CHAPTER - 1
INTRODUCTION

The evolution of man has unveiled many new facets of science. In the first four decades of twentieth century, there were limited military resources which were not effectively utilized. In the military context, the efficient ocean transport and effective bombing were not experienced. During the World War II, a bench of scientists from various disciplines were called to examine the tactical and strategic problems associated with air force and military of England. The military commands of U.K and U.S.A undertook scientific research into strategic and tactical from several disciplines and organized them into teams so as to find out solutions relating to tactical military and strategic operations. The scarcity of military resources was realized. The thought of making the optimal utilization of these rare military resources was considered. To implement this decision effectively they designed particular proposals and plans to provide assistance to the military commands. Since this time, one advisor has involved in providing a good intellectual support to the strategic initiatives of the military commands. Therefore, the science of Operations Research or Operational Research came into existence in the military context. With the efforts of two great intellectuals named McClosky and Trefthen, the term Operation Research was coined in 1940 in a small town of Bowdsey in England. Hence it may be known as “art of winning the war without actually fighting it”.

In India, Operation Research came into existence with the opening of an O.R. unit in 1949 at Regional Research Laboratory in Hyderabad. Moreover, Operation Research Society of India (ORSI) was formed in 1957 and its first conference was held in Delhi in1959. While preparing the draft of the Second Five Year Plan, Professor Mahalonobis made the first important application of OR in India. The Draft Plan bears programmes of massive economic development of India with which India could become self-sufficient in food merely by reducing its wastage by 15%.

With the development of industrial organization, the managerial functions in the field of defence, business, industry, civil government etc., have become increasingly intricate and complex. In fact, rapid growth of industrial decisions
regarding purchasing, sequencing and supervising the production, selling, rental and so on. These increased activities have led to the problem of utilizing the limited resources like man, machine and material to the best possible advantages. The science of O.R. attempts to provide techniques for such an objective approach to decision making problems. In fact, O.R. is the quantitative decision making approach suggest an optimal solution to the problems which is the chief concern of organization. Operation Research problems fall into any of the following categories: sequencing, routing, allocation, replacement, inventory, queuing, competitiveness and search.

1.1 LITERATURE SURVEY

Scheduling theory has been developed to solve problems occurring in the production facilities in which set of jobs to be executed on the set of machines, such that all side- constraints are met. Clearly, this ought to be done in a manner that the subsequent arrangement, which is known as a schedule that minimises the given core objective. Early mechanical specialists and administration experts were caught up with attempting to deal with numerous parts of advanced assembling and generation control. Knoeppel examined pulling work through a processing plant, Gantt disclosed how to utilize visual diagrams. For as far back as four decades, scheduling has been explored from a scientific perspective, epitomized by the O.R, Operations administration and simulated intelligencia groups. In these groups, the scheduling is taken a sequencing i.e. the creation framework sequencing means allotting an arrangement of machines to perform an arrangement of work-requests inside a specific time period or as such scheduling manages sequencing of operations on a numerous machines.

Johnson [46] made a remarkable concept to discover best result utilizing heuristic calculation for n jobs which are to be performed on two/three machines in flow shop problem for given processing time on every machine under a few limitations. Mitten [64] treated some-what less restrictive cases which was applicable to a wider variety of difficulties. Wagner, C. [22] et al. formulated the integer programming models for scheduling problems. The branch and bound technique has been used by Ignell,E. & Scharge,L. [43], Gupta, J.N.D.[38] studied economic aspect of scheduling theory.
A number of heuristic approaches are used in flow shop scheduling. Moreover through the use of computer program various scheduling procedures and their impact on job-performance have been investigated under relatively homogeneous conditions Kaulamas, C.[48].

Maggu, P.L. and Das, G. [58] and Johnson, S.M. [46] established equivalent job-block theorem for 2xn sequencing problems. Palmer, D.S. [71], Bestwick,P.F. & Hastings,N.A.J. [10], Maggu, P.L. et al. studied the break down effect on processing of jobs. The work was further extended by Singh, T.P.[81], [82], [83] taking into account the various parameters as a concept of transportation times, arbitrary times, break down interval and job block criteria. Ching,W.K. [21], Gupta ,D., Sharma,S, Bala,S. [33] used Variable Range in scheduling problems. The work was further extended by Cormen,T.H [23], Gupta, D. [32], [33], [34], [35], [36], [37], Sharma, S.[34], Gupta, D. & Sharma,S. [35], [37] by considering various parameters.


Since the foremost paper comes out in 1954. Numerous variations of the fundamental sequencing problem have been defined by differentiating between machine situations, side restrictions and target capacities. Until the late 1980s, in any case, it was regular practice that in the practice works one and an only execution criterion was considered. In actuality quality is a multi-dimensional concept. An organization, for case, judges a creation plan on the premise of various criteria, for instance, work-in-procedure inventories and recognition of due dates. If one and only criteria is considered, then the result is prone to be uneven, regardless of what
paradigm is considered. On the off chance that everything is determined to keeping work-in-procedure inventories low, then a few items are prone to be finished a long ways past their due dates. Though, if the fundamental objective is to keep the clients fulfilled by seeing due dated, then the work-in procedure inventories are prone to be substantial. Keeping in mind the end goal to achieve a worthy trade off, nature of arrangement must be measured on extremely vital criteria. This notification has prompted the advancement of the zone of multi-target sequencing. Nagar et. al. have studied papers in the bi-criteria and multi-criteria sequencing upto 1994 for normal execution measures.

For as far back as three or four decades a lot of work has been done on schedule for production problem concentrating on the improvement of deterministic model where the information/data is thought to be known ahead of time .The fundamental work in the scheduling was made by Johnson [45] who built up a polynomial time calculation to minimize make range in two, three stage flow shop. Pass on et al [22] detail the whole number programming model for sequencing. Ignall, E. and Scharge, L. [43] applied Branch and Bound Technique in flow/flow shop problem. Dudek, R.A [26] conducted an exploratory investigation of a far reaching execution measure in the flow shop plan. Maggu and Das [61] presented the job block hypothesis of field which has numerous applications in the creation concern, healing center administration and so forth where need of one occupation over different gets to be noteworthy it might emerge the extra cost for giving this feature

The work has further extended by Singh, T.P. [39], [40], [41] taking into account the various parameters as concept of transportation time, arbitrary time, break down interval and associate possibilities with processing time or set up time depending upon the realistic situations. Lomric K, Z.A. [54] Bagga, P.C. [6] Narain, L. [69] studied some special cases of flow shop models bi-objective scheduling problem using branch and Bound technique. Singh, T.P. et al. [81] made an effort to minimize rental cost of machine including various parameters through simple heuristic approach. It has been observed that from practical point of view these conventional approach to real world flow shop problems are difficult to apply. Since processing time of jobs could be imprecise or uncertain thus making Fuzzy approach better and effective to tackle uncertainty in the complex flow shop
scheduling problems Szware, W. [88]. Lee, E.S. and McCahon, C.S. (1990) were first to deal the implementation of Fuzzy set theory as a with the objective to analysis performance characteristics for a flow system. Sanja Petrovic and Xueyan Song (2003-05) used α cut technique under Fuzzy environment in flow shop problem.

1.2 DEFINITIONS

Many prominent researchers have put forth to delve deep in new science operation research. O.R. has been variously described as the “science of use”, “quantitative common sense”, “scientific approach to decision-making problems”, etc. some important definition are given as:

1.2.1 “Operations research is the art of giving bad answers to problems which otherwise have worse answers.” T.L. Saaty

1.2.1 “Operations Research is the application of scientific methods, techniques and tools to problems involving the operation of a system so as to provide those in control of the system with optimum solution to the problem.” C.W. Churchman.

1.2.1 “O.R. is the application of scientific methods to problem arising from operations involving integrated system of men, machines and material. It normally utilizes the knowledge and skill of an inter-disciplinary research team to provide the managers of such systems with optimum operation solutions.” Febrycky and Togersen

1.2.2 “O.R. is the application of scientific method by interdisciplinary teams to problems involving the control of organized (men-machines) systems so as to provide solution which best serve the purpose of the organisation as a whole.” Ackoff & Sasieni

1.2.5 “O.R. is an aid for the executive in making his decision by providing him with the needed quantitative information based on the scientific method of analysis.” C. Kittel.
1.3 FEATURES OF OPERATION RESEARCH

System (or Executive) Orientation of O.R mainly, it studies the whole system and its relative parts i.e. activity done on any part of system put some effect on every another part. So one must study and understand all expected interactions and find their impact on each part of system because optimum operations varies in decision on each segment.

(i) Use of interdisciplinary teams: O.R. came into existence with the unison effort made by various researchers from several disciplines. It is performed by a group of researchers whose individuals have been drawn from various scientific and engineering disciplines. It has been recognized beyond doubt that people from different disciplines can produce more unique solutions with greater probability of success, than could be expected from the same number of persons from a single discipline.

(ii) Scientific method: this method is used to find the solution of problem under investigation. Most of the scientific researches like chemistry, physics etc. can be carried out under controlled conditions in their corresponding laboratories, having no reference with the outer world. So the same cannot be applied for the systems under study by O.R teams.

(iii) Uncovering new problems: this feature highlights that the solution of an O.R problem may unveil many new problems which need not to be solved at the same time. All the uncovered problems must be solved in order to get the maximum profit. A researcher should not be confined with solving a specific problem.

(iv) Improvement in the quality of decisions: by implementing scientific method, O.R helps in refining the quality of solution of bad or worse answers. But it is not feasible to get the perfect answers.

(1) The use of computers has proved conducive as they can be used extensively in solving and manipulating the complicated mathematical model, large number of calculations.

(2) The most crucial focus is on decision-making that has a quantitative basis.
A study of human factors is essential in deriving quantitative solutions.

1.4 SCOPE OF OPERATION RESEARCH

Operation research has been practised in solving the problem of optimization for many years. Since World War II, the scope of operation research has been broadened while using its techniques in a number of following situations:

1.4.1 Industry

In the industrial management, it is observed that industries are failed in accepting O.R. methods as they find it difficult to purchase raw materials and dispatch finished goods. Considering this complication, O.R groups are formed to take decision on scientific basis so as to concentrate on the situation of optimization and methods of producing the goods. Hence O.R has been successfully applied in industry in the various fields like scheduling, transportation, sale and purchase, blending, inventory control, product mix, demand forecast, repair and maintenance, scheduling and sequencing, sequencing, production, and control of projects and scores of other associated areas.

1.4.2 Defence

The scope of O.R in defence operations was quite less in the last four decades of twentieth century. In these periods only simple logistic problems were studied. In 1957 an effort was made to expose O.R techniques by organizing a series of lectures at Defence Science Laboratory. In modern warfare, new technologies, sophistication in military hardware and procurement of weapon systems has become the most urgent need to take decision in defence. Thus it is required to coordinate the various activities like operations, intelligence, administration, training etc. aims to achieve the best optimum strategy and consistent goals.

1.4.3 Agriculture

The rapid increase in population has led to the shortage of food and the difficulty of optimal distribution of land to various crops in accordance with climatic conditions and accessibility of facilities. Considering this numerous efforts have been made to bring out an improvement in crops, distribution of seeds and optimization of agricultural land and facilities on national and international level
since 1970. So the application of O.R and systems approach has left an imprint in agricultural development programmes. Moreover, many attempts have been made in the areas of fertilizers, irrigation and power, quality requirements of fertilizers, their production and distribution to farmers in a most cost-effective manner, determination of optimal reservoir operating policies, etc. to bring out the best results in agriculture.

1.4.4 Banking and Finance

The year 1969 marks the major development in the banking sector with the nationalization of banks. In order to reach the maximum benefit in economic development, O.R teams were made to extend the banking facilities to agriculture, small-scale industries, exports and regional developments. Training in application of O.R and other management techniques in their programmes are also provided to banking executives. Credit sequencing, location of branches, cash management, project appraisal and corporate sequencing has become easier with the help of O.R.

1.4.5 Transportation

The promotion of Operations Research has contributed successfully techniques in transportation sector. Operations Research was introduced in this sector in 1973. An OR cell was set at different regions of railways up by the Railway Board. This cell aims to study the performance of drivers on electric trains, analysis of freight movement, marshalling yard operation and cost-effectiveness analysis of additional crews and locomotives. Recently, the use of computers in the commercial and operations departments of railway. In addition to this, two separate autonomous bodies consisting of officers from various railway regions have been formed under the chairmanship of Minister of State for Railways to implement modern management techniques for operational improvement of Indian Railways.

1.4.6 Health-care

O.R approach is equally applicable in health-care, as it provides assurance in quality, the plan of medical informatics including resource modelling and diagnosis, emergency room scheduling. There is a demand of operations researchers in emergency services and ambulance in order to reduce response time and fasten response. A most recent use of income administration by healing facility with the
end goal of agreement transactions with sellers may indicate another method for containing medicinal costs. Pharmaceutical companies have been taking assistance from O.R professionals in the manufacture and development of products, and drug portfolios including the assortment of different drugs maintained by companies.

1.5 APPLICATIONS OF O.R TECHNIQUES

A wide scope of Operations Research defines its multifarious applications in various fields. It has been used extensively in industry, business, government, military, transportation, airlines, automobiles, electronics, mining, communication and agriculture to get the best results. The following applications of Operations Research techniques are discussed as:

1.5.1 Linear Programming

Linear programming technique is used to find a solution of problems involving optimizing a given objective that may be maximizing profit, or minimizing cost. It is used to obtain solution of problems which involves investment portfolio selection, least cost diet product mix, transportation blending distribution, advertising media selection, assignment to machines of jobs, and many more. Linear programming techniques solve product mix and distribution problems of enterprises. LPP techniques used to allot limited resources in a best possible mode in problems of product mix scheduling. It comprises of a target capacity which is same measure of viability like benefit, misfortune, or returns a venture and a few limit conditions putting confinements on the utilization of assets.

1.5.2 Queuing Theory

This theory provides the solution to problems which occurred due to formation of queues. There are different types of situations which results in the formation of queues means long waiting lines for clients, e.g. customers waiting for service, machines waiting for repairmen and air crafts waiting for landing strips etc. queuing theory works on the objective of minimizing the excess expenditure of cost and time due to servicing and waiting. On the other hand if queue becomes long there will be a cost due to waiting of units in the queue. This technique is used to analyse and assess the possible facilities and the amount and cost of waiting time
which can be added further. These enumerations prove helpful to get favourable facilities of services resulting in no -waiting of clients in queues.

1.5.3 Inventory Control Models

Production managers, purchase managers, and material managers face some complexities of inventory like which is the right time of purchasing and accurate quantity of purchasing etc. Inventory control aims at optimizing inventory levels. Inventory may be defined as a useful idle resource which has economic value by raw materials, spare parts, finished products etc. inventory control theory provides us Economic Order Quantity (E.O.Q) models help an above said managers to find the level and certain quantity of re-ordering level.

1.5.4 Network Analysis

Network models are a very popular and widely used quantitative technique. This model helps the managers to propose a schedule, monitor and control large projects, such as construction of a building, making a ship, or sequencing for a space flight. The network analysis help the managers to determine time of project completion probability for a certain project will be ended up on a fixed date and also method to minimize the project length time. Critical Path Method (CPM), Programme Evaluation and Review Technique (PERT), and other network methods such as Gantt chart come under network analysis.

1.5.5 Replacement Problems

The theory of replacement is concerned with situations that comes when items like electric light bulbs, machines, men, or require replacement due to their decreasing efficiency, failure or break down. At some point or another all supplies require to be supplanted. Substitution might be important as a result of out of date quality because of new revelations and better plan of the gear. In replacement decision the cost of the equipment to be installed and the one being replaced, scrap value, useful life, return and other relevant aspects have to be considered. The replacement theory helps to solve all replacement problems.

1.5.6 Sequencing

Models have been developed to find a sequence for processing jobs so as to minimize the make-span. The models also help to resolve the conflict between the
objectives of maximizing machine utilization and complying with predetermined delivery dates.

1.5.7 Integer Programming

Integer means complete or whole number. One important limitation of linear programming models is the assumption that all the variables can take any value, may be decimals or fractions. Sometimes some of the variables are restricted and can take only integer value e.g. number of taxis in a fleet, the number of power plugs in a factory and so on. With the technique of linear programming sometimes it is difficult to get the best solution when the approximation of figures is taken. Rounding off figures to the closest result in poor choice of solution. Integer programming has been developed to meet the increments of such situations. By using the integer programming algorithm a series of continuous linear programming problem are solved in such a way that the solution containing unacceptable non-integer value are ruled out to find out the best solution. These are certain techniques which are applied for the purpose getting the best solution of the given problem.

1.5.8 Assignment Problems

Task problem is an extraordinary kind of direct programming problem. It Concerns in apportioning the different assets or things to different exercises on a balanced premise in a manner that the time or cost included in minimizes one; deal or benefit.

1.6 BASICS OF SCHEDULING

‘Scheduling’ is basically defined as an allocation of a bunch of assets over fixed time to carry out a set of tasks. Scheduling emerges in various domains such as Hospital management, airlines, trains, production scheduling etc. The present thesis focuses on ‘Production Scheduling’. Production scheduling was recognized as a specific problem at the beginning of this century. Before scheduling and sequencing the departments were formalized. There was a period at what time industrial facilities did not know, when work was begun where it was, the manner by which it travelled through the plant and when it would be finished. There was general class in the factories. The choice of the fitting request in which working clients/jobs might be served is called 'Sequencing'. The choice of the fitting request in which working
Sequencing alludes to the determination of requests in which the jobs are to be taken care of on various machines while Scheduling alludes to the Time-table that incorporates the beginning time and finishing time of jobs on machines. This thesis will deal the circumstance in which the viability measure (time, cost, and so forth.) is a component for the successive performance of jobs. Scheduling contains time-tabling as well as sequencing information. The two terms viz sequencing and scheduling though distinct to some extent are used synonymous terms in this thesis. The general optimised criteria employed in defining are the problem is for minimization of cost of opportunity. Thus, the scheduling/sequencing problem may redefine due to Gupta [31], [32], [33]:

“Given n jobs to be carried-out on M machines, the process time for job i, existing for processing at time \(A_i\) taking place on machine \(m\), accessible to take up the job for dealing out at time \(B_m\) being \(t_{im}\) (\(i = 1, 2, \ldots, n\); \(m = 1, 2, \ldots, m\)); the technological order in which job \(i\) is processed on machine \(m\) being \(f_{im}\), and if job \(k\) proceeds job \(i\), the setup time on machine \(m\) for job \(i\) being \(S_{kim}\), find the manner in which these \(n\) jobs should be processed on the \(M\) machines to reduce overall opportunity cost.”

1.7 IMPORTANT TERMS AND DEFINITIONS

The following terminology is important to portray jobs in a deterministic production scheduling.

1.7.1 Processing time (\(t_k\))

It is the time needed to processing of work \(k\). It incorporates both existent time and additionally time of set-up.

1.7.2 Ready Time (\(r_k\))

It is the distinction among time of arrival and the time at which that work \(k\) is gone for procession includes set-up time.

1.7.3 Due Date (\(d_k\))

It is the time at which the completion of the jobs \(k\) is to be finished.
1.7.4 Completion Time \((C_k)\)

It is the time at which job \(k\) is actually finished in a system. Some example execution measures are flow time, Lateness, Tardiness and so on.

1.7.5 Flow Time \((f_k)\)

It is the distinction b/w the finishing point time of job \(k\) differs from its due date. Lateness can be +ve or -ve.

1.8 COST OF PRODUCTION

The analysis of Scheduling/Sequencing problem as made known in the Literature suggests the following parts of production cost:

1. Cost of Operation
2. Cost of Job waiting
3. Cost of idle machine
4. Cost of all Penalty

Each of the above four cost components may be visualized to be made of two parts:

1. **The manageable costs** depend on the schedule and by a suitable choice of the schedule; these costs may be lowered and thus minimized.

2. **The uncontrollable costs** are independent of the schedule and hence the choice of a schedule has no effect on increasing or decreasing these costs.

Hence, the Scheduling/Sequencing systems can be associated to minimize just the controllable costs. Let us discuss the four fundamental components of the Production cost.

1. **Cost of Operation**: That component of cost which represents Cost caused by production schedule and which might be dealt with as the processing cost of the jobs on every machines is characterized as the operation costs.

2. **Cost of Job waiting**: That component of cost which indicates the opportunity cost occurred due to the waiting of the half-finished jobs in the shop for processing on machines. The job which holds up in the shop is a type of capital tied up in the shop. This capital could have been utilized to produce additional return on capital.
3. **Cost of Idle Machine:** At the point when machines are unmoving, some open door is lost in light of the fact that, by using this unmoving limit of the machines, some arrival on machine could be obtained. Determination of machine unmoving cost might be partitioned into two categories The unmoving time of the machines can be used to perform some other work which may not be as productive as the current work.

4. **Cost of Penalty of Jobs:** If the jobs are not finished by their given dates, certain costs are sustained
   
i) Direct managing the client's paper work, phone calls, execution time taken up.
   
ii) Penalty clause signed in contract.
   
iii) Loss in positiveness of service provider results in the losing the client for a few or the majority of his future business; or maybe a harmed notoriety which will dismiss clients.
   
iv) Speeding up of the jobs through the shop results in the additional setup cost wasteful use or labourers and apparatus.

1.9 **OVERALL OPPORTUNITY COST**

The general cost is the entirety of the cost of opportunity which is Cost of Operation, Cost of Job waiting, Cost of idle machine, and Cost of all Penalties.

1.10 **CRITERIA OF OPTIMALITY**

This section describes the four most relevant criteria for Scheduling/Sequencing problems. These criteria are the minimization of the cost components i.e.

i) **Make-span Criterion:** This criterion minimization of make span of all the jobs in the system. The logic behind minimization of total completion time is that maximizes the rate of production. But does a maximum rate of production mean producing maximum quantity at the maximum cost? The answer to this question is that maximum rate of production does not imply production at the minimum cost. All maximum rate of production minimizes
is the overhead costs. The direct cost of production may in fact increase and hence offset the benefits of the maximum rate of production. Turning to the cost aspects of the jobs being produced, one notes that minimization of maximum flow-time considers the effect of the machine idle times at the last machine only. If there are some intermediate machines which are more valuable than the last machine then minimization of maximum flow time may result in additional idle time of some intermediate machines.

ii) **Job Waiting Cost Criterion**: These are some papers in the literature which consider the waiting time and/or cost to be important for scheduling/sequencing the jobs on the machines. This criterion assumes that the waiting cost is to be minimized. Minimization of waiting cost may increase some other costs, such as the in-Active cost/cost of the penalty of jobs. Thus, the total cost of production may in fact be increasing instead of decreasing while minimizing the waiting cost of jobs.

iii) **Machine idle Cost Criterion**: It was remarked earlier that machine idle cost of the intermediate machines is usually neglected in the formulation of the problem. The existing literature does not explicitly define that the idle cost of the machines is an important factor.

iv) **Penalty Cost Criterion**: Penalty cost of jobs forms an important part of the scheduling/sequencing problem, because it is highly unlike that all jobs are of equal importance in the shop. A part form the fact that there are due dates assigned to the jobs, the contract clauses of various jobs are different. Minimization of penalty cost also results in a lower job waiting cost. In general, there is no relation between the make-span criterion and the penalty cost criterion. The logic behind using penalty cost as the criterion seems to be the fact that customer satisfaction and goodwill are a most important internal part of any business.
1.11 GENERATION OF PROBLEMS

The real life scheduling/sequencing problems may be approximated to two types of problems; random matrix problems and ordered distribution problems.

i) **Random Problems:** In these problems the process times of the jobs do not bear any relation to one another. Thus, for simulating these problems, the process times are drawn from the uniform distribution. One hundred and eighty (180) flow-shop problems are generated from a random uniform distribution between the limits 0 to 999. An assortment of cost part rates are likewise produced arbitrarily and additional watch over the era of the unit holding up costs of the jobs.

ii) **Ordered Problems:** These problems differ from the random problems in the nature of their process times. Such problems reflect the situations for which the process times of the jobs are not independent of each other, but have some relationship. Specially the process times of the first job on all the machines and the process times of all jobs on the first machine are generated form a random uniform distribution between the limit 0 and 999.

1.12 THE STATIC SEQUENCING PROBLEMS ARE SOLVED BY THE FOLLOWING THREE APPROACHES

1. **Combinatorial Approach:** Combinatorial approaches deal with the conversation of one permutation to another by switching around of jobs that specify a particular criterion. Mitten [64], Yoshida and Hitomi, [92], MacNaughton, E. [57] have discussed the combinatorial approach including gap.

2. **General Mathematical Programming Approach:** The static sequencing problems have been solved by mathematical programming techniques which are linear, Langragians methods, networks of flows, integer programming
convex and quadratic programming. There are many articles published on the
subject by authors like Bellman [8], etc.

3. **Reliable Heuristics Approach:** Reliable heuristic approach is characterised
as “combinatorial programming” or “manageable examination”.

i) The use of controlled enumeration method for obtaining all potential
solutions and

ii) The eradication from overtly consideration of certain expected situations
which are known from the bounding, dominance, and flexibility
consideration to be unacceptable.

### 1.13 SEQUENCING MODELS

The basic models in scheduling due to Johnson [45] and owing to Maggu &
Das [60] Singh, T.P. [81] are explained one by one which form a basis of scheduling
problems dealt in this thesis. Johnson's [45] viewed as the extremely straightforward
instance of n jobs to be handled on two machines A and B, every job requiring the
same arrangement of operations and no passing permitted. Whatsoever jobs are
prepared first on machine A and likewise be handled on machine B and whatsoever
occupation is prepared second on machine. Additionally be handled on machine B
i.e. the flow shop model.

### 1.14 BASIC TERMS OF SCHEDULING

1. **No. of Machines**
   These are the facilities by which jobs are to be
   prepared for the finish of generation alludes to
   number of provided services through which a
   job must go before it is thought to be finished.

2. **Processing time**
   The Time needed for a job on every machine.

3. **Order of Processing**
   It is defined as the strict manner which is for
   necessary for the completion of the job.

4. **Idle Time on a Machine**
   Idle time is described as in-activeness of
   machines during the work in progress.

5. **Total Elapsed time**
   Total elapsed time is the difference of
   beginning of the earliest job and the very last
job which involves the in-activeness of machines as well.

6. No Passing Rule

It is a rule defines the strict validation of the order of the jobs which are meant to be processed on defined machines.

1.14.1 Assumptions

1. Each machine is assumed to be continuously available for the assignment of jobs.

2. No noteworthy division of time scale into movements or days for the machines is accepted. No temporary availability of machines is assumed to meet the certain causes of the machines due to their break down or maintenance etc.

3. No partition of a job is assumed to be allowed.

4. No like machines of the same type are allowed.

5. Not more than single operation can be done on every machine.

6. Pre-emption is not allowed, that is, once a job is started it is performed to completion.

7. The time interims for processing are autonomous of the request in which the jobs are finished.

8. The mechanical requesting of the machines working the jobs is known not foreordained.

9. All jobs are assumed to be given and are supposed to start before the period under consideration begins.

10. Each occupation is thought to be finished at wherever of the conceptl arrangement.

11. A job is a structure which consists of lot of sub- parts, no lot may be processed by more than one machine at one time.

12. The set up are assumed to be given for various jobs.

13. In-process inventory cost for jobs is not assumed to be allowable.

14. Jobs are assumed to be completed individually and not in groups.
1.15 PROCESSING N JOBS THROUGH TWO MACHINES

Let there be n jobs, each of which is to be processed through two machines, M₁ and M₂ in the order M₁ M₂ i.e. each job has to be pass through the same sequence of operations. In other words a job is assigned to machine M₁ first and after it has been completely processed on machine M₁, it is assigned to machine M₂. If the machine M₂ is not free at the moment for processing the same job, then the job has to wait in a waiting line for its turn on machine M₂, so passing is not allowing.

Since passing is not allowed, therefore machine M₁ will remain busy in processing all the n jobs one-by-one while machine M₂ may remain idle time of the second machine. This can be achieved only by determining sequence of n jobs which are to be processed on two machines M₁ and M₂. The technique suggested by Johnson for determining the optimal sequence can be summarized as follows.

The Algorithm

Step 1 List the jobs along with their processing times in a table as shown below:

<table>
<thead>
<tr>
<th>Processing Time on Machine</th>
<th>Job Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M₁</td>
<td>t₁₁</td>
</tr>
<tr>
<td>M₂</td>
<td>T₂₁</td>
</tr>
</tbody>
</table>

Tableau::1.15.1

Step 2 Examine the columns for processing times on machines M₁ and M₂, and find the smallest processing time in each column, i.e. find out, \( \min(t_{1j}, t_{2j}) \) for all j.

Step 3(a) If the smallest processing time is for the first machine M₁, then place the corresponding job in the first available position in the sequence. If it
is for the second machine, the place the corresponding job in the last available position in the sequence.

(b) If there is a tie in selecting the minimum of all the processing times, then there may be three situations:

(i) Minimum among all processing times is same for the machine, i.e. \( \min(t_{1j}, t_{2j}) = t_{1k} = t_{2r} \), then process the kth job first and the rth job last.

(ii) If the tie for the minimum occurs among processing times \( t_{1j} \) on machine \( M_1 \) only, then select the job corresponding to the smallest job subscript first.

(iii) If the tie for the minimum occurs among processing time \( t_{2j} \) on machine \( M_2 \), then select the job corresponding to the largest job corresponding to the largest job subscript last.

**Step 4** Remove the assigned jobs from the table. If the table is empty, stop and go to step 5. Otherwise, go to Step 2.

**Step 5** Calculate idle time for machines \( M_1 \) and \( M_2 \):

(a) Idle time for \( M_1 \) = (Total elapsed time) - (Time when the last job in a sequence finishes on \( M_1 \))

(b) Idle time for \( M_2 \) = Time at which the first job in a sequence finishes on \( M_1 \) + \( \sum_{j=2}^{n} \{ \text{Time when the job in a sequence starts on } M_2 \} - \{ \text{Time when the } (j-1) \text{th job in a sequence finishes on } M_2 \} \)

**Step 6** The total elapsed time to process all jobs through two machines is given by

Total elapsed time = Time when the nth job in a sequence finishes on machine

\[
= \sum_{j=1}^{n} M_{2j} + \sum_{j=1}^{n} I_{2j}
\]
Where $M_{2j}$ = Time required for processing $j$th job on machine $M_2$.

$I_{2j}$ = Time for which machine $M_2$ remains idle after processing $(j-1)$th job and before starting work in $j$th job.

1.16 PROCESSING N JOBS ON THREE MACHINES

Johnson provides an extension of his technique to the case in which there are three instead of two machines, each job is to be processed through three machines $M_1$, $M_2$ and $M_3$ in the order $M_1$, $M_2$ $M_3$. The list of jobs with their processing times is given below. An optimal solution to this problem can be obtained if either or both of the following conditions hold good:

<table>
<thead>
<tr>
<th>Processing Time</th>
<th>Job Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>on Machine</td>
<td>1</td>
</tr>
<tr>
<td>$M_1$</td>
<td>$t_{11}$</td>
</tr>
<tr>
<td>$M_2$</td>
<td>$T_{21}$</td>
</tr>
<tr>
<td>$M_3$</td>
<td>$T_{31}$</td>
</tr>
</tbody>
</table>

**Tableau: 1.16.1**

1. The minimum processing time on machine $M_1$ is at least as great as the maximum processing time on machine $M_2$, that is,

$$\min t_{1j} \geq \max t_{2j}, \quad j = 1, 2, \ldots, n$$

2. The minimum processing time on machine $M_3$ is at least as great as the maximum processing time on machine $M_2$, that is,

$$\min t_{3j} \geq \max t_{2j}, \quad j = 1, 2, \ldots, n$$

If either or both the above conditions hold good, then the steps of the algorithm can be summarized in the following steps.
The Algorithm

**Step 1** Examine processing time of given jobs on all three machines and if either one or both the above conditions hold, then go to Step 2, otherwise the algorithm fails.

**Step 2** Introduce two fictitious machines, say G and H with corresponding processing times given by

\[ G_i = A_i + B_i, \quad H_i = B_i + C_i \]

Then applying the Johnson’s n job 2 machine algorithm

1.17 PROCESSING OF n JOBS THROUGH m MACHINES

Let there be n jobs, each of which is to be processed through m machines, say \( M_1, M_2, \ldots, M_m \) in the order \( M_1 M_2 \ldots M_m \). The optimal solution to this problem can be obtained if either or both of the following condition hold good.

(a) \( \text{Min} \{t_{1j}\} \geq \text{Max} \{t_{ij}\}; \quad j = 2, 3, \ldots, m-1 \)

and/or (b) \( \text{Min} \{t_{mj}\} \geq \text{Max} \{t_{ij}\}; \quad j = 2, 3, \ldots, m-1 \)

that is, the minimum processing time on machines \( M_1 \) and \( M_m \) is as great as the maximum processing time on any of the remaining \( (m-1) \) machines.

If either or both these conditions hold good, then the steps of the algorithm can be summarized in the following steps.

**Step 1** Find, \( \text{Min} \{t_{1j}\}, \quad \text{Min}\{t_{mj}\} \) and \( \text{Max}\{t_{ij}\} \) and verify above conditions. If either or both the conditions mentioned above hold, then go to Step 2. Otherwise the algorithm fails.

**Step 2** Convert m-machine problem into 2-machine problem by introducing two fictitious machines, say G and H with corresponding processing times given by
\[(i) \quad t_{Gj} = t_{ij} + t_{2j} + \ldots + t_{m-1j}; \quad j = 1, 2, \ldots, n\]

i.e. processing time of n-jobs on machine G is the sum of the processing times on machines \(M_1, M_2, \ldots, M_{m-1,j}\)

\[(ii) \quad t_{Hj} = t_{2j} + t_{3j} + \ldots + t_{mj}; \quad j = 1, 2, \ldots, n\]

i.e. processing time of n-jobs on machine H is the sum of the processing times on machines \(M_1, M_2, \ldots, M_{m-1,j}\)

**Step 3** The new processing times so obtained can now be used for solving n-job, two-machine equivalent sequencing problem with the prescribed ordering HG in the same way as discussed earlier.

### 1.20 CONCEPT OF EQUIVALENT JOB IN FLOW SHOP

The most common optimizer in flow shop requiring has been for the minimization the total elapsed time (make span or maximum flow time) for a bunch of n independent jobs to be processed over m ordered machines. Now consider a situation in which some sets of specified jobs are required to be processed together as a block in a sequence either by virtue of technological constraint or some externally imposed restriction. This type of situation is known as a Group Technology which has very wide applications to a variety of production systems for the purpose of improving the productivity. The problem of determining an optimal sequence under the stated restriction is difficult to be stored with the help of available method.

#### 1.21 Equivalent Job Block Theorem given by Maggu, P.L. & Das, G.[59]

Let there be two jobs \(i\) and \(j\) is a sequence \(S\) to be processed on two machines A and B in the order A B. Let the equivalent job of \(i\) and \(j\) be denoted by \(a'\)

Then

\[A_a = A_i + A_j - \min (A_j, B_i)\]

\[B_a = B_i + B_j - \min (A_j, B_i)\]
Where \(A_a\) and \(B_a\) denote the processing time of equivalent job ‘a’ on machine A and B respectively.

1.22 Concept of Transportation Time in Flow Shop

In many practical situations of scheduling it is seen that machines are distantly situated and therefore, definite finite time is taken in transporting the job from one machine to another if the form of.

i) Loading time of jobs.

ii) Moving time of jobs.

iii) Unloading time of jobs.

The sum of all the above times has been designated by various researches as transportation time of a job. This transportation time is the amount of time required to dispatch the job \(i\) after it has been completed on machine A, to the next succeeding machine B for its onward processing. It is denoted by \(t_i\) for job \(i\).

1.23 Flow Shop Problem with Break Down of Machines

It has been assumed so far that no machine fails and hence no disturbance occurs in the processing of the jobs. Many a times it is practically possible that machine may not work:

i) Due to failure of electric supply from mains. Or

ii) Machines stop working due to failure of one or more components suddenly.

Machines are required to stop for certain interval of time due to excessive leading or some other external course. Therefore now we are considered to take into account the effect of break down interval of machines on the completion time of the set of jobs. Now we presses a heuristic method for providing an optimal or near optimal solution for a \(n \times 2\) flow shop problem.