Module-4

PROCESS PLANNING AND LINE BALANCING

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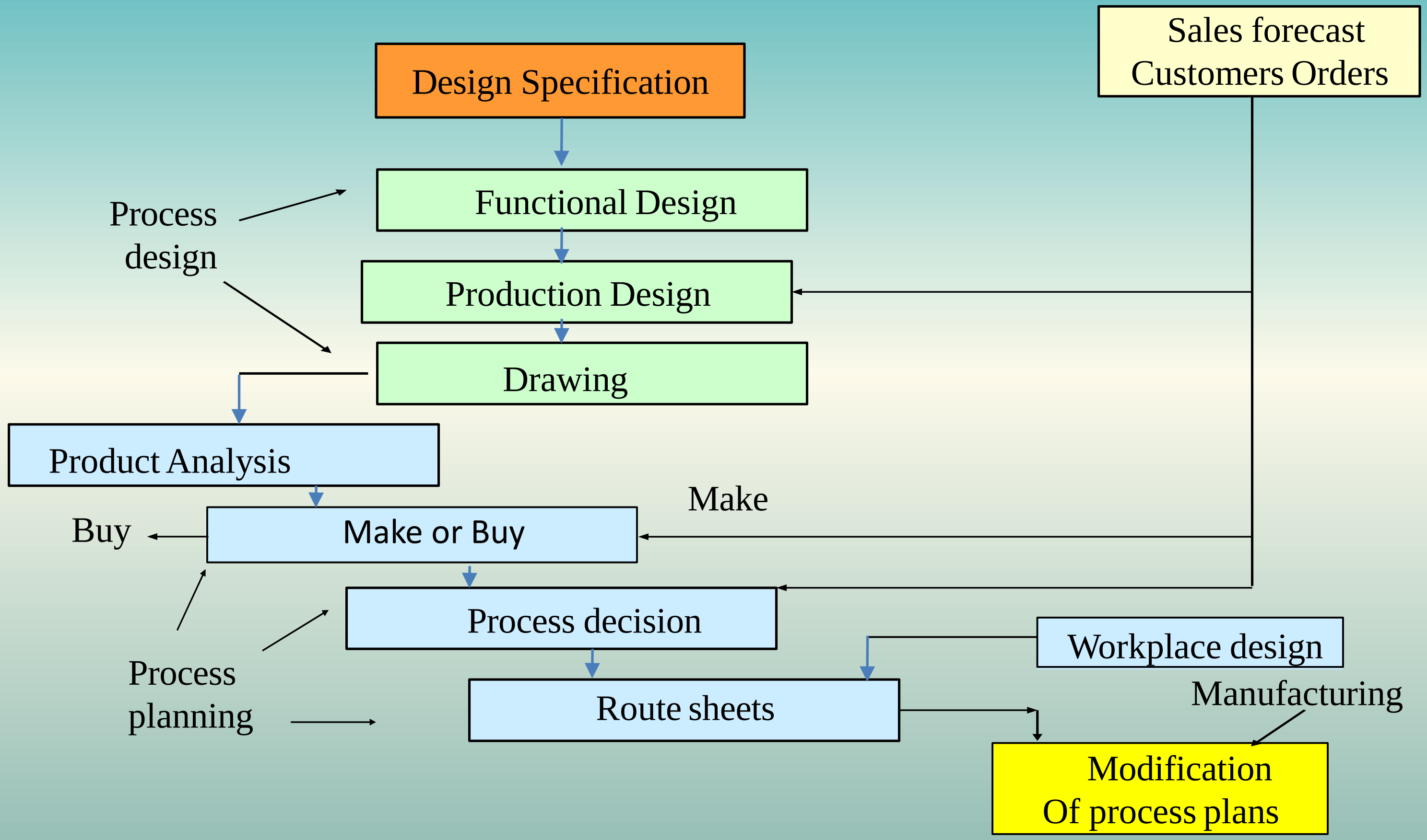
PROCESS PLANNING

What is Process Planning:

- Process planning is concerned with planning the conversion or transformation processes needed to convert the materials into finished products.
- Process planning specifies the type of work stations that are to be used, the machines and the equipments necessary & the quantities in which each is required.
- The process planning is mainly concerned with, determining the manufacturing processes, sequence of operations, equipments, tools and labour required for the production of a component or a product, coordinating the efforts of all factors in manufacturing the product and to furnish a guideline to use the existing or the proposed facilities.



Sales forecast
Customers Orders
Design Specification
Functional Design
Process
design
Production Design
Drawing
Product Analysis
Make
Buy
Make or Buy
Process decision
Workplace design
Process
planning
Route sheets
Manufacturing
Modification
Of process plans

Prerequisite Information Requirement

- Knowledge of Various manufacturing processes.
- Engineering drawing of the component.
- functional requirements of the product.
- Volume of output.
- The necessary operations and their sequence.
- The Knowledge of various tooling and fixtures.
- Tools and equipment necessary
- Relative costs of various processes, tooling and raw materials.
- Resources available in the factory.
- Ability to do computations on machining time and cost.
- Estimated manufacturing time and cost for producing the product.
- Requirements of tools, labour, etc
- Knowledge to use reference books, such as machinability data handbook.

Steps in Process Planning

1. **Analysis of the Product Print and Specifications :**
   In this step, the process planning takes as input the drawings and other specifications which indicates what is to be made, and also the forecast orders in hand or contracts which indicates how many are to be made. The quantity of the product to be manufactured is usually given in the product specification, otherwise it can be obtained from the sales department or the management. The process engineer should make a mental or written list of every item in the specifications to obtain a full grasp of the project.
2. **Improvement of the Specifications :**
   Product specifications must be clear and explicit. If the specifications are faulty like overlapping dimensions, missing tolerances, etc. they are rectified by the process engineer in consultation with the production engineer.

Steps in Process Planning

3. **Make or Buy Decision:**
   The product may consist of number of parts or components. The process planning determines what parts are to be manufactured in the factory itself and what parts are to be purchased from the outside suppliers.
4. **Selection of Basic Manufacturing Process:**
   Once the decision is taken regarding what parts are to be manufactured in house, the next step is, to prepare a list of basic operations required to produce each component of the product. The operations listed are examined to determine the practical methods by which the product can be manufactured. The various alternative methods are compared and the most practical and economical method is decided by calculating and comparing the total costs for two or more feasible processes.

Steps in Process Planning

5. **Determine the Sequence of Operations Process Planning :**
   Once the best manufacturing process is selected, the sequence of operations to be performed on each component is determined.
6. **Combine the Operations :**
   In general, as many basic operations should be combined as are practical and economical.
7. **Prepare the List of Raw Materials:**
   The raw materials needed to manufacture all the components of the products are determined, considering the quantity to be produced.

Steps in Process Planning

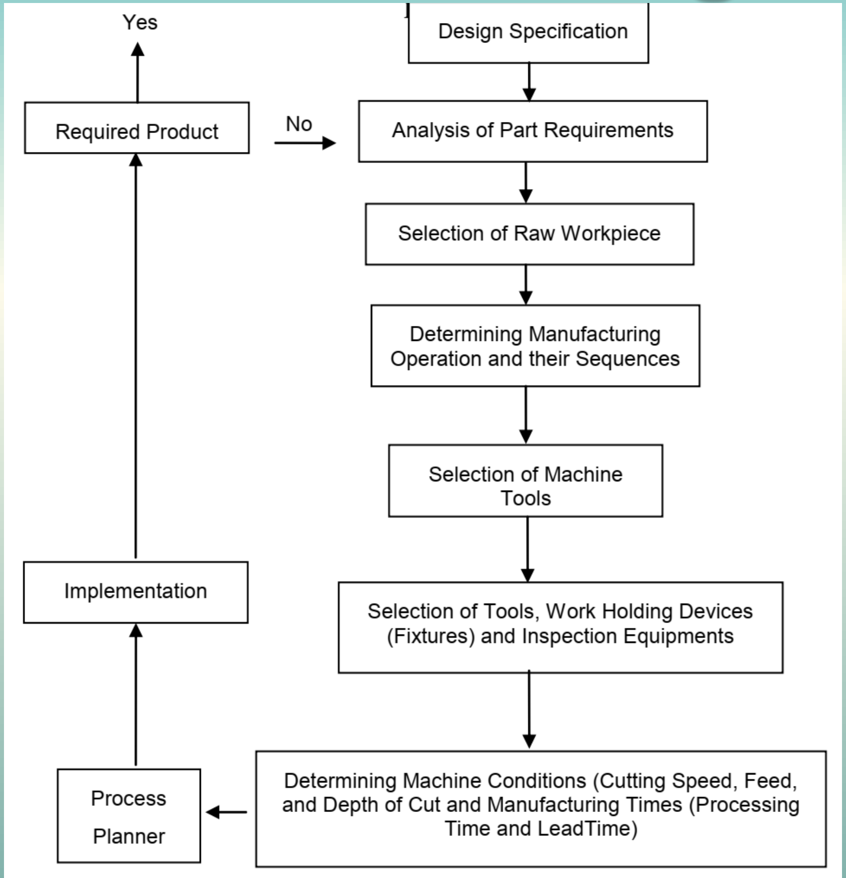
8. **Selection of the Machine Tools or Equipments :**
   The selection of the correct equipment or machine tool is closely related to the selected process of manufacture. The factors that are usually considered while selecting a correct equipment are size and shape of the work piece, the work material, the accuracy and surface finish required and quantity required.
9. **Inspection :**
   Determination of the stages of inspection and also the need of designing inspection devices and limit gauges to be used at different stages of manufacturing.
10. **Labour Requirements :**
    Estimating the kind of labour required to do the job. This information is based on to the personnel department of the organisation for recruitment and selection.

Steps in Process Planning

9. **Time Standards :**
   Determination of the time standards for performance of the job, and fixing the rates of payment.
10. **Cost of Production ;**
    Estimation of the cost of production before the manufacturing starts.
11. **Prepare the Operation Sheet and the Route Sheet :**
    The operation sheet shows everything about the operation, i.e., description of operations, their sequence, type of machinery, tools and equipment used, set up and operation times, speeds, feeds depth of cut, etc.

Summary of Steps in Process Planning

1. Analysis of the product print and specifications
2. Improvement of the specifications
3. Make or buy decisions
4. Selection of basic manufacturing process
5. Determine the sequence of operations
6. Prepare the list of raw materials
7. Selection of the machine tools or equipments
8. Selection of auxiliary equipment
9. Inspection methods
10. Labour requirements.
11. Time standards.
12. Cost of production.
13. Prepare the operation sheet and the route sheet.



Inputs & Outputs

In general, the inputs to Process Planning are:

- Design data
- Raw material data
- Facilities data (machining data, tooling data, fixture data etc)
- Quality requirements data
- Production type data

The output of process planning is the process plan:

- Process Plan Sheet
- Process Sheet
- Operation Sheet
- Planning Sheet
- Route Sheet
- Route Plan
- Part Program

Functions Of Process Planning

Process Planning has the following important functions:

- To determine the basic manufacturing process.
- To determine the sequence of operations.
- To determine the equipment's and tooling required.

Who does Process Planning ?

- Tradionally, Process Planning is done by manufacturing engineers who are familiar with the particular processes in the factory and are able to read engineering drawings.
- Based on their Knowledge, skill and experience, they develop the processing steps in the most **logical sequence** required to make each part.
- Some details are often delegated to specialists, such as tools designers.

Process Planning Consist Of

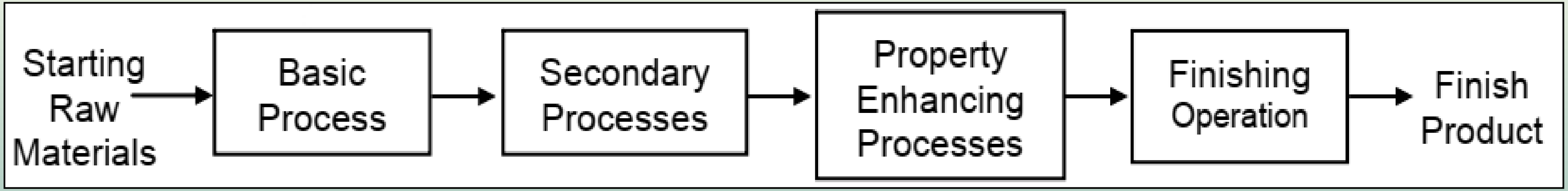
- Sequence of operations to be performed
- Selecting the proper machines
- Selecting the proper tools
- Jigs & fixtures
- Material to be used
- Specifying the inspection stages
- Details like speed, feed, depth of cut, etc.

Factors Affecting Process Planning

- *Production Methods*
- *Size and Type of raw material*
- *Process Capability*
- *Quantity to be manufactured*
- *Delivery dates of the products*
- *Surface finish and accuracy required*

Process Planning in Different Situations

PROCESS PLANNING FOR PARTS : Once the decision has been taken for manufacture a part, the manufacturing processes will be selected according to the requirement of the materials from which the required material is produced. The materials selection decision will be taken by the design engineer while designing the product itself. There are four different processes are identified to manufacturing a part as shown in Figure .



Process planning engineers duty is to find out the most appropriate processes and the order in which they must be manufactured. So that the overall cost must be minimized and the designed quality requirements must be fulfilled.

Process Planning in Different Situations

- In tool-room type manufacturing
  – "make part as per drawing" is sufficient
- In metal-forming type operations
  – The process planning requirements are embedded directly into the die.
  – Process planning is fairly trivial
- Job-shop type manufacturing requires most detailed process planning
  – Design of tools, jigs, fixtures and manufacturing sequence are dictated directly by the process plan.

Process Planning in Different Situations

PROCESS PLANNING FOR ASSEMBLIES :

- Process planning in assembly will be done depending upon the level of the production. If it is low production requirement, all the resources will be gathered at one place including human resources and perform the work elements (or assembles) to complete the product. In medium and high production, assembly is usually performed on production lines.
- For high production assembly lines process planning consists of allocating work elements to particular stations along the line, a procedure called line balancing technique, which minimizes time and cost of the materials movement. The assembly line routes the work units to individual work stations, and the line balancing solution determines what assembly steps must be performed at each station. Process planning for individual parts, the tools, jigs and fixtures required to accomplish a given assembly work element must be divided, and the work place layout must be designed.

Machine / Process Selection

Factors to be considered :

1. Economic Consideration - The machine selection process plays an important role in reducing the cost of production. Machine selection will effect the following economic factors considering :
   - Tooling cost
   - Set up cost
   - Production cost
   - Labour cost
2. Production rate and unit cost of production
3. Durability and dependability (quality & reliability aspects)
4. Lower process rejection
5. Min set up and put away times
6. Longer productive life of machines and equipments
7. Functional versatility- should be able to perform more than one function

Documents in Process Planning

Process documentation is nothing but the information collected and prepared about a post production, production costs, ordering costs, tooling cost, purchase orders, total process, assemblies through which a material moves from raw material stage to finished goods stage. There are various types of documents used in the manufacturing industries, which are :

- Route sheet
- Operation sheet
- Work order
- Purchase requisition

1. Route Sheet :

It is a document, consists of information about part name, part number and the route through which operational processes it goes to carry the required operations, etc. The route sheet also comprises of brief description about the each operation, required tools, on which machine the operation is to be carried, etc. A route sheet of manufacturing a gear is shown in Figure . This information and route sheet will available with personnel and the incharge of a particular production department.

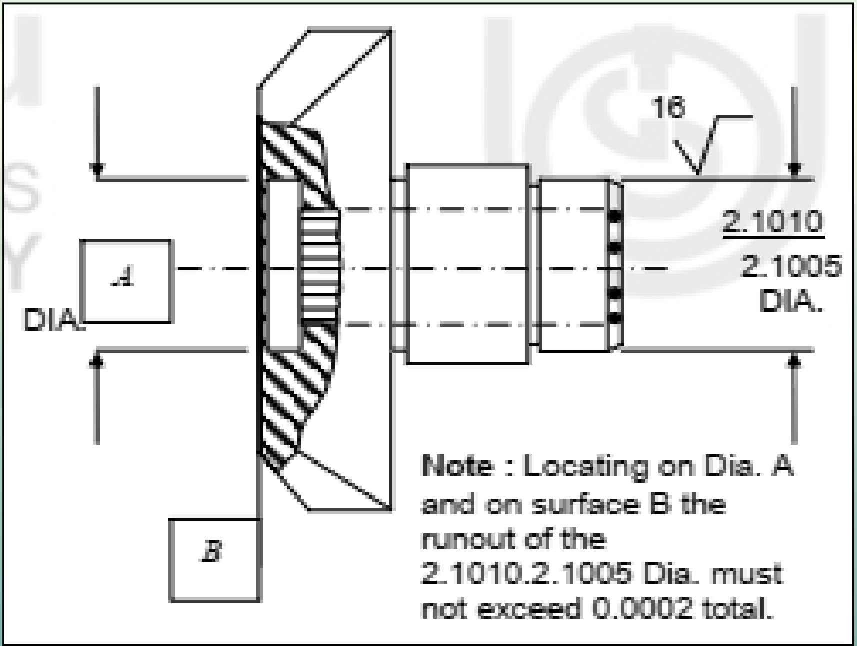
Name : GEAR Assy No. : 15531 MATL : SAE-4140	Date : 8-10-2983 Cust : GM Sheet No. 1	Part No. 40334

Department	Description	Sheet	Oper	Hourly Production	Rate	Labour	Set-up Hours
102	Machine Gear Side	2	10	123	9.45	0.076	4
102	Machine Hum Side	3	20	135	9.45	0.076	4
102	Broach Internal Spline	4	30	150	9.20	0.0619	2
102	Cut Teeth	5	40	75	9.45	0.126	4
102	Shape Spline	6	50	50	9.45	0.189	1
113	Heat Treat	7	60	1000	10.74	0.0107	-
102	Grind Hub	8	70	123	9.85	0.0785	2

Date	Change	By	Date	Change	By	Date	Change	By	Date
9-5-85	Released to Production								

2. Operation Sheet :

It is the document consists of information about a machine operator, drawing of required part, tolerance levels of a product and the quality requirements of the product and processes, etc. This information is utilized by tool room personnel, production and quality personnel. This document is also known as process sheet. It also comprises list of tools, inspection gauges and including inspection frequencies, etc. An operation sheet is shown in Figure .



Name : GEAR Description : Grind Hub Machine : Cyld. Grinder Make From : 40334 – Prog.		Part No. : 40334 Oper. No. : 70 B. T. No. : 5277 Sheet No. : 8		
Tools 40334-F-1 (Collect Chuck) 1 BM No. 25-137-06 (Grd. Wheel) Spec. Gages 40334-G-1 (Runout) Std. Gages Vertical Ext. Comparator Master Disc (2.100 Dia.)				
Rel. For Production	9-5-85			

3. Work Order :

It is very important document or a written requisite for making various parts, tools, **Process Planning** assemblies, raw materials and funds required for manufacturing a particular product. Before manufacturing a product this work order should be approved by the various authorities. Once the senior authorities approved then the work order as shown in Figure , will be released for production of a tool, part, assembly or a product. There are different types of work orders will be :

(a) Tool and die making work order.
(b) Part production work order.
(c) Assembly work order

WORK ORDER

	Rel. Date	W. O. No.
Tool Name	Ref. TL.	Tool No.
Oper. Description	Oper. No.	Dept. No.
Part Name	Part No.	Assy. No.
Mach Name	B. T.	Cost Est.

New Design ( ) Build ( )	Chg Design ( ) Tool ( )	Also Used On	Date Regd. Design Build	Signature
Date to TL. Des.	Date to LT. RM.			Authorised
From TL. Des.	Date to Acct.			

Instructions :

Comments :

4. **Purchase Requisitions :**

It is a document comprising information about the parts or components to be purchased from out side companies or vendors. Mostly the authorities approve these requisitions is purchase and materials management. When ever a purchase requisition releases, one should attach a work order along with, so that the information about the using department will be available. This will minimize the delay in authorizing a purchase requisition form is shown in Figure .

PURCHASE REQUISITION

Order : From :	Ship : To :

Account No.	B. T. No.	Dept. No.	Approp. No.	W. O. No.

Via :	F. O. B.	Terms	Deliver To

Wanted	Quantity	Description	Price

To be used for	Remarks :

Required by	Date	
Approved by	Date	

Advantages of Process Planning

The advantages of process planning are given below :

- Process planning helps in manufacturing a product economically and competitively within the limits of design specifications laid down.
- It helps in the conversion of design data to work instruction.
- As process planning is an intermediate stage between designing the product and manufacturing, a good process plan will produce a quality product.
- A process plan coordinates the efforts of all factors in manufacturing the product.
- It acts as a guide to use the existing or the proposed facilities.

Disadvantages of Process Planning

The disadvantages of manual process planning are given below :

- It requires a significant amount of time and expertise to determine an optimal routing for each new part design.
- As each individual process planners have their own opinion about what constitutes the best routing, accordingly there are differences among the operation sequences developed by various planners. This results in inconsistency in developing the process sheet.
- The manual process planning requires highly skilled process planners therefore, costly. The above problems encountered with manual process planning, resulted in developing the computer aided process planning systems or automated process planning system. They provide the opportunity to generate production routings which are rational, consistent and perhaps even optimal.

Approaches to Process Planning

- There are basically two approaches to process planning which are as follows :
  (i) Manual experience-based process planning, and
  (ii) Computer-aided process planning method.

Requirements In Manual Process Planning

- Ability to interpret an engineering drawing
- Familiarity with manufacturing processes and practice
- Familiarity with tooling and fixtures
- Know what resources are available in the shop
- Know how to use reference books (e.g. machinability data handbooks)
- Ability to do computations on machining time and cost
- Familiarity with raw materials
- know the relative costs of processes, tooling, and raw materials

Manual Process Planning

- The steps mentioned previously are essentially same for manual process planning. Following difficulties are associated with manual experienced based process planning method :
  - It is time consuming and over a period of time, plan developed are not consistent.
  - Feasibility of process planning is dependent on many upstream factors (design and availability of machine tools). Downstream manufacturing activities such as scheduling and machine tool allocation are also influenced by such process plan.
- Therefore, in order to generate a proper process plan, the process planner must have sufficient knowledge and experience. Hence, it is very difficult to develop the skill of the successful process planner and also a time consuming issue.

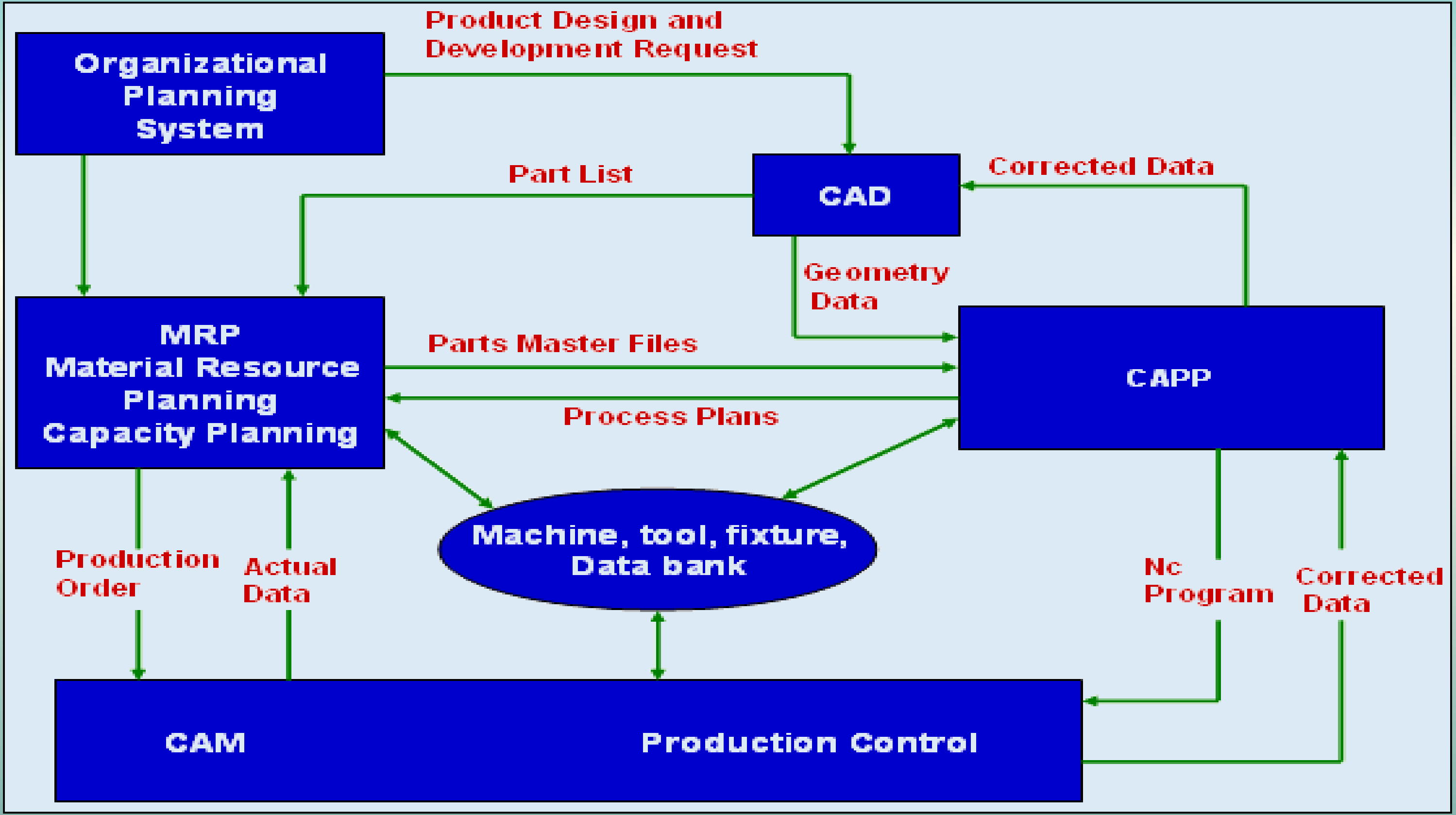
Computer Aided Process Planning

- Computer-aided process planning (CAPP) helps determine the processing steps required to make a part.
- CAPP programs develop a process plan or route sheet by following either a **variant or a generative** approach.
- **The variant** approach uses a file of standard process plans to retrieve the best plan in the file after reviewing the design. The plan can then be revised manually if it is not totally appropriate.
- **The generative** approach to CAPP starts with the product design specifications and can generate a detailed process plan complete with machine settings.

Computer Aided Process Planning

- CAPP systems use design algorithms, a file of machine characteristics, and decision logic to build the plans.
- CAPP has emerged as the most critical link to integrated CAD/CAM system into inter-organizational flow.
- The essentiality of computer can easily be understood by taking an example, e.g. if we change the design, we must be able to fall back on a module of CAPP to generate cost estimates for these design changes. Similarly for the case of the breakdown of machines on shop floor. In this case, alternative process plan must be in hand so that the most economical solution for the situation can be adopted.
- Figure in next slide is one such representation, where setting of multitude of interaction among various functions of an organization and dynamic changes that takes place in these sub functional areas have been shown.

Framework of CAPP

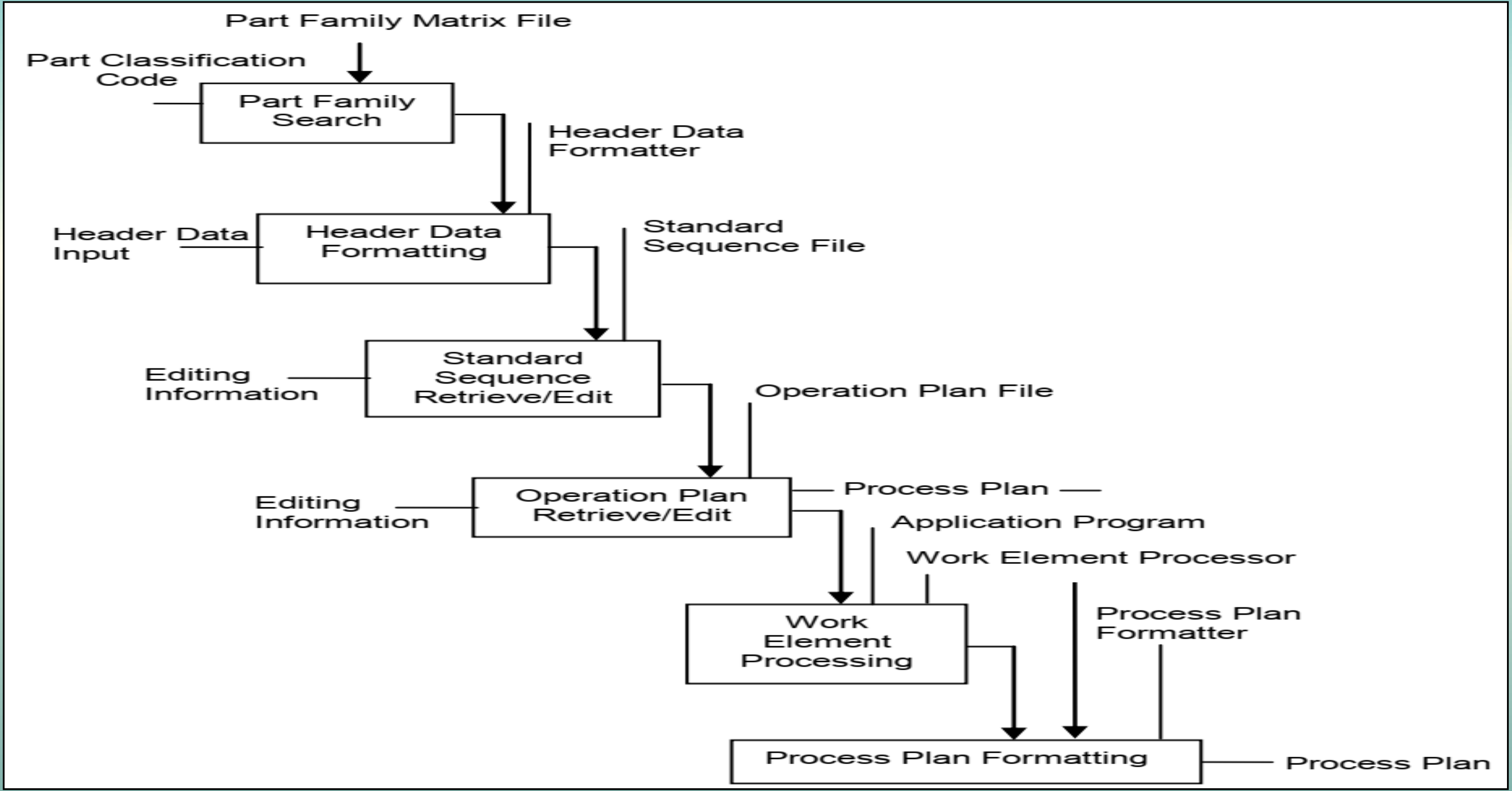


Advantages of CAPP

The uses of computers in process plan have following advantages over manual experience-based process planning :

- It can systematically produce accurate and consistent process plans.
- It leads to the reduction of cost and lead times of process plan.
- Skill requirement of process planer are reduced to develop feasible process plan.
- Interfacing of software for cost, manufacturing lead time estimation, and work standards can easily be done.
- Leads to the increased productivity of process planar

Flow Diagram of the CAPP Process Planning System



Steps Involved in CAPP

- CAPP has the potential to achieve interface between design and production integration. In general, a complete CAPP system has following steps :
  - Design input
  - Material selection
  - Process selection
  - Process sequencing
  - Machine and tool selection
  - Intermediate surface determination
  - Fixture selection
  - Machining parameter selection
  - Cost/time estimation
  - Plan preparation
  - Mc tape image generation.

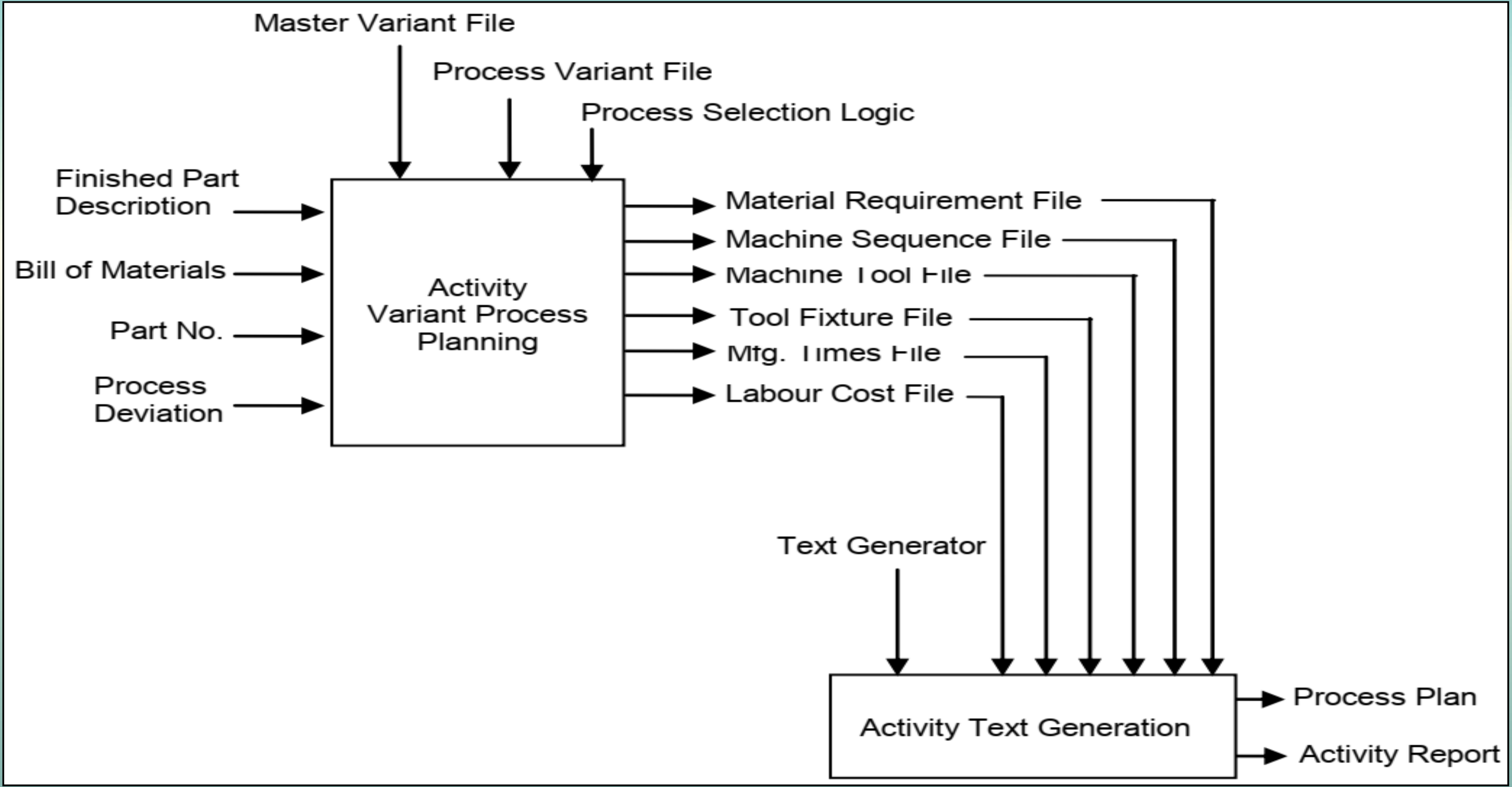
APPROACHES TO CAPP

- Variant computer aided process planning method.
- Generative computer aided process planning method

Variant CAPP

- In this approach, process plan for a new part is generated by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for new part.
- Variant process planning approach is sometimes referred as a data retrieval method.
- In this approach, process plan for a new part is generated by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for new part.
- As name suggests a set of standard plans is established and maintained for each part family in a preparatory stage. Such parts are called master part.
- The similarity in design attributes and manufacturing methods are exploited for the purpose of formation of part families.
- Using coding and classification schemes of group technology (GT), a number of methods such as coefficient based algorithm and mathematical programming models have been developed for part family formation and plan retrieval.
- After identifying a new part with a family, the task of developing process plan is simple. It involves retrieving and modifying the process plan of master part of the family.

Framework of Variant CAPP



Steps For Data Retrieval Modification

Establishing the Coding Scheme

A variant system usually begins with building a classification and coding scheme. Because, classification and coding provide a relatively easy way to identify similarity among existing and new parts. Today, several classification and coding systems are commercially available. In some extreme cases, a new coding scheme may be developed. If variant CAPP is preferred than it is useful for a company to look into several commercially available coding and classification systems (e.g. DCLASS, JD-CAPP etc.). Now, it is compared with companies before developing their own coding and classification system. Because using an existing system can save tremendous development time and manpower.

(i) **Form the Part Families by Grouping Parts**

The whole idea of GT lies into group numerous parts into a manageable number of part families. One of the key issues in forming part families is that all parts in the same family should have common and easily identifiable machined features. As a standard process plan are attached with each part family, thereby reducing the total number of standard process plans.

Steps For Data Retrieval Modification

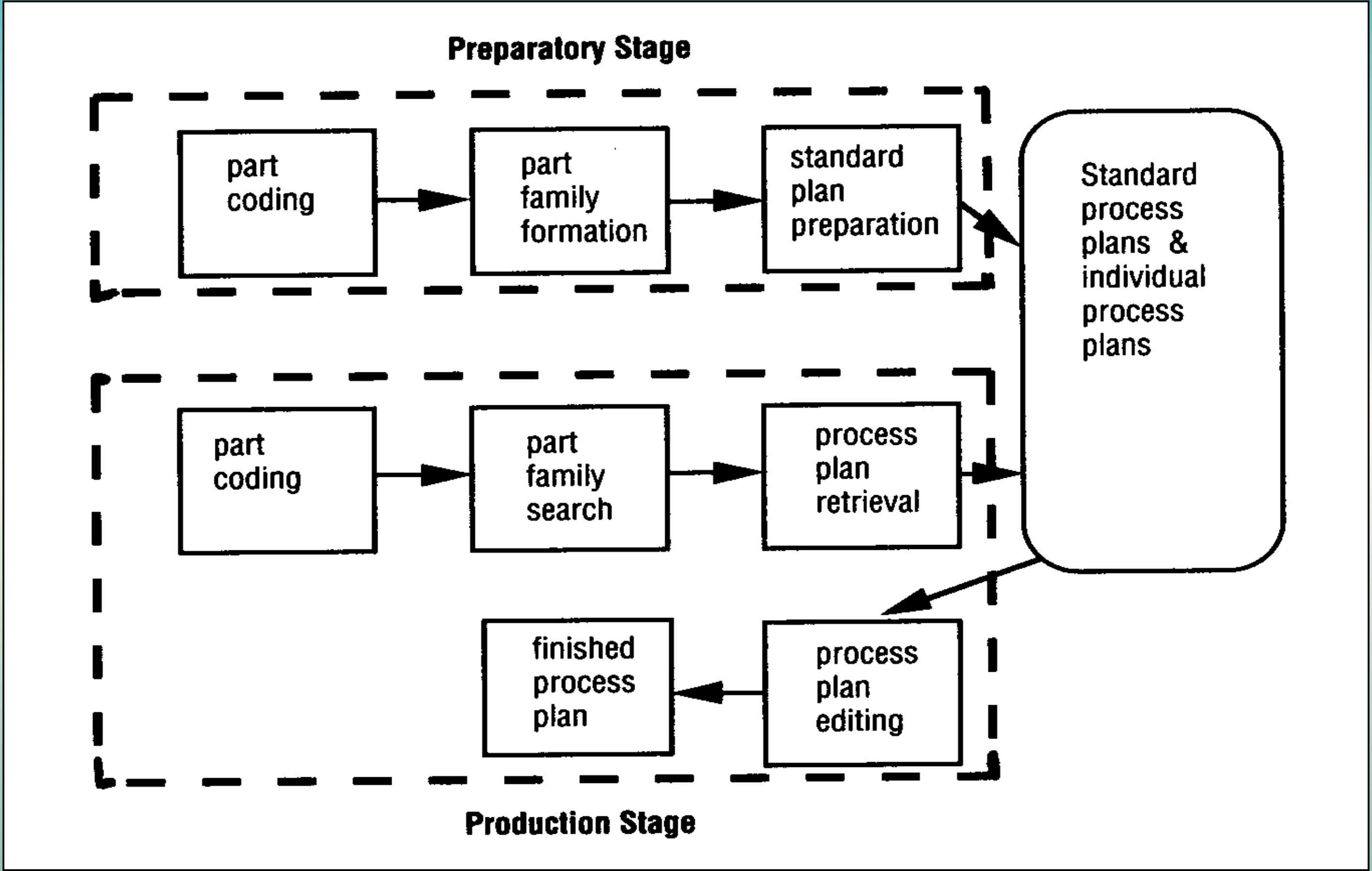
(ii) **Develop Standard Process Plans**

After formation of part families, standard process plan is developed for each part families based on common part features. The standard plan should be as simple as possible but detailed enough to distinguish it from other.

(iii) **Retrieve and Modify the Standard Plans for New Parts**

Step1 to step 3 are often referred as preparatory work. Each time when a new part enters the systems, it is designed and coded based on its feature, using the coding and classification scheme, and than assigned to a part family. The part should be similar to its fellow parts in the same family. Also, family’s standard plan should represent the basic set of processes that the part has to go through. In order to generate detailed process routes and operation sheets to this part, the standard plan is retrieved from the data base and modified. Modification is done by human process planar. After this stage parts are ready for release to the shop.

The success of this process planning system is dependent on selection of coding scheme, the standard process plan and the modification process, because the system is generally application oriented.



GROUP TECHNOLOGY BASED RETRIEVAL SYSTEM

Advantages of Variant CAPP

- Processing and evaluation of complicated activities and managerial issues are done in an efficient manner. Hence lead to the reduction of time and labour requirement.
- Structuring manufacturing knowledge of the process plans to company's needs through standardized procedures.
- Reduced development and hardware cost and shorter development time This is an essential issue for small and medium scale companies, where product variety is not so high and process planner are interested in establishing their own process planning research activities.

Disadvantages of Variant CAPP

- It is difficult to maintain consistency during editing.
- Proper accommodation of various combinations of attributes such as material, geometry, size, precision, quality, alternate processing sequence and machine loading among many other factors are difficult.
- The quality of the final process plan largely depends on the knowledge and experience of process planner. The dependency on process planner is one of the major shortcomings of variant process planning.

Generative CAPP

- In Generative Process Planning, process plans are generated by means of decision logic, formulas, technology algorithms, and geometry based data to perform uniquely processing decisions.

Generative CAPP

- In generative process planning, process plans are generated by means of decision logic, formulas, technology algorithms, and geometry based data to perform uniquely processing decisions. Main aim is to convert a part form raw material to finished state. Hence, generative process plan may be defined as a system that synthesizes process information in order to create a process plan for a new component automatically. Generative process plan mainly consists of two major components :
  - Geometry based coding scheme.
  - Proportional knowledge in the form of decision logic and data.

Generative CAPP

- **Geometry-based Coding Scheme**
  All the geometric features for all process such as related surfaces, feature dimension, locations, on the features are defined by geometry based coding scheme. The level of detail is much greater in generative system than a variant system. For example, various details such as rough and finished state of the part are provided to transform into desired state.
- **Proportional Knowledge in the Form of Decision Logic and Data**
  Process knowledge in the form of decision logic and data are used for matching of part geometry requirement with the manufacturing capabilities. All the methods are performed automatically. Operation instruction sets are automatically generated to help the operators to run the machines in case of manual operation. NC codes are automatically generated, when numerically controlled machines are used.

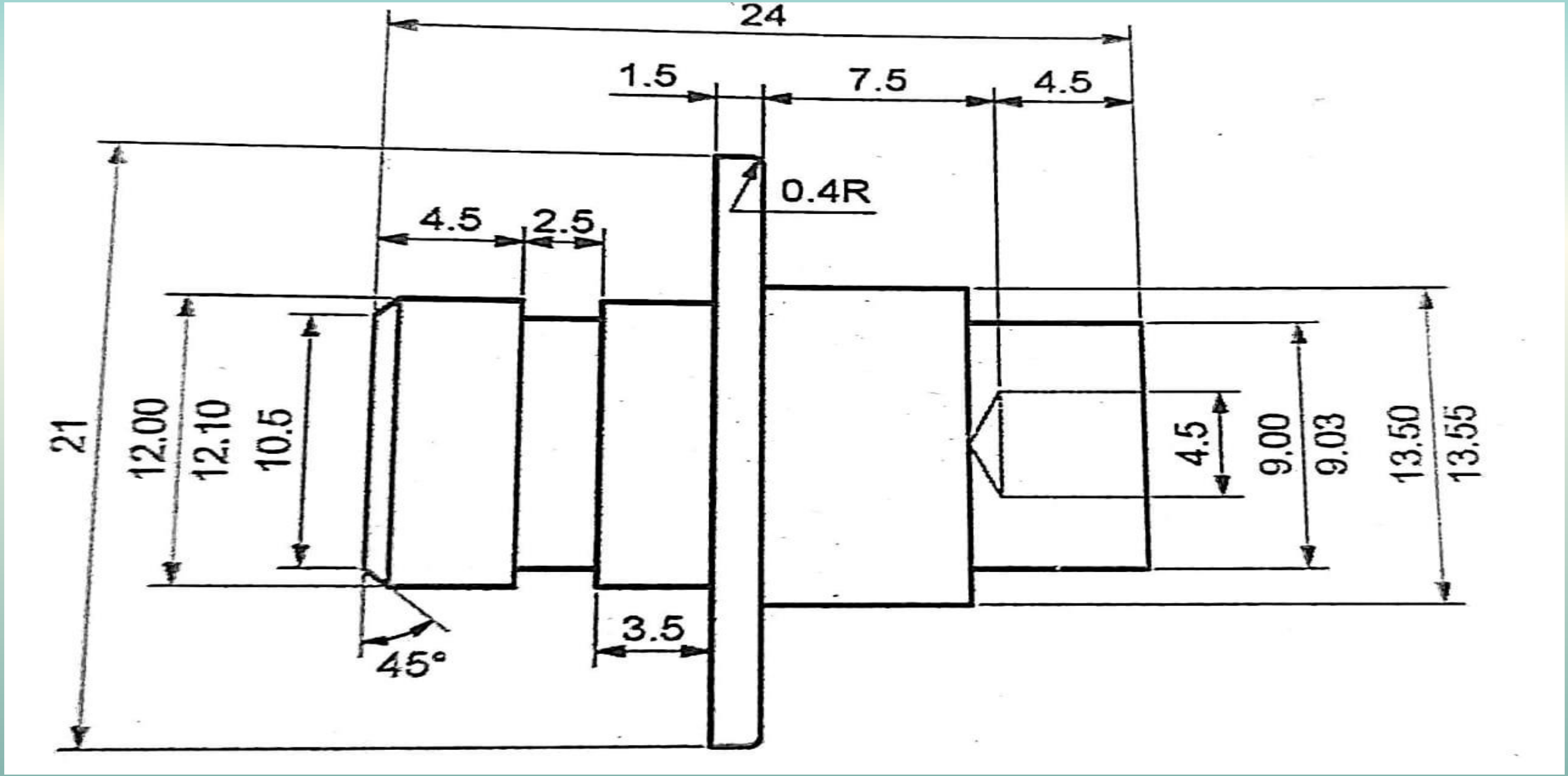
Advantages of Generative CAPP

- They rely less on group technology code numbers since the process, usually uses decision tree to categorize parts into families.
- Maintenance and updating of stored process plans are largely unnecessary. Since, any plan may be quickly regenerated by processing through the tree. Indeed, many argue that with generable systems, process plans should not be stored since if the process is changed, and out-of-dated process plan might find its way back into the system.
- The process logic rules however must be maintained up to dated and ready for use. This provides the process planner with an assurance that the processes generated will reflect state-of-the-art technology.

Variant or Generative, Which to Use?

- A variant system is better for manufacturing setting where similar parts are manufactured repetitively. Because parts are similar, Group Technology can easily be implemented and shows quick and significant return on investment (ROI). Because similar parts are produced repetitively, process plan can be retrieved, slightly modified and used, without going through too much trouble.
- Generative process planning is better suited for a manufacturing environment in which part does not exhibit too much similarity and new part are introduced on a regular basis. In this case, benefits cannot be gained from Group Technology due to dissimilarity of parts. Because, new parts are regularly introduced, historical data does not have too much value to the process planner.

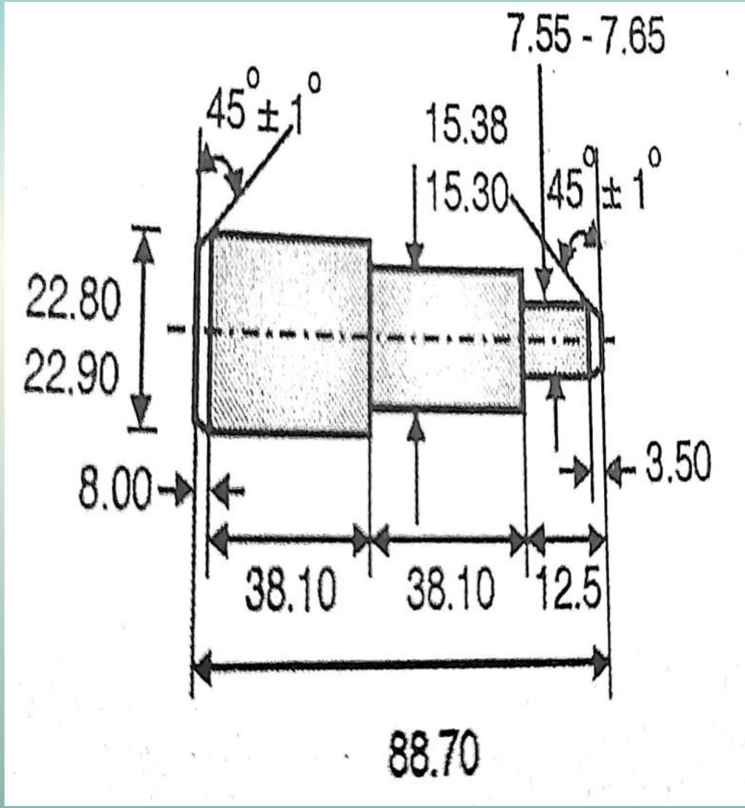
Examples of Process sheet



Examples of Process sheet

Job Part No.	Operations performed	Dimensions in mm	Fixture or tooling	Time taken
Part 1	Facing operation. Reduce the job to the required length of 24 mm. Turning operation, reduce diameter to 21 mm throughout the length.	L = 24 mm Q = 21 mm	Hold job in 4 jaw chuck of lathe machine For turning hold the job in centres	Facing 10 mm Turning 10 min
Part 2	Turning operation to reduce ϕ 9.03 to ϕ 4.5mm, with given tolerance ϕ 9.00 + 0.03	ϕ = 9.00 mm and ϕ = 9.03 mm L = 4.5 mm	Hold job between centres	12 min
Part 3	Turning operation to reduce ϕ 13.55 to ϕ 13.50 for length of 7.5 mm. given tolerance ϕ13.50 + 0.05	ϕ = 13.50 mm and ϕ = 13.55 mm L = 7.5 mm	Hold job between centres	12 min
Part 4	Turning operation to form ϕ21 mm from the length of 1-5 mm	ϕ = 21 mm L = 1.5 mm	Hold job between centres	8 min
Part 5	Taper turning operation to form a radius of 0.4 mm at angle of 45°.	R = 0.4 mm	Compound rest at 45° and taking radius of 0.4 mm	12 min
Part 6	Turning operation reduce the length upto ϕ12 mm. tolerance given ϕ 12 + 0.1	ϕ = 12.00mm ϕ = 12.10 mm L = 2.5 mm	Hold job between centres	12 min
Part 7	Turning operation. Reduce diameter upto ϕ12 mm. Tolerance given 12 + 0.1. In between length of 4.5 mm and 2.5 mm pan off for 3.5 mm for ϕ12 – 0.1 mm	L = 4.5 mm ϕ = 12.00 mm ϕ = 11.99 mm L = 3.5 mm	Parting off tool, hold a tool post	5 min
Part 8	Taper turning operation swivel compound rest upto 45° for ϕ 10.5 mm	ϕ = 10.5 mm Angle = 45°	Compound rest arrangement	8 min
Part 9	Drilling operation. Drilling of ϕ4.5mm on ϕ9.00mm for L = 4.5 mm	ϕ = 4.5 mm L = 4.5 mm	Drill bit of ϕ 4.5 mm attached to tail stock and hold a job in chuck.	5 min

Examples of Process sheet



Job, Part No.	Operations performed	Dimensions in mm	Fixture of tooling	Time taken
Part 1	Facing operation, Reduce the job to the required length of 88.7 mm. Turning operation, Reduce diameter upto 22.90mm	L = 88.7 mm Q = 22.90 mm	Hold a job in 4 jaw chuck of Lathe machine For turning operation, hold a job in centres	Facing 10 min Turning 10 min
Part 2	Turning operation, To reduce ϕ 22.90 mm to length of 38.10 mm with given tolerance 22.80 + 0.10 mm	ϕ = 22.90 and ϕ = 22.80 mm L = 38.1 mm	Hold the job between centres	12 min
Part 3	Turning operation, To form ϕ15.30 mm From length of 38.1 mm with tolerance 15.30 + 0.08 mm	ϕ = 15.30 mm & ϕ = 15.38 mm L = 38.1 mm	Hold the job between centres	12 min
Part 4	Turning operation, To form ϕ 7.55 mm for a length of 12.5 mm with tolerance 7.55 + 0.10 mm	ϕ = 7.55 mm ϕ = 7.65 mm & L = 12.5 mm	Hold the job between centres	8 min
Part 5	Taper turning operation, upto 45° for ϕ 7.55 mm	ϕ = 7.55 mm, Angle = 45°	Compound rest at 45° and taking radius of 3.5 mm	4 min
Part 6	Taper turning operation upto 45° for ϕ 22.80 mm	ϕ = 22.80 mm Cycle = 45°	Compound rest at 45° and taking radius of 8 mm	4 min

Examples of Process sheet

4.2.4.4 Illustration Process Planning Sheet for Manufacturing of 'Ring Nut'

Name of part : Ring nut

Function : It is in the form of a ring provided with slots in the curved surface for a special c. spanner. These nuts are generally used in pair, one nut acting as a lock-nut for the other.

Material : Mild steel.

Blank Selection : Routed Ms ROD

Blank Size Selection : Ms rod of $\phi 34 \times 14$ mm.

Assumptions:

Type of Industry : Medium scale industry

Type of production : Mass production

Organisation Chart : Generally displayed in the department

Machinery available : Light duty centre lathe machine (Tapping machine) Drilling machine, Milling machine, Cylindrical grinding machine.

1. List of Operations

1. Facing of 1 mm.
2. Turning to $\phi 32$ mm for a length of 18 mm.
3. Step turning, $\phi 32$ to $\phi 26$ mm for length of 2 mm.
4. Drilling a hole of $\phi 18$ mm.
5. Step turning and parting.
6. Slot milling, Slot of 4×2 mm (6 Nos.)
7. Tapping M 20×1 mm.

2. Machine Selection

According to requirement of job, following machines are selected :

1. Centre lathe
2. Tapping machine.
3. Cylindrical grinding machine.

3. Master Process Sheet

Table 4.2.2 : Process Sheet

Op. No.	Description	Machine Used	Dimensions achieved
5	Inspection of raw material		
10	Clamp the job on Lathe machine and set the tool	Lathe	
20	Facing of 1 mm on end AA'	Lathe	
30	Turning of $\phi 34$ to $\phi 32$ mm for a length of 13 mm.	Lathe	$\phi 32 \times 2$ mm
40	Check diameter with vernier calliper		
50	Turning from $\phi 32$ to $\phi 25$ for a length of 2 mm on AA'	Lathe	$\phi 26 \times 2$ mm
60	Check diameter with vernier calliper	Lathe	
60	Set the tool and machine for drilling		
70	Drill a hole of $\phi 18$ mm	Lathe	Hole of $\phi 18$mm
75	Set the tool and machine for turning	Lathe	
80	Step turning and parting off of end BB'	Lathe	
90	Clamp the job in milling fixture and set the machine	Milling	
100	Slot milling of 4×2 mm, 6 nos.	Milling	Slot of 4×2 mm
110	Clamp the job on tapping fixture and set the tool	Tapping	
120	Tapping of M20 $\times$ 1 mm	Tapping	M 20×1
130	Inspection	Vernier	

4. Machining Time Calculations

(i) Op. No. 20. Facing of 1 mm or surface AA'

(ii) Speed (V) = 40 m/min, depth of cut = 0.5 mm

Feed = 0.2 mm/rev.

Length to be machined

(l) = 17 mm

Depth to be achieved = 1 mm

No. of passes (p) = $\frac{1}{0.5} = 2$

Examples of Process sheet

Table 4.2.3 : Operation Routing Chart

Name of Company:	Capacity (Prod./Day): 82	Sheet No.:
Name of Part: ring Nut	Required (Prod./Day): 65	Part No
Raw Material: MS Rod ϕ34 x 14 mm		Date:

Op. No.	Description	Shop No.	Machine Name	Tooling		Inspection		Cutting Parameters			Man Power		Standard Time		Remarks
				Cutting	Special	Stage	Method	Speed rpm	Feed mm/rev	Depth of Cut mm	Skill	Labour Reqd.	Man (Sec.)	M/C (Sec.)	
5.	Inspection of raw material				Vernier	Initial	Manual				Skilled	1	10		
10	Clamp the job on a Lathe machine and set the tool		Lathe					375			Skilled	1	10		
20	Facing of 1 mm on end AA'		Lathe	Single point cutting tool				375	0.2	0.5	Skilled	1		27	
30	Turning ϕ34 to ϕ32 mm for 13 mm.		Lathe	Single point cutting tool				375	0.2	0.5	Skilled	1		21	
40	Check dia with vernier caliper				Vernier	Intermediate	Manual				Skilled	1	5		
50	Turning from ϕ32 to ϕ26 mm upto 2 mm		Lathe	Single				398	0.2		Skilled	1		4.5	
60	Check dia with vernier				Vernier	Intermediate	Manual				Skilled	1	5		
65	Set the tool and machine for drilling		Lathe					708	0.1	9	Skilled	1	20		
70	Drill hole of ϕ18 mm.		Lathe	Twist drill				708	0.1	9	Skilled	1		16.2	
75	Set the tool and machine for turning		Lathe								Skilled	1	10		
80	Step turning and parting off at end		Lathe	Parting tool				398	0.2	1	Skilled	1	0	18	
90	Clamp the job in mill fixture and set the machine		Milling		Milling Fixture						Skilled	1	60		

Examples of Process sheet

Name of Company:				Capacity (Prod./Day): 82							Sheet No.:				
Name of Part: ring Nut				Required (Prod./Day): 65							Part No				
Raw Material: MS Rod ϕ34 x 14 mm											Date:				
Op. No.	Description	Shop No.	Machine Name	Tooling		Inspection		Cutting Parameters			Man Power		Standard Time		Remarks
				Cutting	Special	Stage	Method	Speed rpm	Feed mm/rev	Depth of Cut mm	Skill	Labour Reqd.	Man (Sec.)	M/C (Sec.)	
100	Slot milling of 4 × 2m 6 nos.		Milling	Plain Milling	Milling Fixture			250	0.08	2	Skilled	1		374.4	
110	Clamp the job on tapping fixtures		Trapping		Tapping fixture						Skilled	1	30		
120	Tapping M20×1		Tapping		Tapping			150	1		Skilled	1		18	
125	Deburring										Semi-Skilled	1			
130	Inspection				Vermier						Skilled	1			
													220.2	479.1	

Examples of Process sheet

1. A Simplified Operation Sheet for turning a pin

Table 4.2.4 : Operation Sheet

Operation Sheet									
Part No.: Name : Material Specification: Quantity: To be completed on:									
Operation of Number	Description of Operation	Jigs and Fixtures	Tools		Speeds and feeds				
			Cutting	Measuring	Depth of cut mm	Feed mm/rove	Cutting speed m/min	Speed rpm	No. of cuts
1	Clamp stock in un universal chuck with 71 mm of stock projecting from chuck	3 jaws universal chuck	-	-	-	-	-	-	-
2	Face end dia. 24 mm	3 jaws universal chuck	Facing tool H.S.S.	Steel rule	1	0.25	60	800	1
3	Turn dia. 12 mm to length 68 mm	3 jaws universal chuck	Single point cutting	Vermier calliper	2	0.25	50	800	1

Operation Sheet									
Part No.: Name : Material Specification: Quantity: To be completed on:									
Operation of Number	Description of Operation	Jigs and Fixtures	Tools		Speeds and feeds				
			Cutting	Measuring	Depth of cut mm	Feed mm/rove	Cutting speed m/min	Speed rpm	No. of cuts
4	Turn dia 12 mm to length 47 mm	3 jaws universal chuck	Single pt. cutting	-	2	0.25	-	-	-
5	Chamfer 2 mm at 45°	3 jaws universal chuck	Straight turning tool	-	-	-	-	-	-
6	Cut groove dia 15 mm width 3 mm	3 jaws universal chuck	Grooving tool	V. Calliper template gauge					
7	Cut off stock	3 jaws universal chuck	Cutting of tool	Vermier calliper	4				
8	Clamp blank on other end	3 jaws universal chuck	-	-	-	-	-	-	-
9	Finish face end of head	3 jaws universal chuck							
10	Chamfer 2 mm at 45°	3 jaws universal chuck	Straight turning tool	Straight turning tool	-	-	-	-	-

LINE BALANCING

What is assembly-line balancing?

- It is associated with a product layout in which products are processed as they pass through a line of work centers.
- To a workstation within an assembly line in order to meet the required production rate and to achieve a minimum amount of idle time.
- Line balancing is the procedure in which tasks along Assigning each task the assembly line are assigned to work station so each has approximately same amount of work.

Effects

Unbalance Line and Its effect

- High work load in some stages (Overburden)
- Maximizes wastes (over-processing, inventory, waiting, rework, transportation, motion)
- High variation in output
- Restrict one piece flow
- Maximizes Idle time
- Poor efficiency

Balanced Line and its effect

- Promotes one piece flow
- Avoids excessive work load in some stages (overburden)
- Minimizes wastes (over-processing, inventory, waiting, rework, transportation, motion)
- Reduces variation
- Increased Efficiency
- Minimizes Idle time

How Can Assembly-Line Balancing Help Organization ?

- Increased efficiency
- Increased productivity
- Potential increase in profits and decrease in costs

Objectives

- To equalize the work load among the assemblers
- To identify the bottleneck operation
- To establish the speed of the assembly line
- To determine the number of workstations
- To determine the labor cost of assembly and packaging
- To establish the percentage workload of each operator
- To assist in plant layout
- To reduce production cost

The objective in line balancing is to distribute the total workload on the assembly line as evenly as possible among the workers

$$\text{minimize} \quad (wT_s - T_{wc}) \text{ or minimize } \sum_{i=1}^{w}(T_s - T_{ei})$$

subject to:

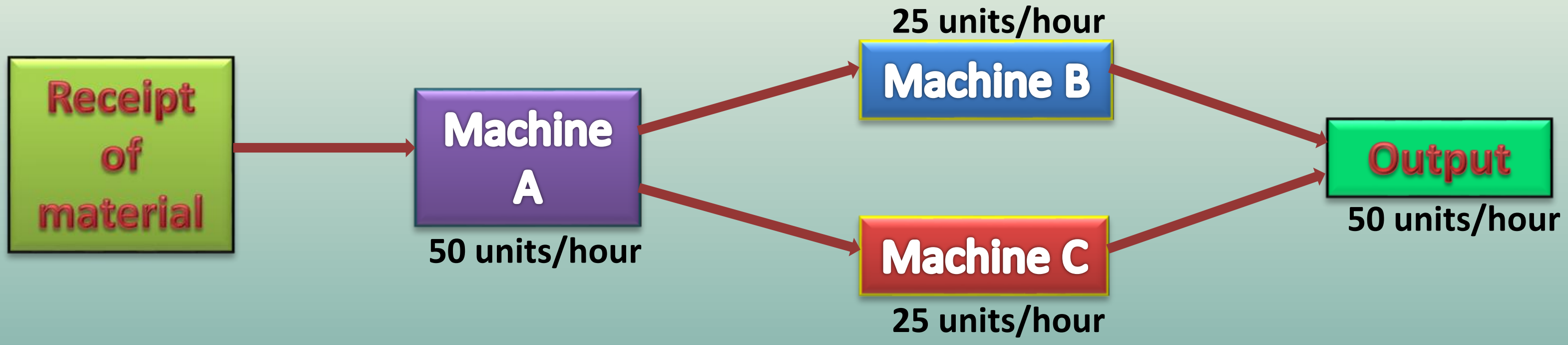
$$(1) \ \sum T_{ei} \le T_s$$

and

(2) all precedence requirements are obeyed.

The problem of line balancing arises due to

- *The finished product is the result of many sequential operations*
- *There is a difference in production capacities of different machines*
- *Line balancing is the apportionment of sequential work activities into workstations in order to gain a high utilization of labour and equipment so as to **minimize the idle time***



Terminology in Assembly Line

Cycle Time- It is the amount of time for which a unit that is assembled is available to any operator on the line or it is the time the product spends at each workstation

Cycle time = Available time period/output unit required per period, $T_c = \dfrac{60E}{R_p}$

- where T_c = cycle time of the line, min./cycle;
- R_p = production rate, units/hr;
- E = line efficiency;

Balance Delay- Percentage of total idle time on the line to total time spent by the product from beginning to end of line

$$\text{Balance Delay} = \frac{\text{Total idle time for all workstations}}{\text{Total available working time on all stations}} \times 100\%$$

Terminology in Assembly Line

Line Efficiency-

$$\text{Line efficiency} = \frac{\text{Total station time}}{\text{Cycle time x no. of workstations}} \times 100\%$$

Production Rate - $$R_p = \frac{D_a}{50 S_w H_{sh}}$$

- where R_p = average hourly production rate, units/hr;
- D_a = annual demand, units/year;
- S_w = number of shifts/week;
- H_{sh} = hrs/shift.
- This equation assume 50 weeks per year.

Terminology in Assembly Line

- The ***number of workers*** on the line can be determined as

$$w = \frac{WL}{AT}$$

  - where *w* = number of workers on the line;
  - *WL* = workload to be accomplished in a given time period.

$$WL = R_p T_{wc}$$

  - *Twc* = work content time, min/piece.
  - *AT* = available time in the period.

- If we assume one worker per station, then following ratio gives the theoretical minimum ***number of workstations*** on the line.

$$w^* = \text{minimun integer} \geq \frac{T_{wc}}{T_c}$$

Steps in Balancing an Assembly Line

1. List the sequential relationships among tasks and then draw a precedence diagram.
2. Calculate the required workstation cycle time.
3. Calculate the theoretical minimum number of workstations.
4. Choose a primary rule that will determine how tasks are to be assigned to workstations.
5. Beginning with the first workstation, assign each task, one at a time, until the sum of the task times is equal to the workstation cycle time or until no other tasks can be assigned due to sequence or time restrictions.
6. Repeat step 5 for the remaining workstations until all the tasks have been assigned to a workstation.
7. Evaluate the efficiency of the line balance.
8. Rebalance if necessary.

1. Heuristic Methods

- ***A heuristic method is a procedure that can find a good feasible solution for a given class of problems, but which is not necessarily an optimal solution.***

  ❖ It add tasks to a workstation in a precedence task order.

  ❖ To each task added to the station, operators are added when necessary, and the station utilization is calculated by equation.

  ❖ Tasks are added at the used station until its utilization is 100%, or until a reduction occurs, considering the new task and another operator when necessary.

  ❖ Then, a new station is considered, and the procedure is repeated on the next workstation for the remaining tasks.

Steps for Heuristic Method

In this method, numbers are assigned to each operation to denote how many predecessors it has. Those operations showing the lowest predecessor number are taken first on the work stations.

1. Draw the precedence diagram of work element first and then succeeding elements. Elements within the columns are assigned to work station after all the elements of previous columns have been assigned.
2. Select cycle time which is feasible. i.e $T_{max} \leq CT \leq \sum_{i=1}^{n} n \; T_{ei}$

   Where Tei = Time for work element

   n = Number of work elements

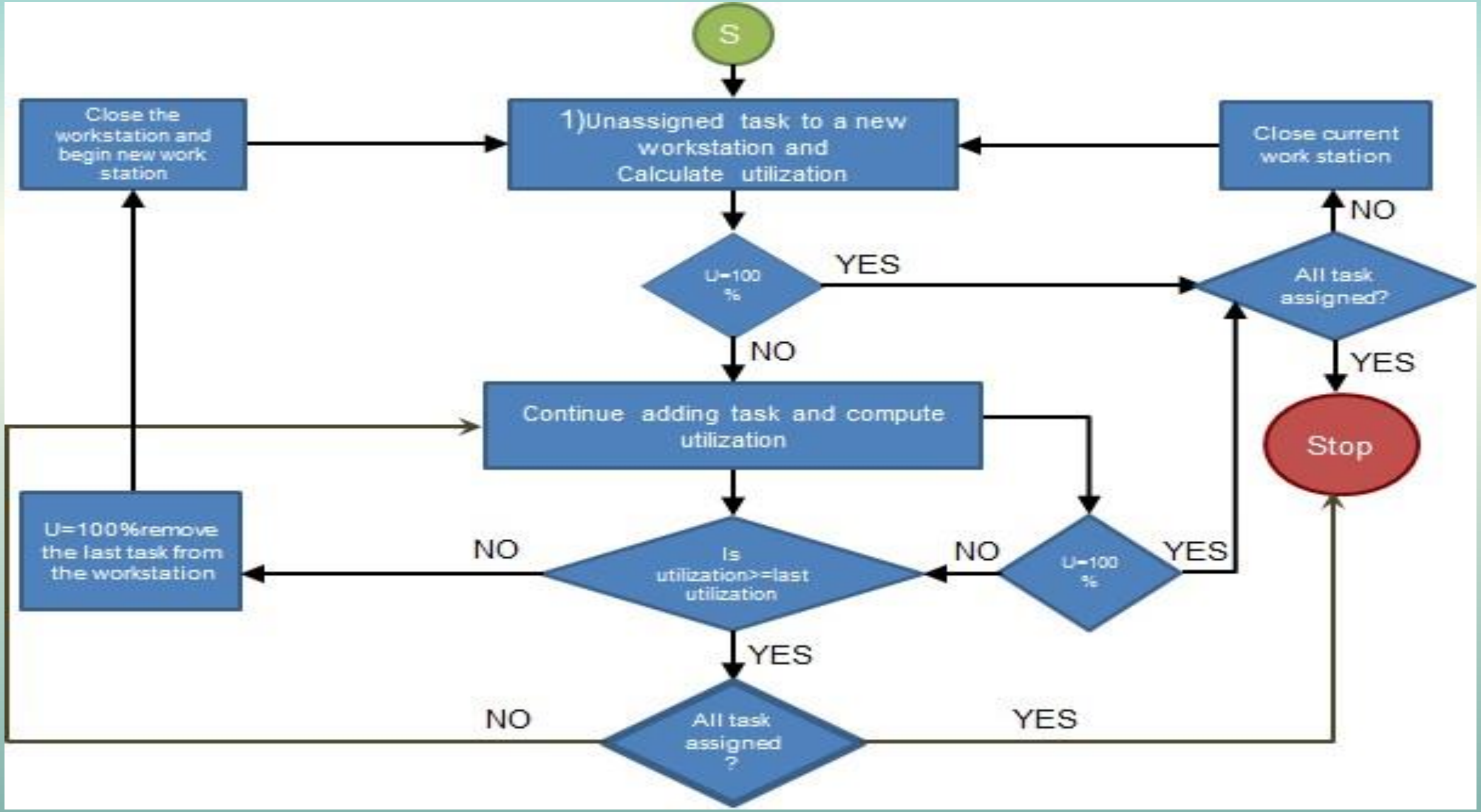
   T_{max} = Max. work element time

   CT = Cycle time

Steps for Heuristic Method (Cont..)

3. Assign work elements to work stations sum of elemental times should not exceed cycle time (CT) while doing so proceed from Column I to Column II and so on. Break intra column tie by using max. number of precedence.
4. Deduct Assigned work elements from total elements . Repeat step (3).
5. If workstations (ws) time is more than CT, identify work element due to which this happens and carry it forward to next workstation.
6. Repeat step (3) to (5) till all the elements are fully assigned.

Steps for Heuristic Method (Cont..)



Example

A small electrical appliance is to be produced on a single model assembly line. The work content of assembling the product has been reduced to the work elements listed in table below along with other information. The line is to be balanced for an annual demand of 100,000 units per year. The line will be operated 50 weeks/yr, 5 shifts/wk, and 7.5 hrs/shift. Manning level will be one worker per station. Previous experience suggests that the uptime efficiency for the line will be 96%, and repositioning time lost per cycle will be 0.08 min. Determine :

(a) total work content time T_{wc}

(b) required hourly production rate R_p to achieve the annual demand,

(c) Cycle time,

(d) theoretical minimum number of workstations required on the line and

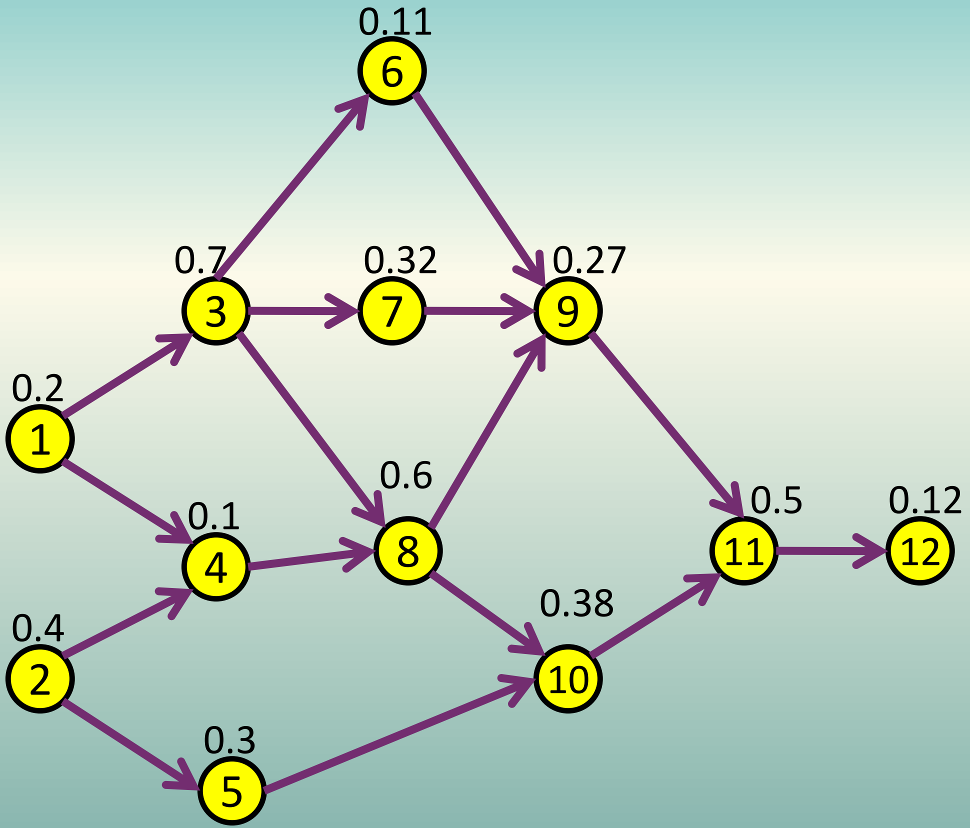
(e) service time Ts to which the line must be balanced.

Cont..

No.	Work element description	Tek (minutes)	Must be preceded by
1	Place frame in workholder and clamp	0.2	-
2	Assemble plug, gromment to power cord	0.4	-
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1, 2
5	Wire power cord to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3, 4
9	Aline blade and attach to motor	0.27	6, 7, 8
10	Assemble switch to motor bracket	0.38	5, 8
11	Attach cover, inspect, and test	0.5	9, 10
12	Place in tote pan for packing	0.12	11

Solution

Activity	Predecessor	Duration
1	-	0.2
2	-	0.4
3	1	0.7
4	1,2	0.1
5	2	0.3
6	3	0.11
7	3	0.32
8	3,4	0.6
9	6,7,8	0.27
10	5,8	0.38
11	9,10	0.5
12	11	0.12
Total (Twc)		4.0 Min



Solution

- Given: The previous precedence diagram and the standard times. Annual demand=100,000 units/year. The line will operate 50 wk/yr, 5 shifts/wk, 7.5 hr/shift. Uptime efficiency=96%. Repositioning time lost=0.08 min.
- Determine
  - a) total work content time,
  - b) required hourly production rate to achieve the annual demand,
  - c) cycle time,
  - d) theoretical minimum number of workstations required on the line,
  - e) service time to which the line must be balanced.

Solution

(a)The total work content time is the sum of the work element times given in the table

$$T_{wc} = \sum_{i=1} T_{ei}$$

T_{wc} = 4.0 min

(b) The hourly production rate $R_p = \dfrac{100{,}000}{50(5)(7.5)} = 53.33 \quad \text{units/hr}$

(c) The cycle time ***Tc*** with an uptime efficiency of 96% is:

$$T_c = \frac{60E}{R_p} \qquad T_C = \frac{60(0.96)}{53.33} = 1.08\,\text{min}\ .$$

Solution

(d) The theoretical minimum number of workers/workstations is given by:

$$w^* = \min \ \text{int} \ \geq \frac{T_{wc}}{T_c} = 4.0/1.08 = 3.7 \cong 4$$

(e) The average service time against which the line must be balanced is:

$$T_s = T_c - T_R = 1.08 - 0.08 = 1.00 \text{ min} .$$

2. Largest Candidate Rule Method

- **Step 1:** Rank the Tei in the descending order.
- **Step 2:** Assign the elements to the worker at first station by starting at the top of the list and selecting the first element that satisfies precedence requirements and does not cause the total sum of Tei at that station to exceed the allowable Ts; when an element is selected for assignment to the station, start back at the top of the list for subsequent assignments.
- **Step 3:** when no more element can be assigned without exceeding Ts, then proceed to the next station.
- **Step 4:** repeat steps 2 and 3 for as many additional stations as necessary until all elements have been assigned.

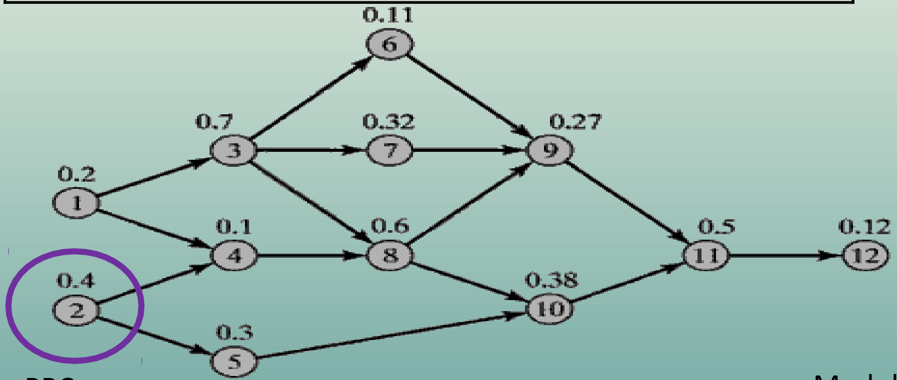
Example: Largest Candidate Rule

- Work Elements Arranged According to T_{ei} Value for the Largest Candidate Rule. (T_s = 1 min)

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8

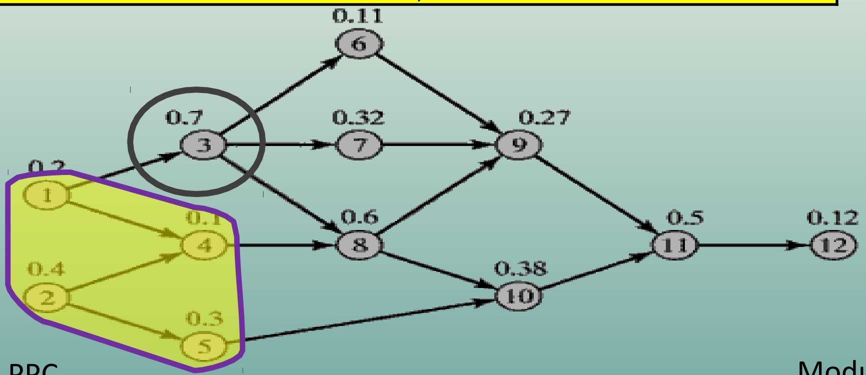


Iteration 1:

- 3, 8, and 11 require preceding elements
- Element 2 is selected.
- Alternatives are 5 and 1.
- It assigns element 5.
- $\sum T_{ei}$= 0.4 + 0.3 = 0.7 min
- Alternative is 1
- It assigns element 1
- $\sum T_{ei}$= 0.7 + 0.2 = 0.9 min
- Alternatives are 3 and 4
- 3 can not be assigned, since $\sum T_{ei} > T_s$
- It assigns element 4
- $\sum T_{ei}$= 0.9 + 0.1 = 1.0 min

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8

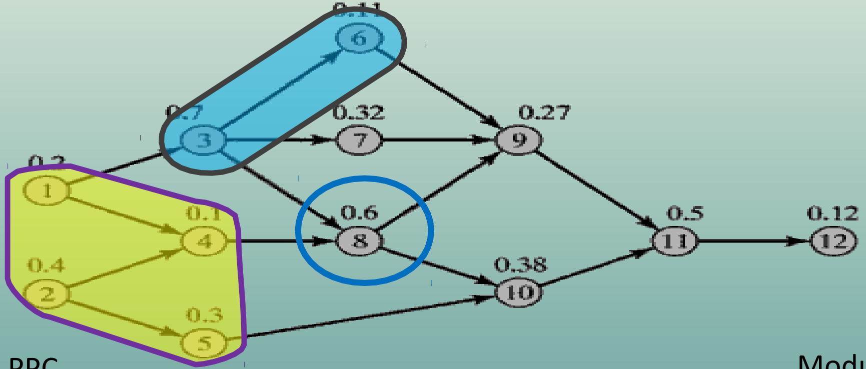


Iteration 2:

- Element 3 is selected.
- Alternatives are 8, 7 and 6.
- 8 and 7 can not be assigned, since $\sum T_{ei} > T_s$
- It assigns element 6.
- $\sum T_{ei} = 0.7 + 0.11 = 0.81$ min
- Alternatives are 8 and 7.
- 8 and 7 can not be assigned, since $\sum T_{ei} > T_s$

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8



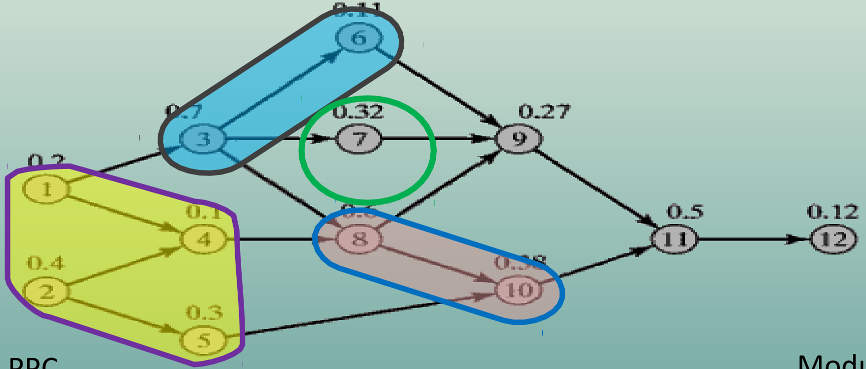
Iteration 3:

- Element 8 is selected. Alternatives are 10 and 7. It assigns element 10.
- ∑Tei = 0.6 + 0.38 = 0.98 min
- Alternative is 7.
- 7 can not be assigned, since ∑Tei

> Ts

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8

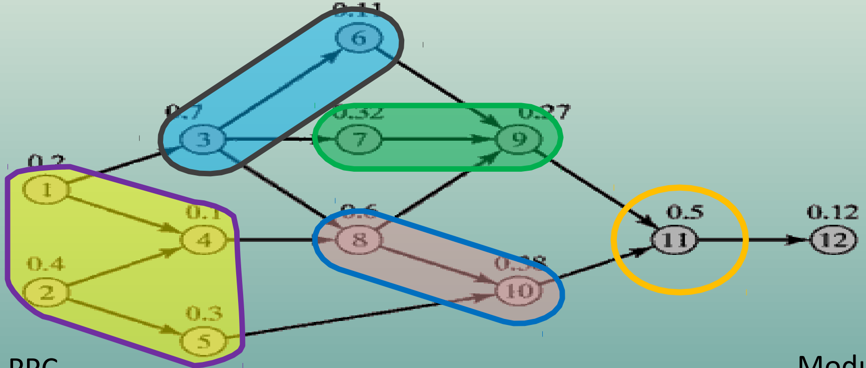


Iteration 4:

- 11 requires preceding elements Element 7 is selected.
- Alternative is 9.
- It assigns element 9.
- $\sum T_{ei}$= 0.32 + 0.27 = 0.59 min
- Alternative is 11.
- 11 can not be assigned, since ∑Tei > Ts

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8

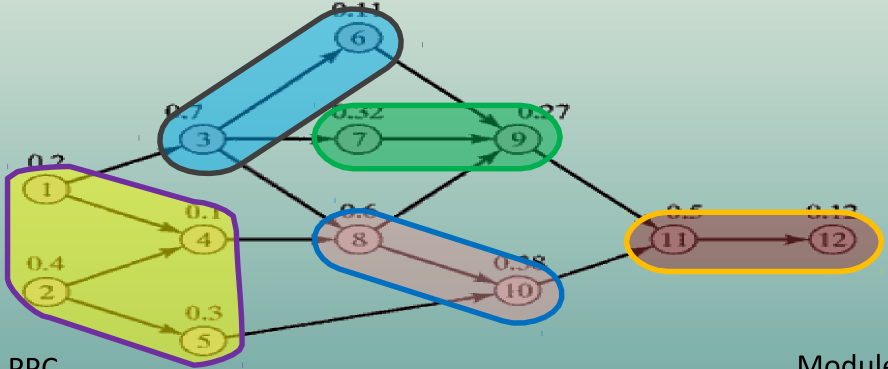


Iteration 5:

- Element 11 is selected. Alternative is 12.
- It assigns element 12.
- ∑Tei = 0.5 + 0.12 = 0.62 min
- All elements have been assigned

Example: Largest Candidate Rule

No	T_{ei} (min)	Predecessors	Successors
3	0.7	1	6,7,8
8	0.6	3,4	9,1
11	0.5	9,1	12
2	0.4	-	4,5
10	0.38	5,8	11
7	0.32	3	9
5	0.3	2	10
9	0.27	6,7,8	11
1	0.2	-	3,4
12	0.12	11	-
6	0.11	3	9
4	0.1	1,2	8



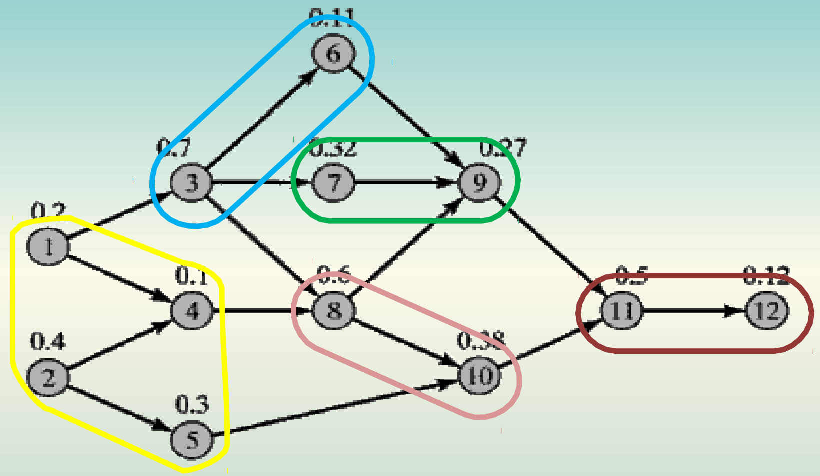
Final Solution:

- Workstation 1 : 2-5-1-4 = 1.0 min
- Workstation 2 : 3-6 = 0.81 min
- Workstation 3 : 8-10 = 0.98 min
- Workstation 4 : 7-9 = 0.59min
- Workstation 5 : 11-12 = 0.62min

Example: Solution

Work Elements Arrangement . T_s= 1 min.

Workstation	No	T_{ei} (min)	ΣT_{ei}
1	1	0.2	1.0
	2	0.4	
	4	0.1	
	5	0.3	
2	3	0.7	0.81
	6	0.11	
3	8	0.6	0.98
	10	0.38	
4	7	0.32	0.59
	9	0.27	
5	11	0.5	0.62
	12	0.12	

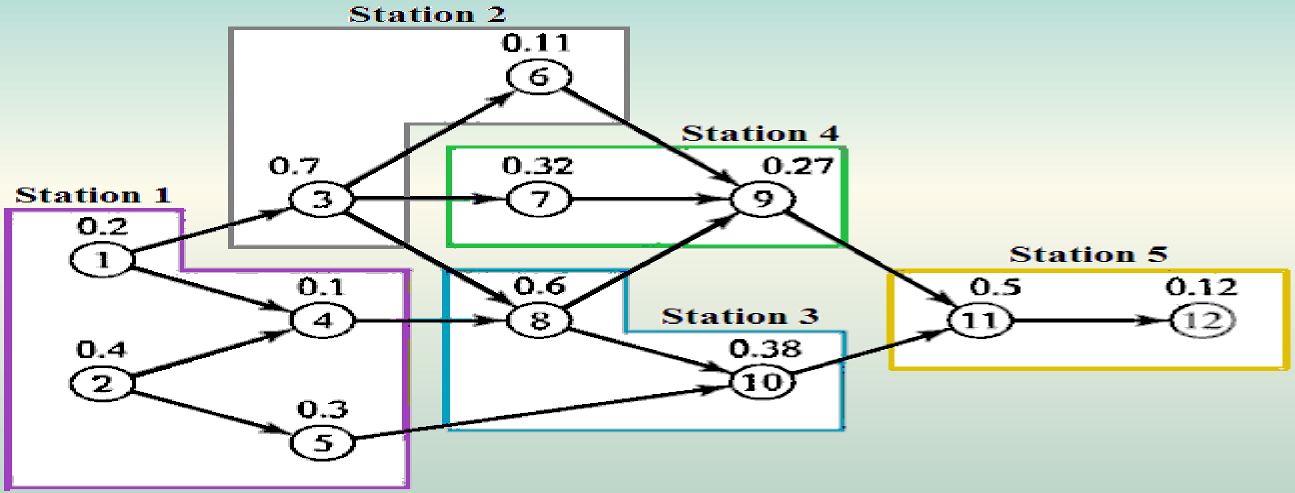


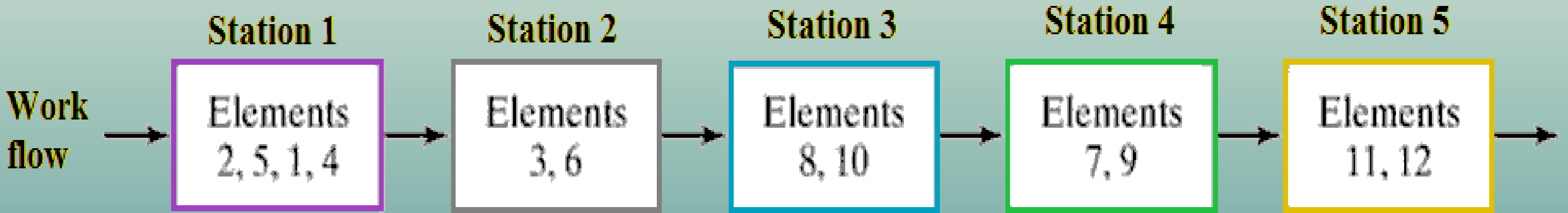
$$\text{Line efficiency} = \frac{\text{Total station time}}{\text{Cycle time x no. of workstations}} \times 100\%$$

$$= \frac{4}{5\ x\ 1} x100 = 80\%$$

Example: Solution

Work Elements Arrangement . T_s= 1 min.



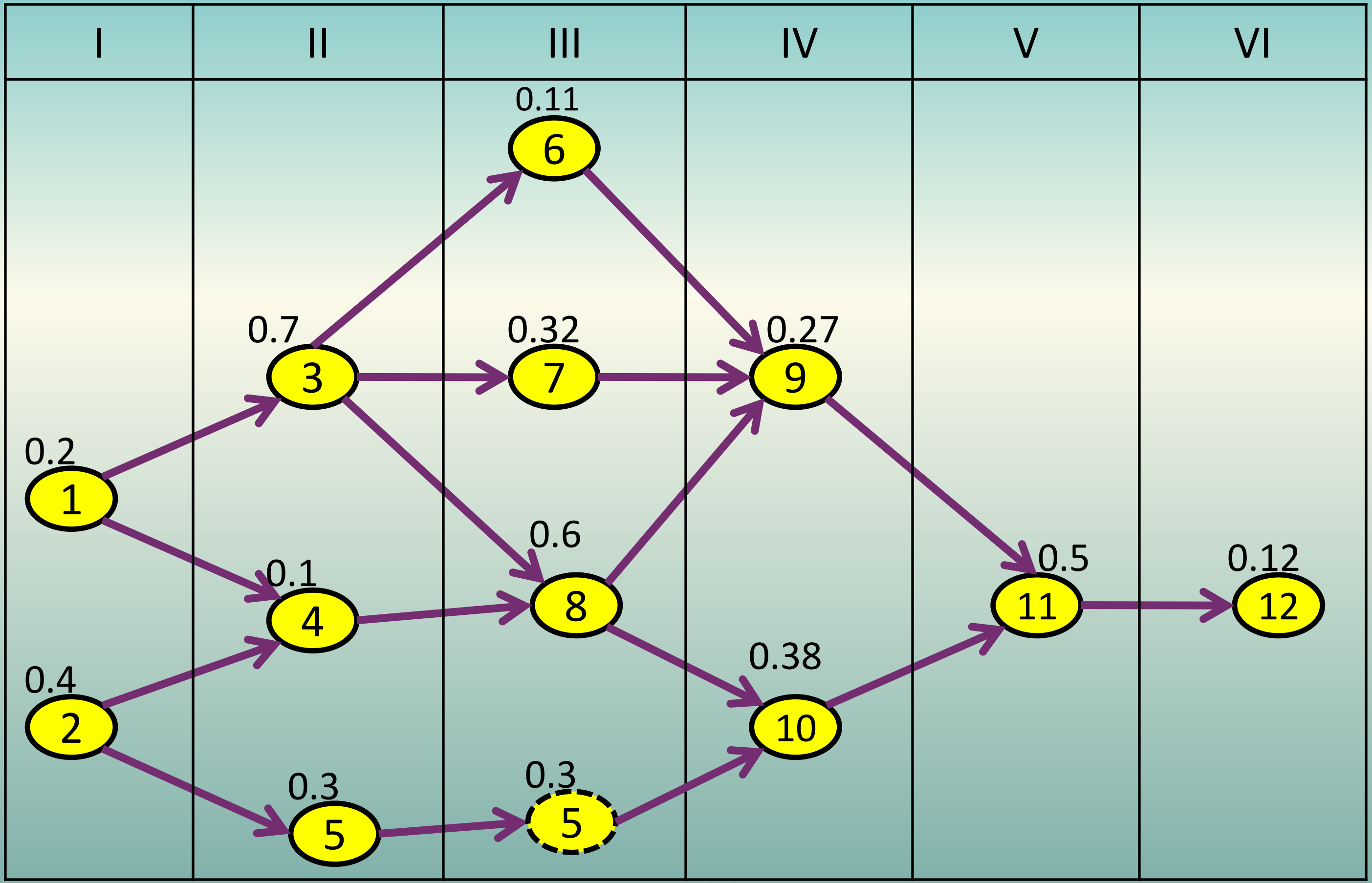


3. Kilbridge and Wester Method

Steps:

1. Selects work elements for assignment to stations according to their position in the precedence diagram
2. Work elements in the precedence diagram are arranged into columns
3. The elements can be organized into a list according to their columns, with the elements in the first column listed first
4. If a given element can be located in more than one column, then list all of the columns for that element
5. Proceed with same steps 1, 2, and 3 as in the largest candidate rule

Example: Kilbridge and Wester Method



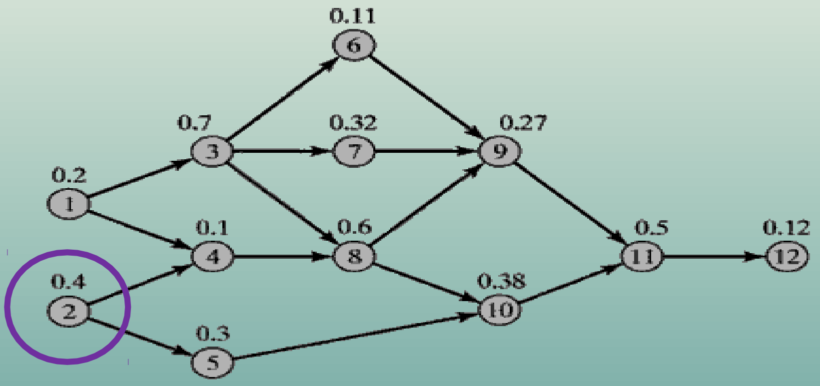
Example: Kilbridge and Wester Method

Work Elements Arranged According to T_{ei} Value for the Kilbridge and Wester Method. (T_s = 1 min)

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-

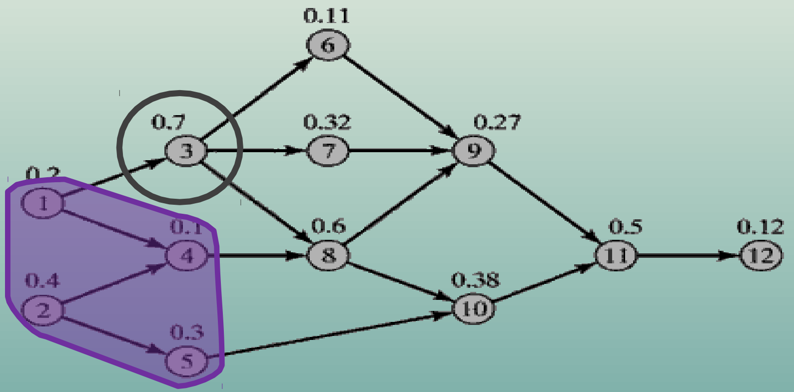


Iteration 1:

- Element 2 is selected. Alternatives are 1 and 5. It assigns element 1.
- $\Sigma T_{ei} = 0.4 + 0.2 = 0.6$ min
- Alternatives are 3, 4 and 5
- 3 can not be assigned, since $\Sigma T_{ei} > T_s$
- It assigns element 4
- $\Sigma T_{ei} = 0.6 + 0.1 = 0.7$ min
- Alternatives are 3 and 5
- 3 can not be assigned, since $\Sigma T_{ei} > T_s$
- It assigns element 5
- $\Sigma T_{ei} = 0.7 + 0.3 = 1.0$ min

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-



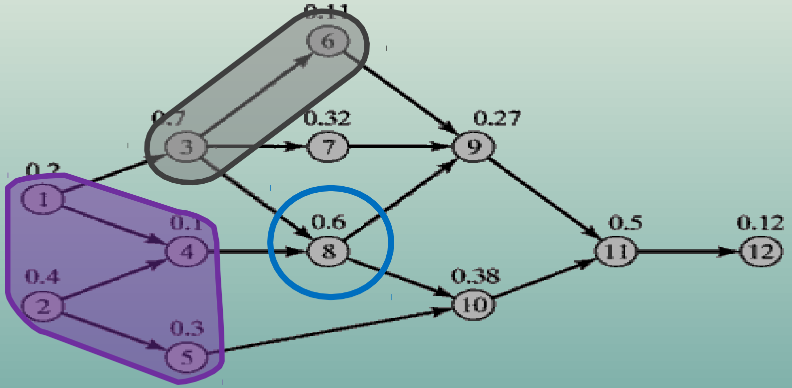
Iteration 2:

- Element 3 is selected.

  Alternatives are 8, 7 and 6.
- 8 and 7 can not be assigned, since
- $\Sigma T_{ei} > T_s$
- It assigns element 6.
- $\Sigma T_{ei} = 0.7 + 0.11 = 0.81$ min
- Alternatives are 8 and 7
- 8 and 7 can not be assigned, since
- $\Sigma T_{ei} > T_s$

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-

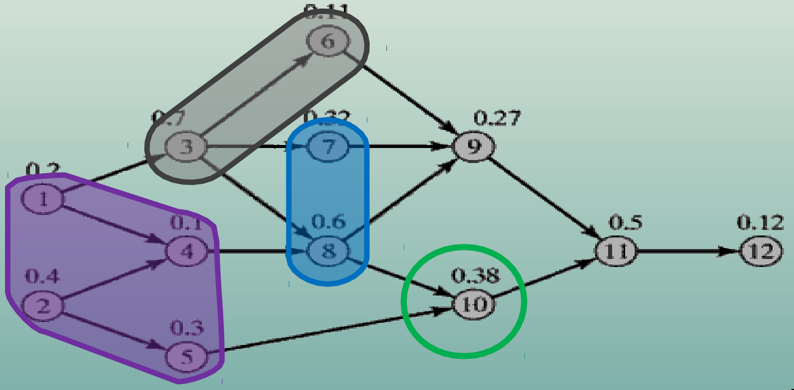


Iteration 3:

- Element 8 is selected. Alternatives are 7 and 10. It assigns element 7.
- ΣT_{ei}= 0.6 + 0.32 = 0.92 min
- Alternatives are 10 and 9
- 10 and 9 can not be assigned, since $\Sigma T_{ei} > T_s$

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-

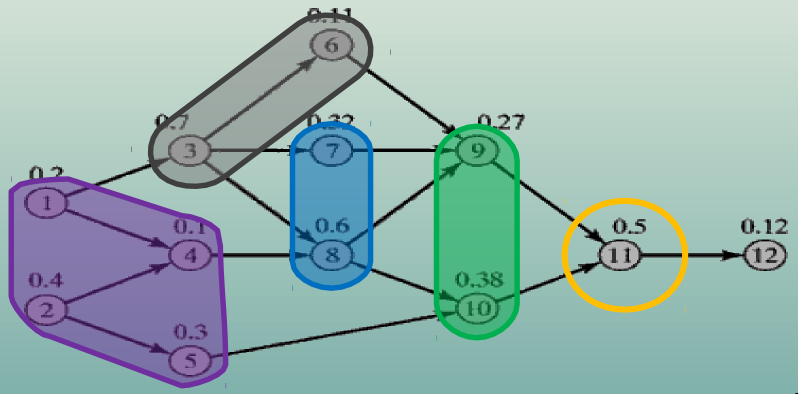


Iteration 4:

- Element 10 is selected. Alternatives is 9.
- It assigns element 9.
- ΣT_{ei}= 0.38 + 0.27 = 0.65 min
- Alternative is 11
- 11 can not be assigned, since $\Sigma T_{ei} > T_s$

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-



Iteration 5:

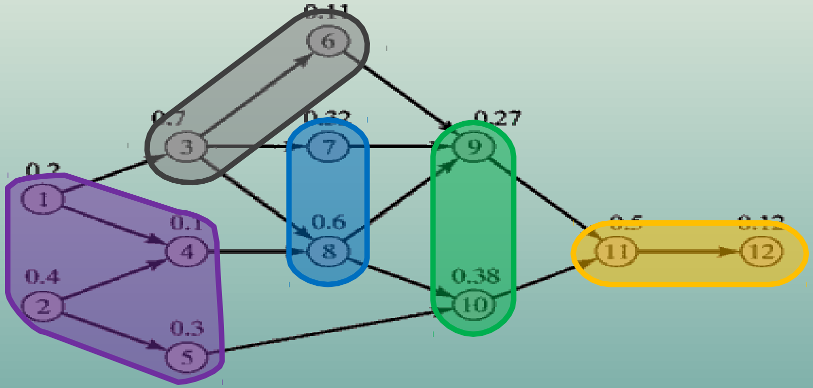
- Element 11 is selected. Alternatives is 12.
- It assigns element 12.
- ΣT_{ei}= 0.5 + 0.12 = 0.62 min
- All elements have been assigned

Example: Kilbridge and Wester Method

No	T_{ei} (min)	Region	Predecessors	Successors
2	0.4	I	-	4,5
1	0.2	I	-	3,4
3	0.7	II	1	6,7,8
4	0.1	II	1,2	8
5	0.3	II / III	2	10
8	0.6	III	3,4	9,1
7	0.32	III	3	9
6	0.11	III	3	9
10	0.38	III / IV	5,8	11
9	0.27	IV	6,7,8	11
11	0.5	V	9,1	12
12	0.12	VI	11	-

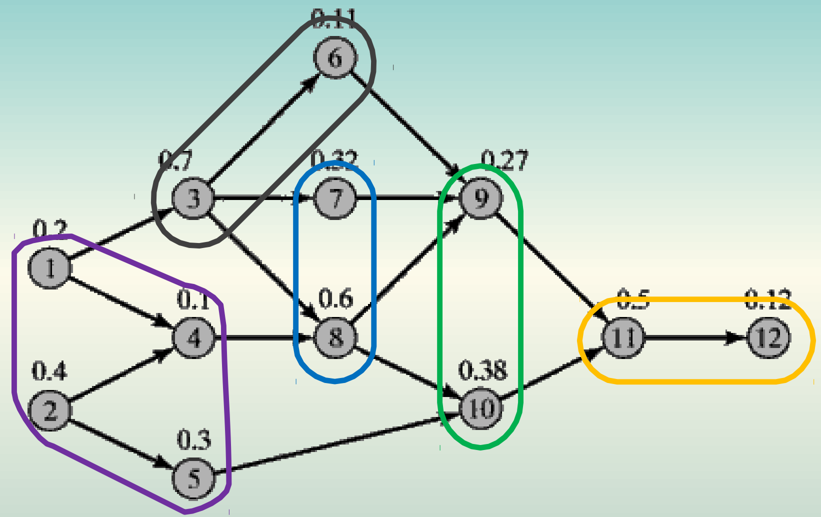
Final Solution:

- Workstation 1 : 2-1-4-5 = 1.0 min
- Workstation 2 : 3-6 = 0.81 min
- Workstation 3 : 8-7 = 0.92 min
- Workstation 4 : 10-9 = 0.65 min
- Workstation 5 : 11-12 = 0.62 min



Example: Solution

Workstation	No	T_{ei} (min)	$\sum T_{ei}$
1	1	0.2	1.0
	2	0.4	
	4	0.1	
	5	0.3	
2	3	0.7	0.81
	6	0.11	
3	7	0.32	0.92
	8	0.6	
4	9	0.27	0.65
	10	0.38	
5	11	0.5	0.62
	12	0.12	

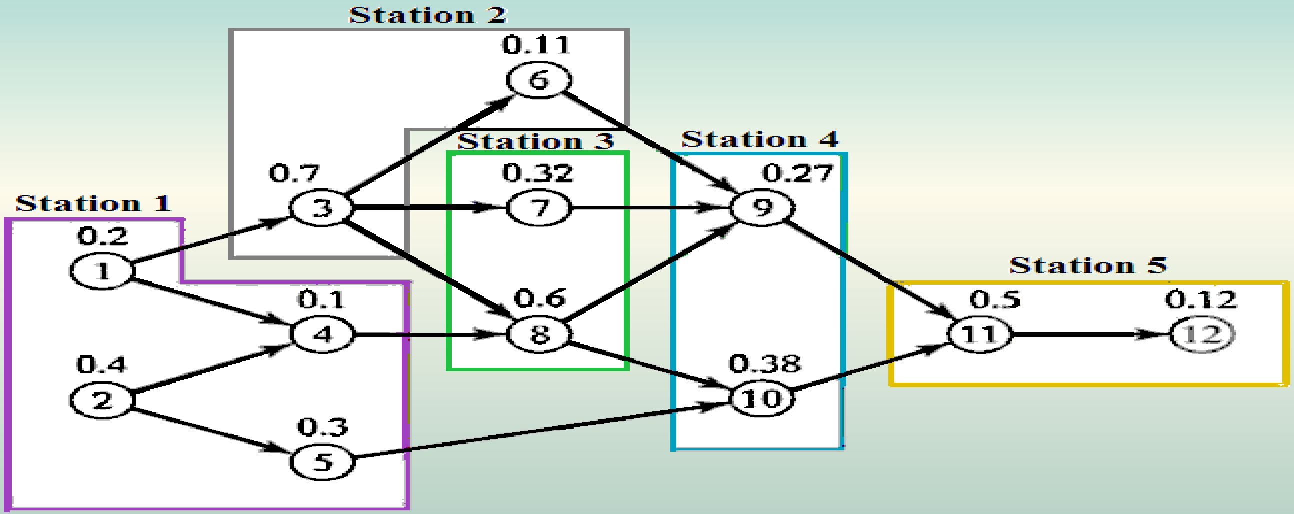


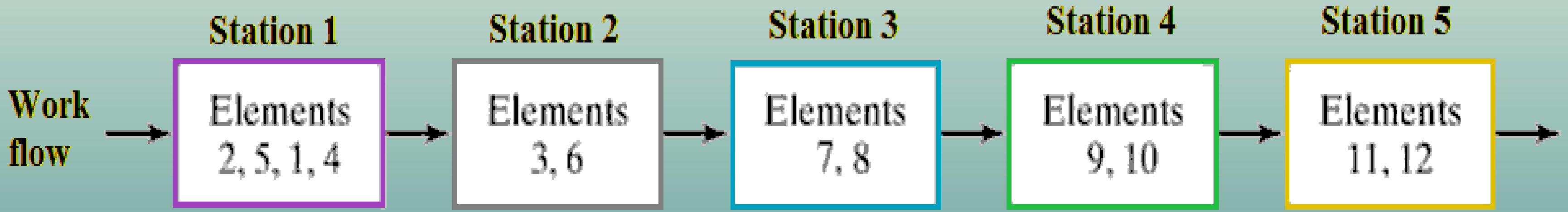
$$\text{Line efficiency} = \frac{\text{Total station time}}{\text{Cycle time x no. of workstations}} \times 100\%$$

$$= \frac{4}{5 \ x \ 1} x 100 = 80\%$$

Example: Solution

Work Elements Arrangement . T_s= 1 min.



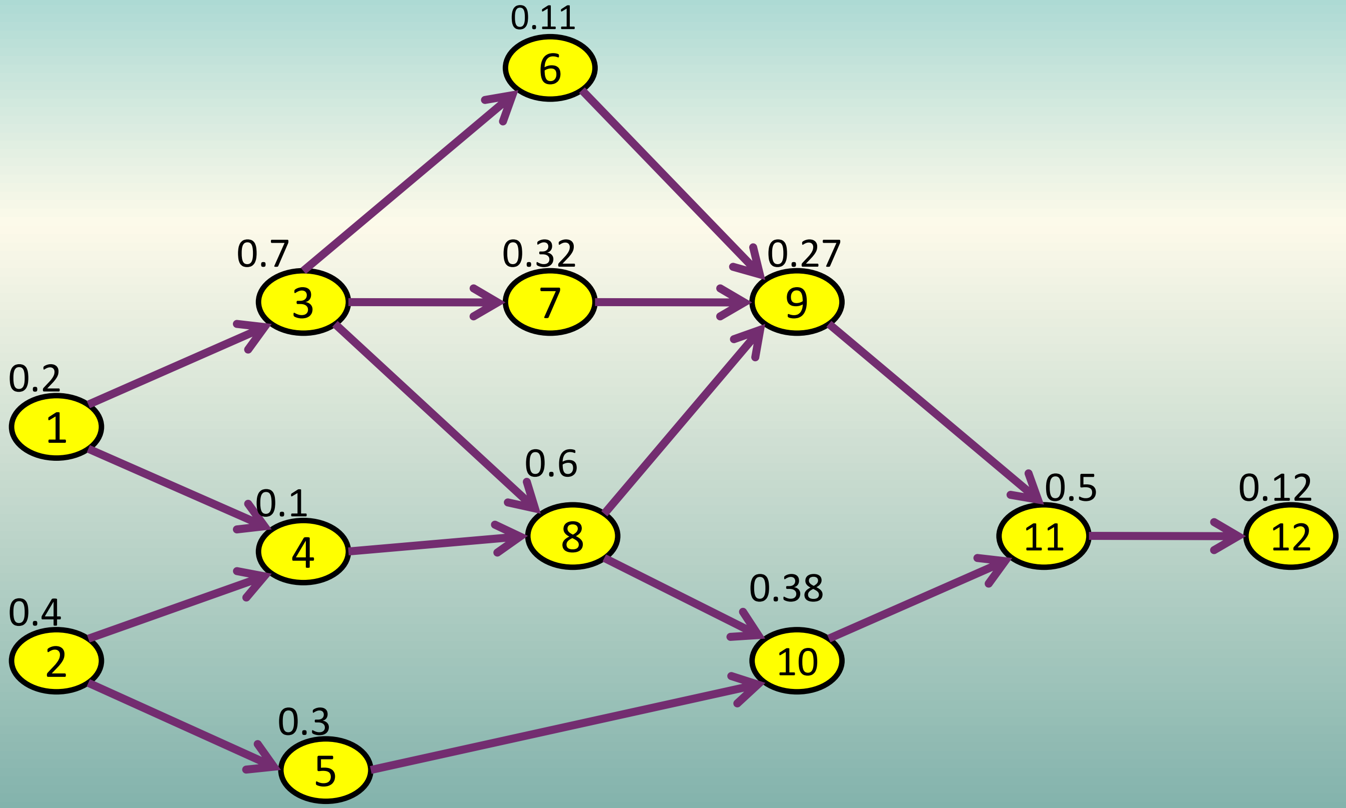


4. Ranked Positional Weights Method

1. A ranked position weight (RPW) is calculated for each work element
2. RPW for element *i* is calculated by summing the T_{ei} values for all of the elements that follow element *i* in the diagram plus T_{ei} itself
3. Work elements are then organized into a list according to their RPW values, starting with the element that has the highest RPW value
4. Proceed with same steps 1, 2, and 3 as in the largest candidate rule

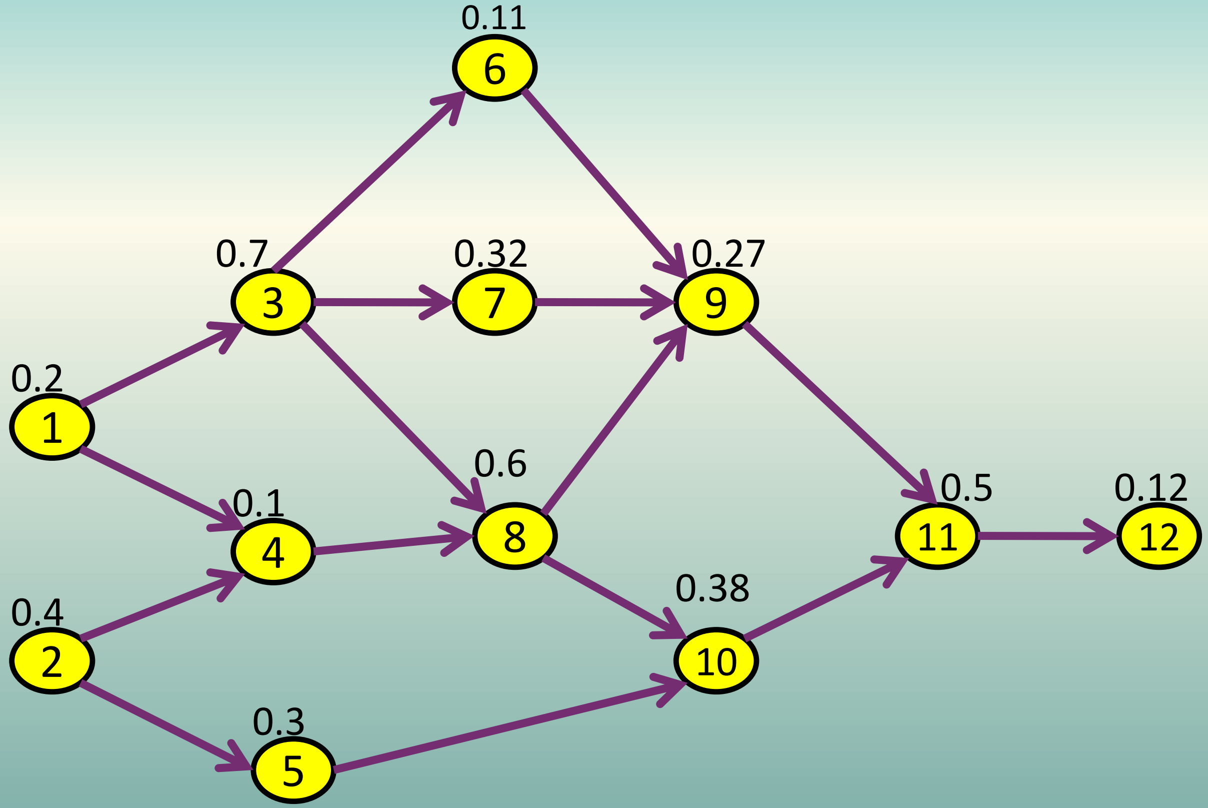
Example: Ranked Positional Weights Method

Continuing with same example ….



Example: Ranked Positional Weights Method

RPW= Total time from start element to end element



RPW of 1

Path 1-3-6-9-11-12

Path 1-3-7-9-11-12

Path 1-3-8-9-11-12

Path 1-3-8-10-11-12

Path 1-4-8-9-11-12

Path 1-4-8-10-11-12

Elements of RPW 1 are :

1-3-4-6-7-8-9-10-11-12

RPW-

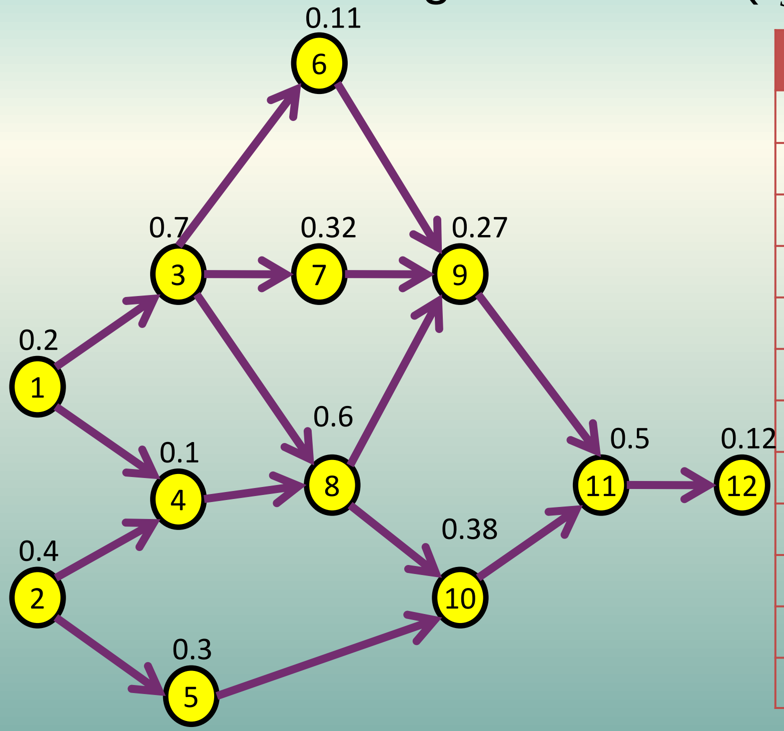
0.2+0.7+0.11+0.27+0.5+

0.12+0.32+0.6+0.38+0.1

= 3.30

Example: Ranked Positional Weights Method

Work Elements Arranged According to T_{ei} Value for the Ranked Positional Weights Method. (T_s = 1 min)



No	T_{ei} (min)	RPW	Predecessors	Successors	Elements of RPW
1	0.2	3.30	-	3,4	1, 3, 4, 6, 7, 8, 9, 10, 11, 12
3	0.7	3.00	1	6,7,8	3, 6, 7, 8, 9, 10, 11, 12
2	0.4	2.67	-	4,5	2, 4, 5, 8, 9, 10, 11, 12
4	0.1	1.97	1,2	8	4, 8, 9, 10, 11, 12
8	0.6	1.87	3,4	9,1	8, 9, 10, 11, 12
5	0.3	1.30	2	10	5, 10, 11, 12
7	0.32	1.21	3	9	7, 9, 11, 12
6	0.11	1.00	3	9	6, 9, 11, 12
10	0.38	1.00	5,8	11	10, 11, 12
9	0.27	0.89	6,7,8	11	9, 11, 12
11	0.5	0.62	9,1	12	11, 12
12	0.12	0.12	11	-	12

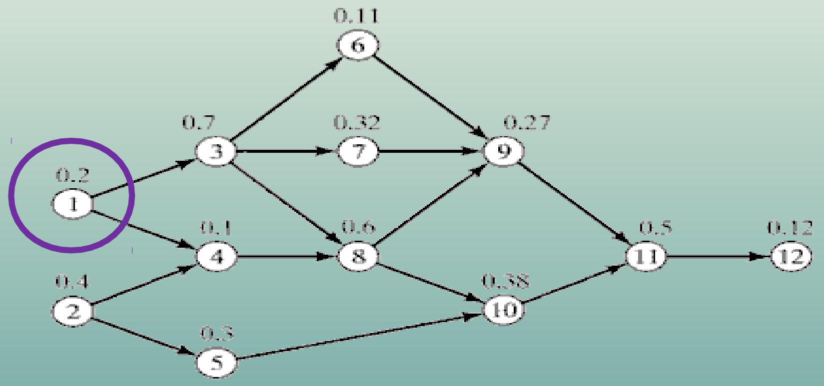
Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-

Iteration 1:

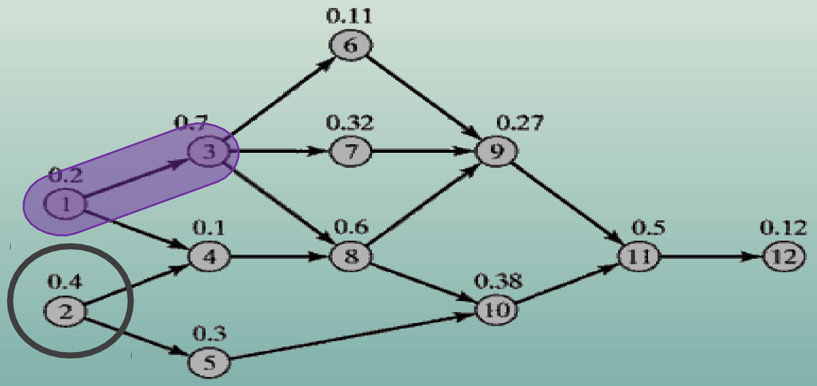
- Element 1 is selected.

  Alternatives are 3 and 2. It assigns element 3.
- $\sum T_{ei} = 0.2 + 0.7 = 0.9$ min
- Alternatives are 2, 7 and 6
- 2, 7 and 6 can not be assigned, since $\sum T_{ei} > T_s$



Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-

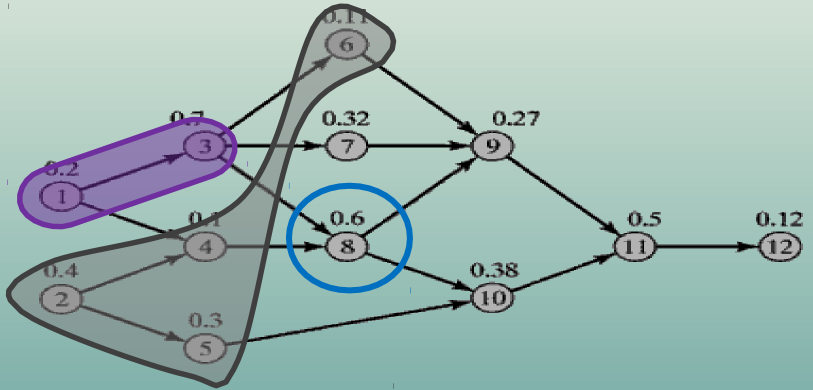


Iteration 2:

- Element 2 is selected. Alternatives are 4, 5, 7 and 6. It assigns element 4.
- $\sum T_{ei}$= 0.4 + 0.1 = 0.5 min
- Alternatives are 8, 5, 7 and 6.
- 8 can not be assigned, since $\sum T_{ei} > T_s$
- It assigns element 5.
- $\sum T_{ei}$= 0.5 + 0.3 = 0.8 min
- Alternatives are 8, 7 and 6.
- 8 and 7 can not be assigned, since $\sum T_{ei} > T_s$
- It assigns element 6.
- $\sum T_{ei}$= 0.8 + 0.11 = 0.91 min

Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-



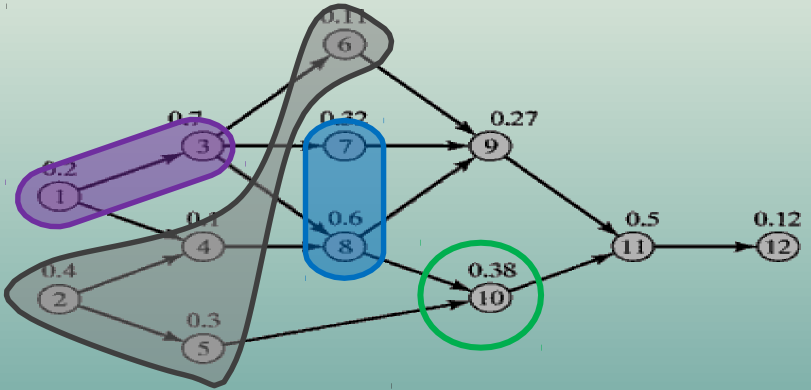
Iteration 3:

- Element 8 is selected.

  Alternatives are 7 and 10. It assigns element 7.
- $\sum T_{ei} = 0.6 + 0.32 = 0.92$ min
- Alternatives are 10 and 9
- 10 and 9 can not be assigned, since $\sum T_{ei} > T_s$

Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-



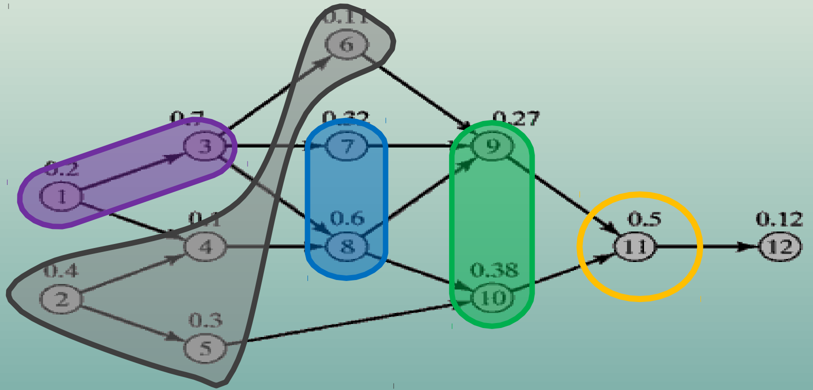
Iteration 4:

- Element 10 is selected.

  Alternative is 9.
- It assigns element 9.
- $\sum T_{ei}$= 0.38 + 0.27 = 0.65 min
- Alternative is 11
- 11 can not be assigned, since $\sum T_{ei} > T_s$

Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-



Iteration 5:

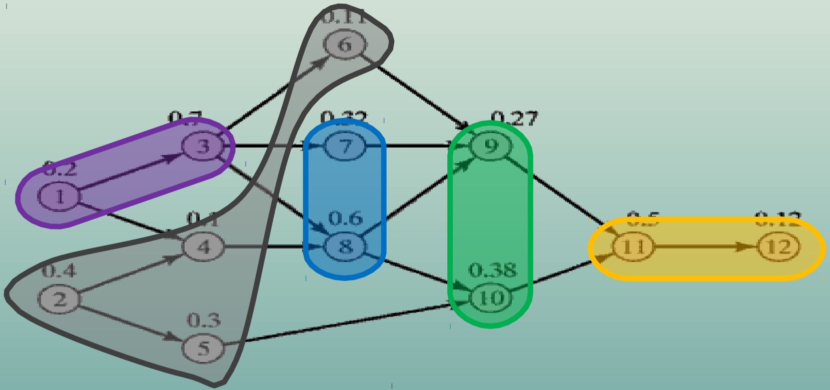
- Element 11 is selected.

  Alternative is 12.

- It assigns element 12.
- $\sum T_{ei} = 0.5 + 0.12 = 0.62$ min
- All elements have been assigned

Example: Ranked Positional Weights Method

No	T_{ek} (min)	RPW	Predecessors	Successors
1	0.2	3.30	-	3,4
3	0.7	3.00	1	6,7,8
2	0.4	2.67	-	4,5
4	0.1	1.97	1,2	8
8	0.6	1.87	3,4	9,1
5	0.3	1.30	2	10
7	0.32	1.21	3	9
6	0.11	1.00	3	9
10	0.38	1.00	5,8	11
9	0.27	0.89	6,7,8	11
11	0.5	0.62	9,1	12
12	0.12	0.12	11	-



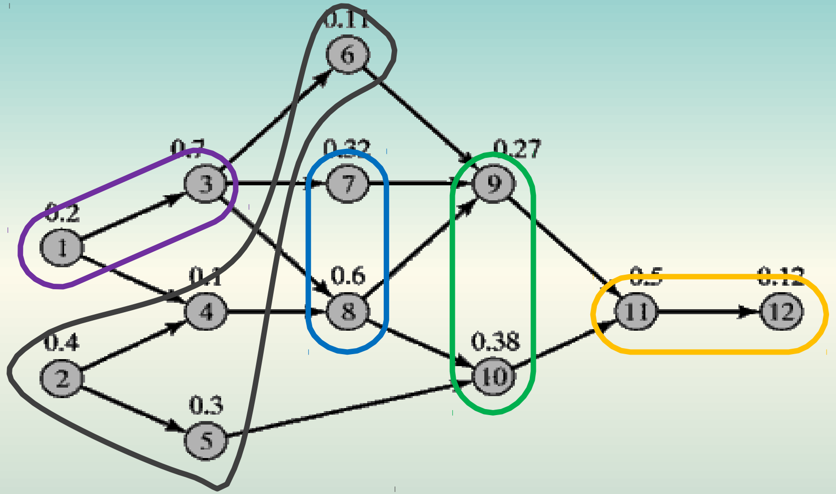
Final Solution:

- Workstation 1 : 1-3 =0.9 min
- Workstation 2 : 2-4-5-6 = 0.91 min
- Workstation 3 : 8-7 = 0.92 min
- Workstation 4 : 10-9 = 0.65 min
- Workstation 5 : 11-12 = 0.62 min

Example: Ranked Positional Weights Method

Work Elements Arrangement . T_s= 1 min.

Workstation	No	T_{ek} (min)	ΣT_{ek}
1	1	0.2	0.9
	3	0.7	
2	2	0.4	0.91
	4	0.1	
	5	0.3	
	6	0.11	
3	7	0.32	0.92
	8	0.6	
4	9	0.27	0.65
	10	0.38	
5	11	0.5	0.62
	12	0.12	

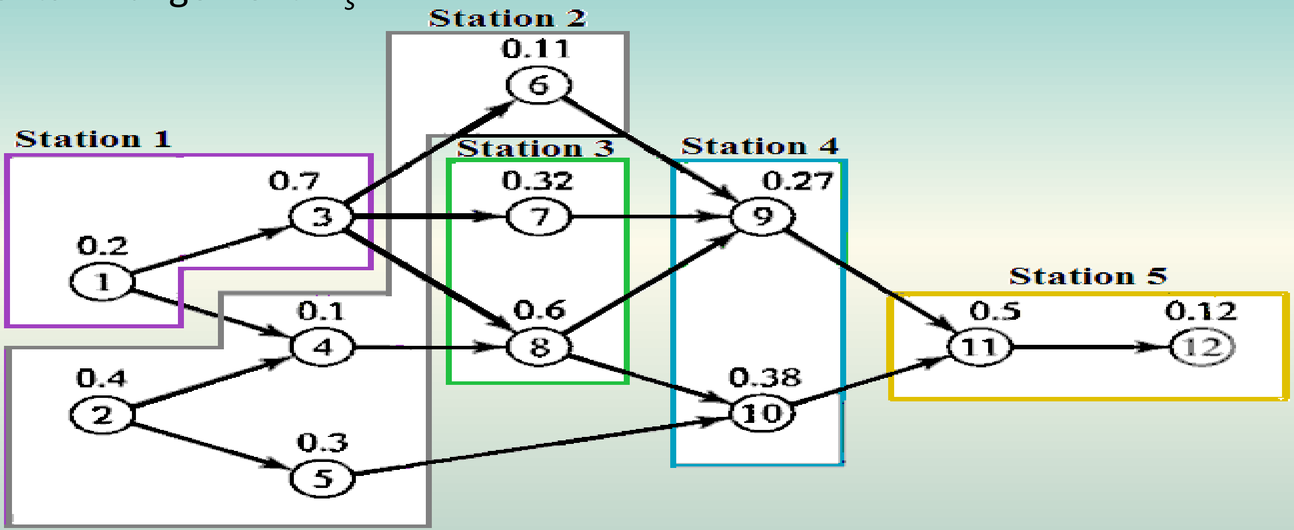


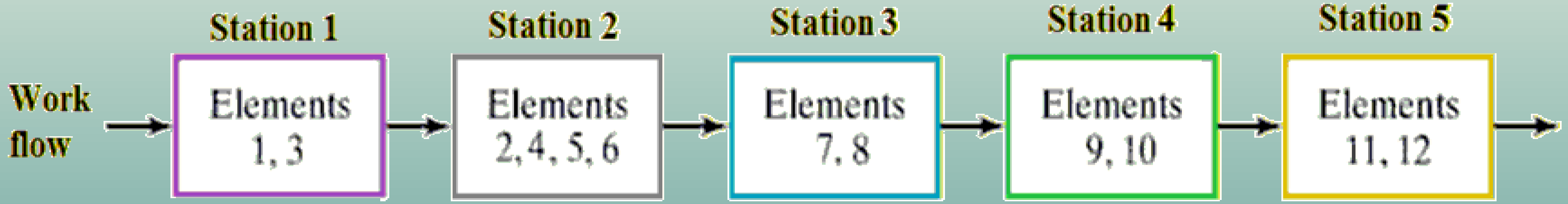
$$\text{Line efficiency} = \frac{\text{Total station time}}{\text{Cycle time x no. of workstations}} \times 100\%$$

$$= \frac{4}{5\ x\ 1} x100 = 80\%$$

Example: Ranked Positional Weights Method

Work Elements Arrangement . T_s= 1 min.





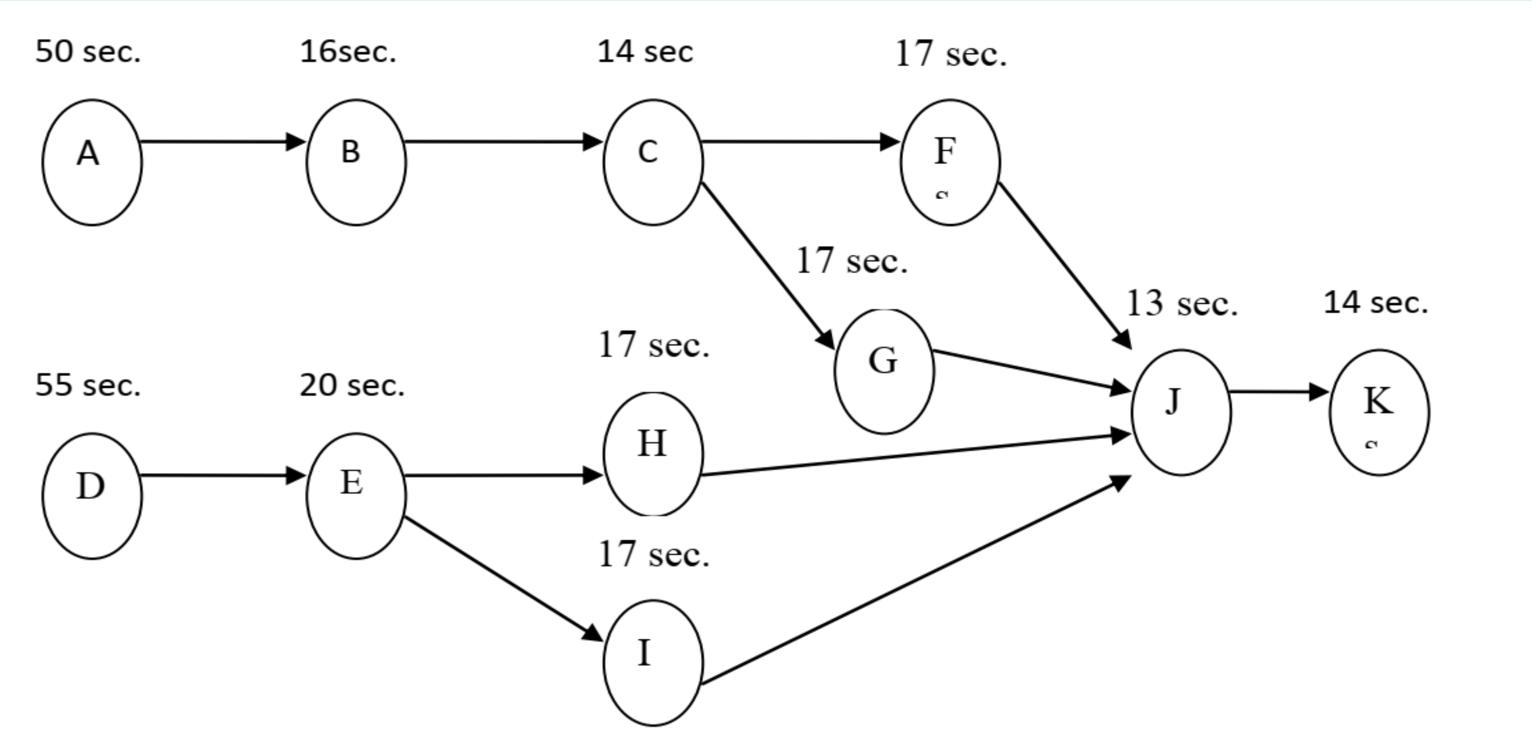
Example

The Model Z Bicycle is assembled in an assembly line. Four hundred and twenty bicycles are required each day. Production time per day is 420 minutes. Find the balance that minimizes the number of workstations, that stays within the workstation cycle time limitation, and that complies with task precedent constraints.

Task	Task Time (in seconds)	Task Description	Tasks that must precede	Task	Task Time (in seconds)	Task Description	Tasks that must precede
A	50	Connect the front tire to the bicycle frame.	-	G	17	Attach left hand brake to handle bar.	C
B	16	Insert the handle bar.	A	H	17	Attach right side pedal.	E
C	14	Tighten handle bar with two screws and nuts.	B	I	17	Attach left side pedal.	E
D	55	Connect the rear tire to the bicycle frame.	-	J	13	Position chain onto chain mechanism.	F,G,H,I
E	20	Position chain mechanism to the frame.	D	K	14	Attach seat post.	J
F	17	Attach right hand brake to handle bar.	C		250		

Solution

STEP 1. List the sequential relationships among tasks and then draw a precedence diagram



Solution

STEP 2. . Calculate the required workstation cycle time

Convert minutes to seconds because task times are in seconds.

CYCLE TIME = (PRODUCTION TIME PER DAY) /(OUTPUT PER DAY)

= (60 sec. X 420 min.) / (420 bicycles)

= 25,200 / 420 = 60 sec

STEP 3. Calculate the theoretical minimum number of workstations.

NUMBER OF WORK STATIONS = (SUM OF TOTAL TASK TIMES) / (CYCLE TIME)

= 250sec's / 60 sec's

= 3.97 = 4 (rounded)

Solution

STEP 4.Choose a primary rule that will determine how tasks are to be assigned to workstations

-For this example, our primary rule is to prioritize tasks based on the largest number of following tasks.

-If there is a tie, our secondary rule is to prioritize tasks in the order of the longest task time.

- In general, select rules that prioritize tasks according to the largest number of followers or based on length of time.

Task	Number of Following Tasks
A	6
B or D	5
C or E	4
F, G, H, or I	2
J	1
K	0

Solution

- STEP 5. Beginning with the first workstation, assign each task, one at a time, until the sum of the task times is equal to the workstation cycle time or until no other tasks can be assigned due to sequence or time restrictions.
  STEP 6. Repeat step 5 for the remaining workstations until all the tasks have been assigned to a workstation
  STEP 7.Evaluate the efficiency of the line balance.
  EFFICIENCY = (SUM OF ALL TASK TIMES))/(ACTUAL NO OF WORKSTATIONS)X(CYCLE TIME)
  = (250) / (5) X (60)
  = 0.83 OR 83 %

Solution

STEPS 5& 6. Balance made according to the Largest-Number-of-Following Tasks Rule

Stations	Task	Task Time (in seconds)	Number of Following Tasks	Remaining Unassigned Time	Feasible Remaining Tasks	Task with Most Followers	Task with Longest Operating Time
Station 1	A	50	6	10 idle	None		
Station 2	D	55	5	5 idle	None		
Station 3	B E C	16 20 14	5 4 4	44 24 10 idle	C, E C, F,G, H, I,J None	C, E C	E
Station 4	F G H	17 17 17	2 2 2	43 26 9 idle	G, H, I H, I, J None	G, H, I H, I	G, H, or I H or I
Station 5	I J K	17 13 14	2 1 0	43 30 16 idle	J K None		