complexity of a job.

The above formulation is based on the following assumptions:

- In the rigid transfer lines the processing times are equal to the lead times. The characteristic of these systems are its special product and number of set ups in a transfer line.
- As the number of types of products in a manufacturing system
increases and the number of set up readily available are reduced, the gap between processing time and lead time increases.

For the present work 'c' is assumed to be 1. 'c' will indicate the additional time required in setting up as the flexibility of the system increases.

Table 2.1 to Table 2.4 show the typical values of set up factor calculated on the basis of number of types of products produceable in the system using above concept. Table 2.5 gives the assumed values of set up factor for manufacturing systems based on physical system classification.

2.5. QUALITY FACTOR

The necessity for continuous improvement in the manufacturing systems as a competitive strategy has changed the quality benchmarks. The additional quality assurance related activities can be for improving the product quality or system quality.

Product quality assurance mechanisms will be concentrated on improvement of quality of specific products and it will add up the time for completion of the job.

System quality assurance mechanism will be based on measures for improving the total manufacturing systems. Implementation of ISO 9000 series specifications is one of the proved method for improving system quality. Even though the total completion time for jobs maybe reduced after successful implementation of system quality standards, the additional quality audit activities related to quality assurance will initially increase the completion time of the job.

This aspect of quality related increase in lead times were
neglected in the past. It was also difficult to estimate the quality related time for each operation separately. However in a manufacturing system with fast processing facilities the total time for completion time of the job will be lesser than compared to a shop with slow processing systems. Keeping this fact in view, a relationship for quality factor is established to estimate the lead time as a multiple of a processing time.

The total parameters on a job to be controlled for quality are divided into parameters controlled by product quality assurance mechanisms and parameters controlled by system quality mechanisms. Quality factor is defined as a ratio of number of total parameters and number of parameters controlled by system quality.

The relationship is given below:

\[ \text{Quality Factor (Q)} = \frac{(Q_1^d + Q_2)}{Q_2} \]  

Where \( Q_1 \) = Number of parameters for quality assurance based on specific products.

\( Q_2 \) = Number of parameters for quality assurance based on system quality.

\( d \) = An exponent for job specific characteristics

\[ Q = 1 + \frac{(Q_1^d + Q_2)}{Q_2} = 1 + \frac{(Q_1^d)}{Q_2} \]  

(2.3)

When the product quality characteristics are independent value of \( 'd' \) will be assumed to be 1. If the product quality is dependent on other parameters the value of \( 'd' \) will be increased (such as assembly with another job etc) correspondingly.

As the automation level increases the parameters controlled by system quality will increase and there will be no requirement
for separate product quality inspections.

The above formulation is based on the following assumptions:

-- The manufacturing systems maintaining and improving system quality will have lesser lead time as the number of jobs increases.

-- The manufacturing systems striving to maintain product quality will increase the lead time as the number of types of job increase.

Product quality assurance mechanisms are to be maintained independently up to higher level decision makers of the organisational hierarchy, whereas system quality assurance mechanisms impose the responsibility of improving quality as an integrated part of processing.

Sample values for quality factor \( Q \) for selected values of \( Q_1 \) and \( Q_2 \) are given in Table 2.6 and Table 2.7.

2.6 LIMITING FACTORS

When the manufacturing lead time is considered as a competitive strategy it is essential to have proper control of lead time. Towards this objective the lead time will be restricted to a competitive level. The time gap between the manufacturing lead time and processing time of the operations is an indicator for area for improvement in the system. In order to avoid deterioration of system performance the maximum and minimum limiting values for the lead time factors are defined interdependently.

2.6.1 Minimum lead time factor

This will be the minimum value for lead time factor. In ideal conditions the manufacturing lead time should be equal to the
processing times. But the lead time value in reality will be much higher. The gap has to be accommodated in manufacturing lead time estimation initially as a limiting factor and gradually efforts are to be made to reduce the minimum limiting factor through continuous improvements in the manufacturing system. The minimum limiting factor is denoted by $r_{\text{min}}$ and the value for the present work is assumed as shown in Table 2.8.

The value of minimum limiting factor is the limiting value for quality factor and set up factor expressed as shown below:

$$P + Q \geq r_{\text{min}}$$  \hspace{1cm} (2.4)

2.6.2 **Maximum Lead Time Factor**

The maximum value for the lead time factor is to be predetermined based on set up and quality requirements. The value is represented by $r_{\text{max}}$. A high value of $r_{\text{max}}$ will lead to earliness of completed jobs or increased work-in-process (WIP).

The value of maximum limiting factor is the limiting value for quality factor and set up factor expressed as shown below:

$$P + Q \leq r_{\text{max}}$$  \hspace{1cm} (2.5)

2.6.3 **Minimum interdependent factor**

This factor will control the minimum requirement of interdependency between the set up factor and quality factor. The value is represented by $s_{\text{min}}$. The interdependency is established with the following relation:

$$\text{Set up time} + \text{Processing time} = \text{Time for quality}$$  \hspace{1cm} (2.6)

For manufacturing systems based on system quality this quality related time will be allotted for in built quality improvements. Considering Equation (2.6) in terms of lead time factors:
\[
(P \times PT) + PT = (Q \times PT) \quad (2.7)
\]
\[
(Q - P) \times PT = PT \quad (2.8)
\]
\[
Q - P = 1 \quad (2.9)
\]

The above limiting factors are desired based upon the job and shopfloor conditions. There will be other restrictions due to trial setting and trial machining on dummy materials to avoid loss of precious materials. Resetting and trial machining related time will be proportional to the initially estimated set up factor. Similarly jobs which are found incomplete as per specification after quality checks are to be reprocessed. This will necessitate re-inspection, which will further add up lead time. The following notations are used for representing this aspects and they will be used as coefficients of the lead time factors:

- \( R_1 \) = Reset time factor as coefficient of set up factor
- \( R_2 \) = Rework time factor as coefficient of quality factor

For jobs without resetting and rework the value of \( R_1 \) and \( R_2 \) will be 1. For other jobs these values will be assigned as per the processing conditions.

2.7 LINEAR PROGRAMMING PROBLEM

The benefits of having more set up facilities and effective quality assurance mechanisms will be advantageous in a make-to-order job shop manufacturing system if it could complete processing of all ordered jobs within the specified minimum time. These conflicting objectives of the system can be modeled as a Linear Programming Problem (LPP). In the present work a LPP is formulated to find out the optimal lead time factor.

The objective function 'Z' minimises a sum of lead time factors subject to the constraints of limiting values of the lead
time factors.

The following notations are used in the formulation:

\( x_1 \) : Set up factor
\( x_2 \) : Quality factor
\( p_{\text{max}} \) : Maximum value of set up factor
\( p_{\text{min}} \) : Minimum value of set up factor
\( q_{\text{ax}} \) : Maximum value of quality factor
\( r_{\text{max}} \) : Maximum limiting factor
\( r_{\text{min}} \) : Minimum limiting factor
\( s_{\text{min}} \) : Minimum interdependency factor
\( R_1 \) : Coefficient of set up factor
\( R_2 \) : Coefficient of quality factor

The LPP is formulated for one stage as follows:

\[
\text{Min } Z = R_1 x_1 + R_2 x_2
\]  

(2.10)

Subjected to

\[ x_1 \leq p \]  
(2.11)

\[ x_2 \leq q_{\text{ax}} \]  
(2.12)

\[ x_1 + x_2 \geq r_{\text{min}} \]  
(2.13)

\[ x_1 + x_2 \leq r_{\text{max}} \]  
(2.14)

\[ x_2 - x_1 \geq s_{\text{min}} \]  
(2.15)

\[ x_1 \geq p_{\text{min}} \]  
(2.16)

For all the five stages the problem can be formulated as follows:

\[
\text{Min } Z_{\text{mini}} = \sum_{m=1}^{5} \left[ p_{\text{T}}( R_1 x_1 + R_2 x_2 ) \right]
\]  

(2.17)

Subjected to

\[ x_{1m} \leq p_{(m)\text{max}} \]  
(2.18)

\[ x_{2m} \leq q_{(m)\text{max}} \]  
(2.19)

\[ x_{1m} + x_{2m} \geq r_{(m)\text{min}} \]  
(2.20)
\[
X_{1m} + X_{2m} \leq r(m)_{\text{max}} \\
X_{2m} - X_{1m} \geq s(m)_{\text{min}} \\
X_{1m} \geq p(m)_{\text{min}}
\]

Based on the optimal values of the lead time factor the lead time can be estimated as follows:

\[
MLT_m = PT_m * Z_m
\]  
\[
MLT_j = \sum_{m=1}^{5} LT_m
\]

2.8 SIMULATION ANALYSIS

The solution of LPP will provide a single optimal lead time estimate. For the benefit of flexibility in planning it is essential to have a tolerance range for the fixed lead time. For this purpose a simulation program was developed considering the estimated lead time as a random variable. The lead time estimates are considered stochastic as assumed in queueing models. Therefore the generally accepted exponential distribution is considered for simulation of lead time estimation. The exponential lead time was randomised with the following equation:

\[
MLT = PT * Z
\]
\[
LAMDA = 1/MLT
\]
\[
RLT = -1/LAMDA * ALOG(RN)
\]

Where LAMDA is the inverse of the expected lead time, RN is a random number in the range of 0 to 1 and LT is the estimated exponential processing time for the stage based on the modified values of the objective function. RLT is the randomised lead time. One simulation trial had 1000 runs. And the following statistics were recorded from the results of 1000 runs.

\[
LTLOW = \text{Lowest value of manufacturing lead time in the simulation trial}
\]
LTHIGH = Highest value of manufacturing lead time in the simulation trial

LTMEAN = LTSUM/NRUNS  \hspace{1cm} (2.31)

Where LTMEAN is the average lead time and LTSUM is the sum of lead time of total runs (ie NRUNS).

SIGMA = Standard deviation of LTMEAN

A frequency distribution histogram for the lead times were also developed with the statistics obtained from the simulation runs.

2.9 NUMERICAL EXAMPLE

In order to illustrate the lead time estimation methodologies a make-to-order demand for a gauge (Fig. 2.5) for measuring the positional tolerances of a job shown in Fig.2.4 has been considered. The quotation for the gauge manufacturing to be submitted to the customer after estimating the lead time for following activities in an integrated manufacturing layout.

The macro process plans for the job was developed in the MAPP program to obtain the following outputs:

-- The demand schedule for the marketing decision (Fig. 2.6).
-- The design schedule for planning the design (Fig. 2.7).
-- The process planning schedule for estimating the processing times at each stage (Fig. 2.8).
-- The delivery schedule for the despatch program (Fig. 2.9).
-- The operation schedule (Fig. 2.10), the maintenance schedule (Fig. 2.11) and the inspection schedule (Fig. 2.12) are shown for turning operation in the manufacturing stage and these three schedules are prepared for all other operations in the manufacturing stage. The maintenance schedule will show in
built preventive maintenance planning and safety precautions included in the systems. The inspection schedules will be an indicator for the in built quality systems. The processing times for each stage obtained from these macro-process plans will be considered as input data for further illustrating the numerical example.

After generating the demand for a make-to-order job a quotation will be offered with a precisely estimated lead time. In an integrated lay out as shown in Fig. 2.2 the demand cell will coordinate the order management in consultation with all other stages. After identifying the job requirements the design for the gauge has to be finalised. According to the design the process plans have to be prepared considering the feasibility of operations in the shopfloor. The manufacturing cell will realise the shape and delivery cell will arrange for packaging and despatch to the customers. The values shown in Table 2.9 are taken as input values for solving the problem using LINDO package [77] and the results obtained after solving the problem are shown in Table 2.10.

Solution of linear programming problem provides the optimal values for the objective function based on the optimal values for the constant variables. But the shopfloor conditions may have limitations to maintain the optimal values.

The simulation program developed has the facility to alter the values of lead time factors \( X_1 \) and \( X_2 \) and their coefficients \( R_1 \) and \( R_2 \). These factors of all the five stages can be alternatively changed and simulation trials can be carried out with 1000 runs. The results of these trials have been analysed for
better insight of the effect of lead time factors. For easy assessment of the effectiveness of the changes in the lead time factors and their coefficients, the simulation statistics from the trails are tallied with the statistics obtained from the trial run with optimal values of lead time factors as bench mark. The source code for the simulation program is developed in FORTRAN and the flowchart for the program is given in Fig. 2.13.

The optimal values obtained from LPP solution were used as input in the simulation model and one trial consisted of 1000 runs. The results of the 1000 runs were obtained in the output as shown in Fig. 2.20.

Simulation trials were repeated by varying the values of setup factor and quality factors for each stage. Result obtained from the simulation trial with optimal values as input data is considered as bench mark and the results from other trials are tallied with it in Table 2.11.

The relative frequency and the cumulative frequency of lead time values obtained with optimal values are plotted in graphs shown in Fig. 2.14 to Fig. 2.19.

2.10 SUMMARY

Preparation of macro process plans for all stages of the integrated manufacturing layout is essential for estimating processing times of all operations of demand, design, process planning, manufacturing and delivery stages of a make-to-order job in a job shop manufacturing system. A module MAPP has been included in the prototype knowledge based expert system to generate the macro process plans. Processing times of all operations are available in the macro process plans generated as
output of the MAPP program.

The relation between processing times and manufacturing lead
time is established by formulating flexibility factor and quality
factor as lead time factors.

Flexibility factor is the ratio between the number of set ups
available in the manufacturing system and the maximum number of
types of products produceable in the manufacturing system.

Quality factor is the ratio of number of total parameters
specified for quality assurance on a job and number of parameters
controlled by system quality.

Based on the characteristics of physical system
classification, limiting values of the lead time factors are
assigned to various types of manufacturing systems.

Considering the limiting conditions of a specific shopfloor
the optimal value of the lead time factors is obtained by
formulating it as a linear programming problem and solving with
LINDO package.

A simulation program is developed to further analyse the
behaviour of lead time estimates. The simulation trials were
conducted with alternate values of input lead time factors and the
results are compared with the benchmark values obtained with
optimal lead time factors. The simulation analysis brings out the
following:

(i) The mean manufacturing lead time (LTMEAN) of simulation
trials of 1000 runs are matching closely with the analytical
optimal lead time values.

(ii) Results of simulation trials do not agree to the Normal
distribution and can be considered to be Erlang distribution
whose parameters require further detailed investigation.

(iii) The high value of standard deviation of simulation results provides the realistic insight of the probable high variability of lead times.

(iv) The highest recorded lead time values (LTHIGH) of simulation results with various lead time factors were six to seven times higher than the mean manufacturing lead time (LTMEAN). This reflects the reality of unforeseen delays in the operations. However number of such values were insignificant.

(v) The lowest recorded lead time values were lower than the minimum required processing times. This reflects the conditions when a job is readily available in system stock, so that it can be delivered without consuming any processing time. Number of such values were also insignificant.

Based on the manufacturing lead time estimation techniques explained in this chapter, due date assignment methods, priority dispatching heuristics and justification models for investment proposals of advanced manufacturing systems have been developed in the following chapters.
### Table 2.1 Value of set up factor ($P_1 = 1$)

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### Table 2.6: Value of quality factor ($Q_1 = 1$)

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### Table 2.7: Value of quality factor ($Q_1 = 10$)

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Table 2.8 Value for limiting factors

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<th>Type of manufacturing system</th>
<th>Value for Limiting Factor (r)</th>
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<tr>
<td>Traditional batch shop systems</td>
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<tr>
<td>Traditional job shop systems</td>
<td>5</td>
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<tr>
<td>Partially flexible systems</td>
<td>3</td>
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<tr>
<td>Fully flexible systems</td>
<td>2</td>
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Table 2.9: Input values for LPP

<table>
<thead>
<tr>
<th>Stage</th>
<th>Demand Cell</th>
<th>Design Cell</th>
<th>Process Planning Cell</th>
<th>Manufacturing Cell</th>
<th>Delivery Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{\text{max}}$</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
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<tr>
<td>$p_{\text{min}}$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>$q_{\text{max}}$</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$r_{\text{min}}$</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>$r_{\text{max}}$</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>4</td>
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<tr>
<td>$s_{\text{min}}$</td>
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<td>1</td>
<td>1</td>
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</table>
Table 2.10: Lead time estimates with optimal lead time factors

<table>
<thead>
<tr>
<th>Stage</th>
<th>Demand Cell</th>
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<th>Process Planning Cell</th>
<th>Manufacturing Cell</th>
<th>Delivery Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
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<td>1</td>
<td>2</td>
<td>1</td>
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<td>$x_2$</td>
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<td>3</td>
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<td>2</td>
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<tr>
<td>$R_1$</td>
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<td>2</td>
<td>1</td>
<td>2</td>
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<td>$R_2$</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>$MLT$</td>
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<td>4.0</td>
<td>5.0</td>
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</table>

Table 2.11: Comparative chart for results of 6 Simulation trials

<table>
<thead>
<tr>
<th>Trial No.</th>
<th>Demand R1 X1 R2 X2</th>
<th>Design R1 X1 R2 X2</th>
<th>Process Planning R1 X1 R2 X2</th>
<th>Manufacturing R1 X1 R2 X2</th>
<th>Delivery R1 X1 R2 X2</th>
<th>LTM</th>
<th>LTH</th>
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<tbody>
<tr>
<td>1</td>
<td>2 1 1 3</td>
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<td>2 1 2 3</td>
<td>1 2 1 3</td>
<td>2 1 1 2</td>
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<td>2 2 2 3</td>
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<td>3 1 1 2</td>
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<td>2 1 2 3</td>
<td>1 2 1 3</td>
<td>2 1 1 2</td>
<td>13.67</td>
<td>91.97</td>
</tr>
</tbody>
</table>
Fig. 2.1 Hierarchical operation layout

Fig. 2.2 Restructured integrated manufacturing layout
START

Job specifications

Select input parameters

Input inspection schedule

Select feasible operations

Select sequence of operations

Flow chart

Select first operation

Select technology data

Technology schedule

Select operator's instructions

Operator's instruction schedule

Select fixtures

Tools fixture schedule

Select inspection parameters

Inspection schedule

Select safety instructions

Safety instructions schedule

Select next operation

Any more operation?

Yes

No

END

Fig 2.3 Flowchart for MACro Process Planner (MAPP) program
Fig. 2.4 Job

Fig. 2.5 Gauge
DEMAND SCHEDULE

1. Quotation No: STL/0054/94
2. Customer Name: XYZ Ltd.
3. Order Acceptance Date: 1-1-94
4. Nomenclature of Job: Gauge
5. Inspection by: XYZ Ltd.
6. Price: Negotiable
7. Mode of Payment: Spot payment after acceptance

Fig. 2.6 Demand Schedule

DESIGN SCHEDULE

1. Quotation No: STL/0054/94
2. Design Agency: Special Tools Ltd.
3. Design approving agency: XYZ Ltd.
4. Modification Authority: XYZ Ltd.
5. Total No of Components: One
6. Total No of Assemblies: One
7. Workstation: TR/DD

Fig. 2.7 Design schedule

PROCESSING TIME SCHEDULE

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
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<td>Demand schedule</td>
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<tr>
<td>Design schedule</td>
<td>2</td>
</tr>
<tr>
<td>Process Planning schedule</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing schedule</td>
<td>2</td>
</tr>
<tr>
<td>Delivery schedule</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 2.8 Processing Time Schedule
DELI V ERY SCHEDULE

1. Quotation No : STL/0054/94
2. Customer Name : XYZ Ltd
3. Job Nomenclature : Gauge
4. Despatch documents : Inspection Certificates
5. Mode of despatch : Road transport
6. E.T.A for despatch : 28.1.94
7. P.D.C of delivery : 30.1.94

Fig. 2.9 Delivery schedule

OPERATIONS SCHEDULE

1. Quotation No : STL/0054/94
2. Stage : Manufacturing
3. Operation No : 10-Turning
4. Parameter : 50 mm out_dia
5. Operator : Turner
6. Facility : Lathe_ABC_789
7. Processing_time : 0.125

Fig. 2.10 Operations schedule
MAINTENANCE INSTRUCTION SCHEDULE

1. Quotation No : STL/0054/94
2. Stage : Manufacturing
3. Operator No : 10_Turning
4. Facility : Lathe_ABC_789
5. Operator : One_Millwright
6. Frequency: Daily
7. Duration : 0.125

Fig. 2.11 Maintenance schedule

INSPECTION SCHEDULE

1. Quotation No : STL/0054/94
2. Stage : Manufacturing
3. Operation : Turning
4. Inspection by : QC staff
5. Inspection record : Dimensions measurement sheet
6. Deviations expected : Out_dia lower than limit
7. Criticality : Functionally important

Fig. 2.12 Inspection schedule
MAINTENANCE INSTRUCTION SCHEDULE

1. Quotation No : STL/0054/94
2. Stage : Manufacturing
3. Operator No : 10_Turning
4. Facility : Lathe_ABC_789
5. Operator : One_Millwright
6. Frequency : Daily
7. Duration : 0.125

Fig. 2.11 Maintenance schedule

INSPECTION SCHEDULE

1. Quotation No : STL/0054/94
2. Stage : Manufacturing
3. Operation : Turning
4. Inspection by : QC staff
5. Inspection record : Dimensions measurement sheet
6. Deviations expected : Out_dia lower than limit
7. Criticality : Functionally important

Fig. 2.12 Inspection schedule
Start

Read processing time
No of runs \( R_1, X_1, R_2, X_2 \),

Randomise \( L \)-estimates

Find \( M L T \)
\[ \text{Sum} \leftarrow \text{Sum} + RLT \]

Run = Run + 1

Is \( \text{Run} > \text{N Runs} \)?

Yes

Record \( LTHIGH \)
Record \( LTLOW \)

Compute \( LT \text{Mean} \)
Compute \( LT \text{Sigma} \)

Print histogram with relative frequency, \( LT \text{mean}, LT \text{high}, LT \text{sigma} \)

End

Fig 2.13 Flowchart for simulation program
Fig. 2.14 Frequency distribution of simulation results (trial 1)

Fig. 2.15 Frequency distribution of simulation results (trial 2)
Fig. 2.16 Frequency distribution of simulation results (trial 3)

Fig. 2.17 Frequency distribution of simulation results (trial 4)
Fig. 2.18 Frequency distribution of simulation results (trial 5)

Fig. 2.19 Frequency distribution of simulation results (trial 6)
<table>
<thead>
<tr>
<th>Stage</th>
<th>PT</th>
<th>R₁</th>
<th>X₁</th>
<th>R₂</th>
<th>X₂</th>
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<tbody>
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<td>1.0</td>
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LTHIGH 95.4437 LTMEAN 14.9337

**HISTOGRAM VALUES**

There are 22 classes with class interval of 3.
The classes are ≤ 1, 1-4, 4-7,..., 58-61, > 61.

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Fig. 2.20 Output from simulation trial with optimal values for lead time factors.