Construct Assembly Line Layout with Earliest Finish Time

SMT Apparel Lanka Limited (Haragama)

MAT3991 | Group 06

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Acknowledgement

In performing our project, we had to take the help and guideline of some respected persons, who deserve our greatest gratitude. We would like to show our gratitude to Dr. Kokum Rekha De Silva, Prof. Niluka Rodrigo and Mrs. Chamathka Thilakarathna in the Mathematical department for giving us good guidelines for the project throughout numerous consultations. We would also like to expand our deepest gratitude to all those who have directly and indirectly guided us to complete our project.

We would like to offer acknowledgment for SMT Apparel Lanka Limited Haragama giving us this opportunity to do our project for their company. We would like to show gratitude to The Administration Manager Mr. Sriyantha Seram for dealing with their company. We would like to show our gratitude to the rest of the people in SMT Apparel for helping us to accomplish our jobs.

Many people, especially our mates and team members themselves, have made valuable comments and suggestions on this proposal which gave us the inspiration to work on the project. We thank all the people for their help directly and indirectly to complete our project

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ABSTRACT

Sri Lanka's apparel and textile manufacturing industry is the largest contributor to the national economy, earning a global reputation for producing high-quality apparel trusted by renowned international fashion brands. Despite its prominence, the industry faces challenges in meeting evolving consumer demands and maintaining competitiveness. One significant limitation is the lack of scientific analysis in the manufacturing process for new garment designs, which often results in extended production times. This study addresses the optimization of production processes, particularly focusing on constructing assembly lines to achieve the earliest possible completion times.

Techniques such as the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) were applied to systematically identify and reduce manufacturing time. Utilizing Power BI for comparative analysis of CPM and PERT results, the study demonstrated the potential to estimate actual operation times while minimizing traditional production durations. By employing mathematical models, this approach reduces lead times and offers a novel perspective on garment manufacturing, enabling the production of contemporary fashion designs more efficiently. The findings highlight the transformative impact of integrating scientific methods and data-driven tools in Sri Lanka's apparel manufacturing sector.

Keywords: Apparel, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Manufacturing, Power BI, Process Layout

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Introduction

Entrance of SMT Apparel Lanka Limited

SMT Apparel is a leading company in Sri Lanka which manufactures and exports readymade garments worldwide. The headquarters is located in Hongkong and other branches are in China, Vietnam, 8 main manufacturing plants all over Sri Lanka (Pallekale, Hunnasgiriya, Haragama, Katunayaka, Katana, Kotadeniyava) and other Asian countries.

- They started their journey in 1978 in Katunayake export processing zone.
- Company supplies more than 1000 employment opportunities with their required facilities with better satisfaction.
- They produce the best products with ISO standards with better satisfaction.
- They assist high contribution for dollar income

Vision and mission

Vision

Outperform the leaders of the global apparel industry by ensuring superior quality in "all" what we do

Mission

To build
Our cooperate image by adhering to socially responsible practices
To exceed
Customer expectations by adopting superior technology to improve product quality and efficiency at the lowest cost
To encourage
The commitment and excellence of our employees to promote teamwork within the organization

Product Portfolio

World class quality products according to customers' requirements.

- Shirt
- T-shirts
- Jeans
- Hoodies

Products

Major Customers

- Polo
- Ralph Lauren
- Club Monacco
- Daniel Cremieux
- Levi's
- Timberland
- Thomas Pink

Brand Logos

Branch of the Research

- Company branch located in Haragama Kandy District

- Contact Number: 0817388130

- Workers
  - Machine operators 760
  - Others 200

- Mainly focus on
  - Stitching and embroidery of clothes

Inside of the company

Production Process

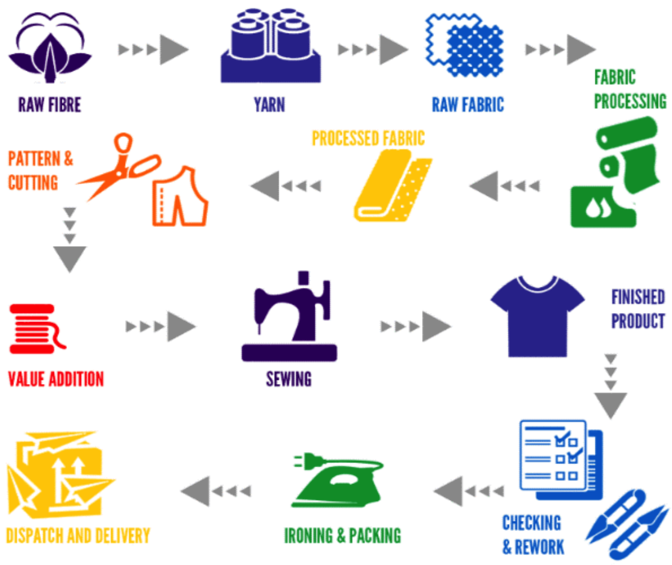
Garment Production involves a series of steps, from cutting fabric to finishing the final product. The process ensures that each garment is made with quality and efficiency.

Design/Sketch → Pattern Design → Sample Making → Production Pattern

Spreading ← Marker Making ← Grading

Cutting → Sorting/Bundling → Sewing/Assembling → Inspection

Dispatch ← Packing ← Final Inspection ← Pressing/Finishing



Production Process

Storing Cut Pieces

- Bundled cut pieces were delivered to the sewing plant from the cutting plant in katana.
- Store the cut pieces in the sub-store.
- Other row materials are also stored in an organized way.
    - Needles
    - Thread
    - Buttons & etc.

- They are using the 5S method to organize everything.
    - The 5S methodology is a systematic approach to workplace organization and productivity that originated in Japan.
    - The 5S Principles include Sort, set in Order, Shine, Standardize, and Sustain.

Storing Department

Numbering Cut Pieces

- Numbering each bundled cut piece according to the order number and corresponding production line.

- They use "Ply Numbering Equipment" to number the cut pieces.
    - To identify cut parts for further operation, the plies are marked with a small Sticker Usually on the back of the cloth.
    - This numbering is duplicated on every cut bundle.

- Numbering is useful to identify the right garment components of a garment when operators stitch the garment.
- After the numbering process is finished, cut pieces are sent to the production lines.

- Benefits of Numbering:
    - Simplifies the Sewing Process by ensuring pieces are assembled correctly.
    - Improves production efficiency and reduces errors.
    - Helps in identifying and correcting issues if a defect is found.

Cutting Department

Sewing

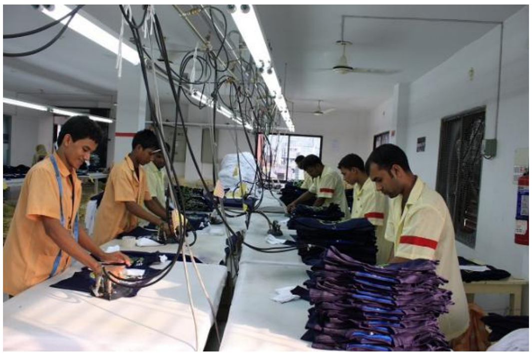
- Garment manufacturing is quite different from any other conventional manufacturing. Sewing section is one of the most important stages of apparel making. The sewing process is the attachment of different parts of the cut pieces. In this workplace. there are many operations who perform single operations. All the factors decide what parts of garment can be sewn at that station. Sewing section is the most important department in apparel industry.

- Sewing is a key process in garment production where cut fabric pieces are joined together to create a complete garment. It involves the use of sewing machines or hand stitching to assemble the fabric into the desired shape and design.

- Parts Preparation
    - Cut pieces are collected from the sub-store and arranged in bundles according to the production plan.
    - Garment components are aligned and prepared for accurate stitching.

- Marking Parts
    - Transfer pattern markings: Use tailor’s chalk, fabric markers, or tracing paper to transfer any markings like darts, pleats, or notches.
    - Garment components are marked to guide accurate and consistent stitching.

❖ Part Folding & Pressing
    ▪ Garment components are marked for precise and consistent stitching.




Sewing & Pressing Department

Production Line Layout

❖ A production line layout refers to the arrangement of workstations, machinery, and equipment in a way that optimizes the manufacturing process, reduces waste, and ensures efficient workflow.

❖ Key Aspects of a Production Line Layout
1. Product Flow
2. Workstation Organization
3. Space Utilization
4. Flexibility
5. Ergonomics

❖ In mass garment industries production line layout is different for every new product. The industrial engineer is responsible for the production layout and line setting.

❖ Industrial Engineering
    ▪ Industrial engineers design efficient production layouts.
    ▪ Industrial engineers develop, evaluate, and improve manufactured products and methods.

❖ Production line is customized for product complexity.
❖ The garment components are assembled by the operators step in a sequence of product construction.

Production Line

Quality Control

- ❖ Quality control is a process used to ensure that products or services meet established standards of quality. It involves systematic inspections, measurements, and testing to defect and eliminate defects, ensuring that the final output meets customer expectations and regulatory requirements.

- ❖ Quality control in the garment industry is a set of processes and checkpoints that ensure garments meet quality standards and are free of defects.

- ❖ During the quality control phase. We inspect the quality of the material. Check for stitching defects and material color. Any identified suggestions provided by the checkers.

- ❖ If there is a stitching fault checker suggests a solution to the worker who is responsible for the fault.


Quality Checking Department

Detailed layout of the production process

- Basic layout of a Shirt
- The Basic layout of a shirt consist of five Key Components

Component Lay out for basic style

Front Body Panel:

- Place the front body panel flat on the fabric, with the grainline parallel to the selvedge (edge of the fabric) for stability and stretch.
- Description: This is the main piece that covers the front of the torso.
- Shape: Typically, a simple rectangular or slightly curved piece, with a neckline cutout.

Back Body Panel:

- Place the back body panel next to the front, making sure both are aligned to use fabric efficiently.
- Description: Similar to the front body panel, this piece covers the back of the torso.
- Shape: Often a mirror image of the front panel without a neckline cutout (unless it's a style with a deeper back or cutout).

Sleeves:

- The sleeves are usually cut in a way that allows them to be folded over with minimal fabric waste. They are positioned along the edges or next to the body panels.
- Description: Two separate pieces for the left and right sleeves.
- Shape: Usually a simple shape, like a rectangle or slightly tapered at the top to fit the armhole.

Neckband:

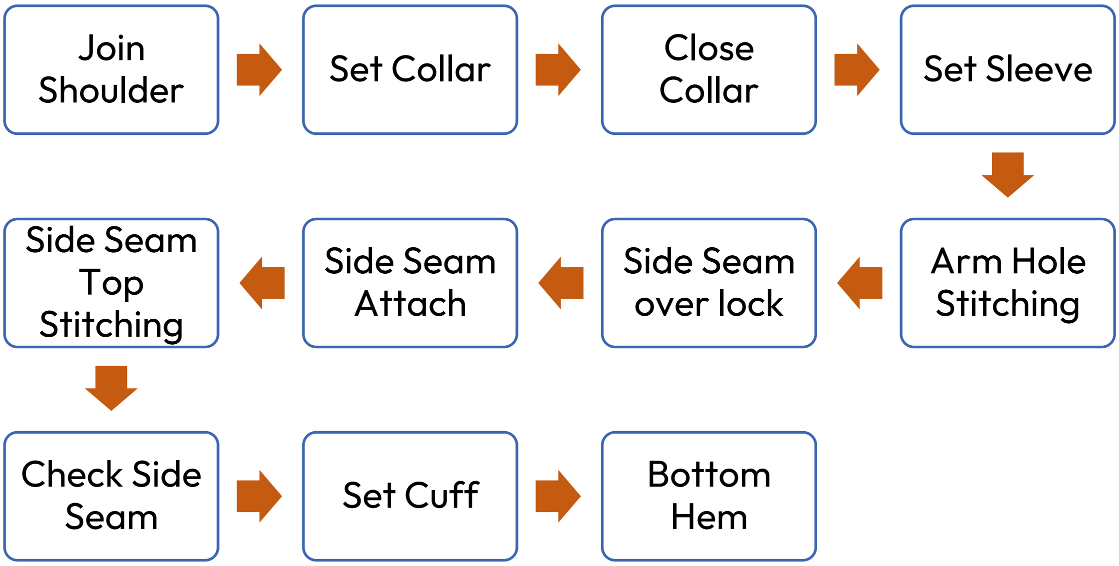
- The neckband strip is cut out separately, usually along the fabric's width to match the stretch direction of the fabric.
- Description: A strip of fabric that is sewn around the neckline to finish it off neatly.
- Shape: Typically, a narrow strip of fabric that matches the curve of the neck.

Hems:

- These are just the edges at the bottom of the body and sleeve pieces and do not require extra layout space as they are just folded over after sewing.
- Description: The bottom edges of the body and sleeves.
- Shape: The fabric is folded and sewn to prevent fraying and to give a clean, finished look.

Assemble Line of Shirt

- The assembly Process of a shirt involves several key steps. First the front and back panels are joined at the Shoulders. Then, the collar is attached to the neckline of the shirt. After that Sleeves are attach to the armholes and secured with appropriate stitching. The side seams are overlocked to prevent fraying. After inspecting the side seams for defects the cuffs are attached to complete the sleeves. Finally, the bottom hem is finished to completing the assembly of the Shirt.



Problems Identified and Motivations

Our project is based on real world application of Operations Research. First, we had different ideas when selecting a company, but as a team we discussed and concluded to visit SMT Apparel (Lanka) Ltd Haragama.

The reason for visiting this company is that the daily interactions are comparatively high, and we thought that we can get a better problem to apply OR for a larger area of raw materials or a production process.

As the next step we met the management of the company and discussed how to apply our theoretical knowledge in a larger practical field. And we found out that there are several problems occurring in the sewing department.

Current problems:

1. Machine breakdowns
2. Operator errors
3. Defects generation in sewing
4. Long line setting time
5. Frequent change in production planning
6. Production delays

By considering the above problems, it is noted that the sewing department takes more time for preparing and assembling the garment than using the traditional method of process flow. Hence study was focused on the assembly line process of the sewing department in depth and then we identified that there is no systematic way to create a production layout. Since the better production layout provides a better product within less time, we focused on introducing a new scientific approach for production. Therefore, this study was carried out to make the optimum assembly line layout of a shirt within the earliest finish time by using project management techniques.

Motivations

The project management techniques provide scientific methods for product manufacturing and whole production management. The project management technique can be used to optimize the layout of an assembly line in a garment factory in several ways.

- **Minimizing production time**
  Identifying the critical path of the assembly line, which is the sequence of tasks that takes the longest time to complete these tasks, the overall production time can be reduced.

- **Improving efficiency**
  Identifying bottlenecks in the assembly line, which are tasks that take longer than expected. By addressing these bottlenecks, the overall efficiency of the assembly line can be improved.

- **Managing resources**
  Using project management techniques can determine the resources (e.g., personnel, equipment) needed for each task on the assembly line. This can help managers make more informed decisions about allocating resources and preventing over or underutilization.

- **Identifying potential delays**
  Identifying tasks that are dependent on each other. If one task is delayed, it can affect the completion of other tasks. By identifying these dependencies, managers can anticipate and mitigate potential delays.

- **Better tracking**
  Track the progress of the assembly line, which can help managers identify issues early on and adjust as needed.

- **Scheduling**
  Creating a schedule for the assembly line, which can help managers plan for and coordinate the use of resources and personnel.

- **To reduce lead time**
  Reduce the lead time by reducing the time required to produce the garments and improve the production process.

Solving Methods

PERT (Program Evaluation and Review Technique)

Project management planning tool used to calculate the amount of time it will take to realistically finish a project

Key features

- Nodes
- Arrows
- Concurrent arrows
- Diverging arrows
- Pessimistic estimate

CPM (Critical Path Method)

A project management technique that helps plan, schedule, and execute complex projects

Key steps:

- Identify tasks
- Identify dependencies
- Estimate task durations
- Create a network diagram
- Monitor and update the project schedule

We use excel as the software to solve the problem using CPM AND PERT Method.

Power BI

A business analytics service provided by Microsoft lets you visualize your data and share insights.

We use power Bi to compare our results obtained using CPM and PERT and illustrate them graphically.

Data Collection Process

Data Collection Methods

Field Visit

Data was gathered through direct field visits, allowing for on-site observations and accurate recording of project details.

Questionnaire

A questionnaire was distributed to gather input from project participants, focusing on task dependencies and sequencing. The following questions were asked:

- What tasks must be completed before this task can begin?
- What tasks can be carried out simultaneously with this task?
- What tasks should follow immediately after this task?

Historical Data Recording:

The time taken for each activity in the production process was recorded daily over 180 days. This provided a comprehensive dataset, capturing variations in process execution due to factors such as worker efficiency, machine performance, and external interruptions.

Establish Dependencies:

Activity	Operation/Description	Immediate Predecessor Activities
A	Sleeve hem	-
B	Join the collar rib	-
C	Open the seam and track	B
D	Join shoulder	-
E	Attach the collar rib to body	C, D
F	Attach the main label	E
G	Attach tape to collar, fold & cut tap	F
H	Close the neck tape	G
I	Attach sleeve	H, A
J	Side seam with care label	I
K	Bottom hemming	J
L	Track sleeve	K

PERT Methodology

The **Program Evaluation and Review Technique (PERT)** is a statistical tool used in project management designed to analyze and represent the tasks involved in completing a project. Unlike CPM, which focuses on deterministic time estimates, PERT incorporates uncertainty in activity completion times by using three-time estimates for each activity:

- **Optimistic time (a_i):** The shortest time in which the activity can be completed (duration of activity *i* assuming the most favorable conditions)
- **Most likely time (m_i):** The best estimate of the time required to complete the activity under normal conditions (estimate of the most likely duration of activity *i)*
- **Pessimistic time (b_i):** The longest time that an activity might take (duration of activity *i* assuming the least favorable conditions)

  The three-time estimates—optimistic, pessimistic, and most likely—used in PERT follow a triangular distribution, effectively capturing variability in task durations.

- PERT then estimates expected duration t_i and variance v_i of each activity's duration as:

$$t_i = (a_i + 4m_i + b_i)/6$$

$$v_i = (b_i - a_i)^2/36$$

- The expected (or mean) time required to complete any path in the network is the sum of the expected times (the t_i) of the activities on the path
- Assuming the individual activity times in a project are independent of one another, we may also calculate the variance of the completion time for any path as the sum of the variances (the v_i) of the activities on the path.
- PERT considers the path with the largest expected completion time to be the critical path.

Data Collection and Time Estimates for PERT Analysis

To incorporate uncertainty in activity durations, the **Program Evaluation and Review Technique (PERT)** was employed. This required obtaining three-time estimates for each activity in the assembly line process. The time estimates were derived from historical data collected over a six-month period (180 days) from the sewing department of SMT Apparel Lanka Limited.

Data Preparation Process

Establishing Time Estimates:

From the collected data, three-time estimates for each activity were determined as follows:

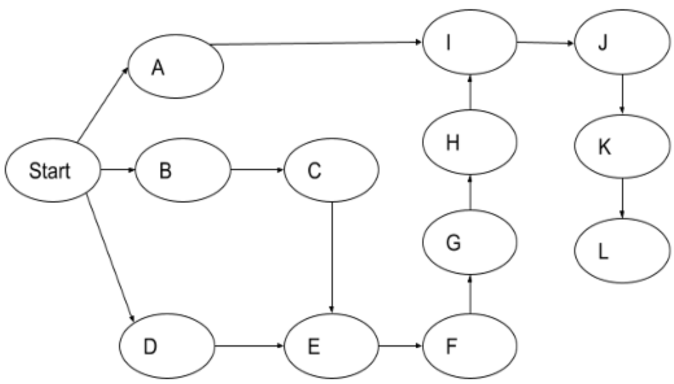
- **Optimistic Time (a_i):** The minimum time observed for the activity over the 180 days. This represents the best-case scenario where all conditions are ideal.
- **Most Likely Time (m_i):** The average of the recorded times for the activity. This value reflects the typical or most probable duration under normal working conditions.
- **Pessimistic Time (b_i):** The maximum time observed for the activity during the 180 days. This accounts for the worst-case scenario where delays and disruptions are at their highest.

Activity	Optimistic time	Most Probable time	Pessimistic time
A	40.56	52.00	62.40
B	14.20	18.20	21.84
C	16.22	20.80	24.96
D	38.53	49.40	59.28
E	48.67	62.40	74.88
F	28.39	36.40	43.68
G	66.92	85.80	102.96
H	43.60	55.90	67.08
I	56.78	72.80	87.36
J	65.91	84.50	101.40
K	48.67	62.40	74.88
L	28.39	36.40	43.68

Activity	Min	Average	Max
A	40.56	52.00	62.40
B	14.20	18.20	21.84
C	16.22	20.80	24.96
D	38.53	49.40	59.28
E	48.67	62.40	74.88
F	28.39	36.40	43.81
G	66.92	85.80	102.96
H	43.60	55.90	67.08
I	56.78	72.80	87.36
J	65.91	84.50	101.40
K	48.67	62.40	74.88
L	28.39	36.40	43.68

These times were recorded in seconds

In the solution process since there are multiple initial points, we add dummy initial node as Start node with a time duration of 0 seconds. Here identified the immediate successor and immediate predecessor of each task. Following figure shows the Activity on node representation of above problem. Here there are three starting activities and then we must add a dummy start node.



AON graph representation

- **Earliest Start Time (EST):** The soonest an activity can begin after its dependencies are completed.
- **Earliest Finish Time (EFT):** Calculated as EST plus the activity duration.
- **Latest Finish Time (LFT):** The latest an activity can conclude without impacting the project timeline.
- **Latest Start Time (LST):** This is derived from LFT minus the activity duration.

The slack time (float time) signifies the period within which an activity can be postponed without affecting the project's completion date. The critical path is defined as the longest route through the network diagram, where activities along this path directly affect the project's deadline. If any activities on the critical path are delayed, the culmination of the project will also be delayed. Here, Slack time can be calculated using either:

***Slack Time** = LST - EST or Slack Time = LFT – EFT*

Activities	Optimistic	Most Probable	Pessimistic	Activity time	EST	EFT	LST	LFT	Slack	
Start	0	0	0	0	0	0	0	0	0	**
A	40.56	52.00	62.40	48.44	0	48.44	247.29	295.73	247.29	
B	14.20	18.20	21.84	18.23	0	18.23	3.13	21.36	3.13	
C	16.22	20.80	24.96	23.59	18.23	41.82	21.36	44.95	3.13	
D	38.53	49.40	59.28	44.95	0	44.95	0	44.95	0	**
E	48.67	62.40	74.88	64.17	44.95	109.12	44.95	109.12	0	**
F	28.39	36.40	43.68	39.01	109.12	148.13	109.12	148.13	0	**
G	66.92	85.80	102.96	87.74	148.13	235.87	148.13	235.87	0	**
H	43.60	55.90	67.08	59.86	235.87	295.73	235.87	295.73	0	**
I	56.78	72.80	87.36	68.02	295.73	363.75	295.73	363.75	0	**
J	65.91	84.50	101.40	84.19	363.75	447.94	363.75	447.94	0	**
K	48.67	62.40	74.88	64.55	447.94	512.49	447.94	512.49	0	**
L	28.39	36.40	43.68	34.79	512.49	547.28	512.49	547.28	0	**

These times were recorded in seconds
"" denotes the critical activities**

Activities	Optimistic	Most Probable	Pessimistic	Activity time	EST	EFT	LST	LFT	Slack	
Start	0	0	0	0	0	0	0	0	0	**
A	40.56	52.00	62.40	54.21	0	54.21	244.19	298.4	244.19	
B	14.20	18.20	21.84	20.57	0	20.57	5.33	25.9	5.33	
C	16.22	20.80	24.96	20.06	20.57	40.63	25.9	45.96	5.33	
D	38.53	49.40	59.28	45.96	0	45.96	-8E-14	45.96	-7.81597E-14	
E	48.67	62.40	74.88	68.5	45.96	114.46	45.96	114.46	-7.81597E-14	
F	28.39	36.40	43.68	38.57	114.46	153.03	114.46	153.03	0	**
G	66.92	85.80	102.96	86.06	153.03	239.09	153.03	239.09	0	**
H	43.60	55.90	67.08	59.31	239.09	298.4	239.09	298.4	0	**
I	56.78	72.80	87.36	83.55	298.4	381.95	298.4	381.95	0	**
J	65.91	84.50	101.40	91.69	381.95	473.64	381.95	473.64	0	**
K	48.67	62.40	74.88	53.43	473.64	527.07	473.64	527.07	0	**
L	28.39	36.40	43.68	42.23	527.07	569.3	527.07	569.3	0	**

These times were recorded in seconds

"" denotes the critical activities**

Activities	Optimistic	Most Probable	Pessimistic	Activity time	EST	EFT	LST	LFT	Slack	
Start	0	0	0	0	0	0	0	0	0	**
A	40.56	52.00	62.40	42.62	0	42.62	214.12	256.74	214.12	
B	14.20	18.20	21.84	18.21	0	18.21	6.87	25.08	6.87	
C	16.22	20.80	24.96	22.9	18.21	41.11	25.08	47.98	6.87	
D	38.53	49.40	59.28	47.98	0	47.98	0	47.98	0	**
E	48.67	62.40	74.88	52.7	47.98	100.68	47.98	100.68	0	**
F	28.39	36.40	43.68	33.97	100.68	134.65	100.68	134.65	0	**
G	66.92	85.80	102.96	73.21	134.65	207.86	134.65	207.86	0	**
H	43.60	55.90	67.08	48.88	207.86	256.74	207.86	256.74	0	**
I	56.78	72.80	87.36	73.91	256.74	330.65	256.74	330.65	0	**
J	65.91	84.50	101.40	76.15	330.65	406.8	330.65	406.8	0	**
K	48.67	62.40	74.88	57.44	406.8	464.24	406.8	464.24	0	**
L	28.39	36.40	43.68	31.86	464.24	496.1	464.24	496.1	0	**

These times were recorded in seconds

"" denotes the critical activities**

Activities	Optimistic	Most Probable	Pessimistic	Activity time	EST	EFT	LST	LFT	Slack	
Start	0	0	0	0	0	0	0	0	0	**
A	40.56	52.00	62.40	52.9	0	52.9	257.25	310.15	257.25	
B	14.20	18.20	21.84	19.08	0	19.08	19.63	38.71	19.63	
C	16.22	20.80	24.96	17.69	19.08	36.77	38.71	56.4	19.63	
D	38.53	49.40	59.28	56.4	0	56.4	-9E-14	56.4	-8.52651E-14	
E	48.67	62.40	74.88	60.71	56.4	117.11	56.4	117.11	-8.52651E-14	
F	28.39	36.40	43.68	35.17	117.11	152.28	117.11	152.28	0	**
G	66.92	85.80	102.96	96.4	152.28	248.68	152.28	248.68	0	**
H	43.60	55.90	67.08	61.47	248.68	310.15	248.68	310.15	0	**
I	56.78	72.80	87.36	83.45	310.15	393.6	310.15	393.6	0	**
J	65.91	84.50	101.40	93.28	393.6	486.88	393.6	486.88	0	**
K	48.67	62.40	74.88	68.42	486.88	555.3	486.88	555.3	0	**
L	28.39	36.40	43.68	37.94	555.3	593.24	555.3	593.24	0	**

These times were recorded in seconds

"" denotes the critical activities**

In the PERT analysis, the activity times are calculated using a triangular distribution, which incorporates three-time estimates: optimistic, most probable, and pessimistic. To model variability and uncertainty in task durations, random numbers are generated and used within the triangular distribution framework to determine the activity time. As a result, the calculated activity times are not static but change with each iteration. This variability directly impacts the identification of critical activities within the project, as changes in activity times may alter the critical path. Consequently, the set of critical activities varies depending on the generated activity times, highlighting the dynamic nature of the analysis. This approach provides a more realistic representation of project scheduling by accounting for uncertainties in task durations and allowing flexibility in decision-making.

Advantages of this Approach

- **Comprehensive Analysis:** By utilizing a robust dataset spanning six months, the derived time estimates effectively capture the variability in the assembly line process.
- **Enhanced Planning:** The inclusion of optimistic and pessimistic scenarios allows for a more informed risk assessment and better contingency planning.
- **Improved Resource Allocation:** The calculated expected times provide a reliable foundation for scheduling and resource allocation, minimizing delays and inefficiencies.

CPM

Theory and Methodology

This section addresses the problem of project scheduling in Project management, which can be solved using the Critical Path Method (CPM).

Critical Path

The critical path refers to the longest chain of tasks necessary to complete a project. Tasks along this path are known as critical activities; delays in any of these tasks will result in a setback of the entire project timeline.

Critical Path Method

The Critical Path Method (CPM) is one of various techniques used in project planning. It involves outlining activities sequentially from the project's initiation to its completion, recognizing that many projects may involve only one critical path. CPM is particularly useful for projects comprised of several distinct activities. If certain activities depend on the completion of others before they can commence, the project evolves into a more intricate series of tasks. Additionally, some projects may incorporate multiple critical paths depending on the workflow logic applied. A delay in any task within the critical path results in a corresponding delay in project deliverables.

Key Steps in Critical Path Method

Utilizing the critical path method during project planning consists of six key steps:

Step 1: Activity Specification: Identify the project activities using the Work Breakdown Structure (WBS), which serves as the primary input for the critical path method.

Step 2: Activity Sequence Establishment: In this step, the appropriate sequence of activities is determined. To accomplish this, you should ask three questions for each task listed.

Step 3: Network Diagram: After accurately identifying the sequence of activities, you can create the network diagram.

Step 4: Activity Estimates: This step involves gathering estimation data from the Work Breakdown Structure (WBS) sheet. CPM relies on established activity durations to proceed.

Step 5: Identifying the Critical Path: To determine the critical path, five key parameters for each network activity must be assessed;

Earliest Start Time (EST)
Earliest Finish Time (EFT)
Latest Finish Time (LFT)
Latest Start Time (LST)
Slack Time = LST - EST or Slack Time = LFT – EFT

Step 6: Critical Path Diagram for Project Monitoring: The critical path diagram serves as a dynamic tool. It should be routinely updated with actual progress data as tasks are completed. This provides a more accurate reflection of timelines and ensures the project management team stays aligned with the project's deliverables.

Types of Networks

Network planning often employs two primary types of diagrams: Activity-On-Node (AON) and Activity-On-Arc (AOA). While both formats assist in project planning, their differing visual representations and characteristics can present challenges for engineering technicians when learning and applying these techniques.

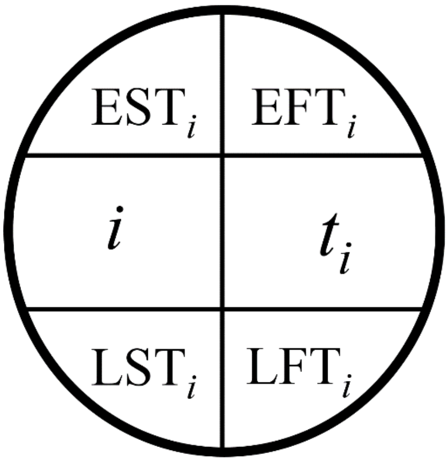
Type 1: Activity-On-Node (AON) Network Design

- Nodes represent activities.
- Arcs indicate the precedence and relationships between activities.

Type 2: Activity-On-Arc (AOA) Network Design

- Arcs signify project activities.
- Nodes mark the start and completion points of each activity.

In AON networks, specific formats are typically used to represent nodes. The diagram below illustrates an example of node representation.



Information Recorded for Each Node

t_i = time required to perform activity i

EST$_i$ = earliest possible start time for activity i

EFT$_i$ = earliest possible finish time for activity i

LST$_i$ = latest possible start time for activity i

LFT$_i$ = latest possible finish time for activity i

Detailed sheet that we have used for CPM: (These times were recorded in seconds)

	Details		
Activity	Operaion	Time_required	predecessor
A	Sleeve hem	52	-
B	join the collar rib	18.2	-
C	Open the seam and track	20.8	B
D	join shoulder	49.4	-
E	Attach the collar rib to body	62.4	C,D
F	Attach the main label	36.4	E
G	attach tape to collar, fold &cut tap	85.8	F
H	close the neck tape	55.9	G
I	Attach sleeve	72.8	H,A
J	Side seam with care label	84.5	I
K	Bottom hemming	62.4	J
L	Track sleeve	36.4	K

Mathematical Model

Earliest Start Time Linear Model

Decision Variables

T_i = ESTi – Earliest Start Time of the i^{th} Activity,

t_i = Time Duration of Each Activity i (in seconds)   where i=A,B,C,D,...,L

Objective Function

- $\text{Min } Z = T_A + T_B + T_C + T_D + T_F + T_G + T_H + T_I + T_J + T_K + T_H + T_I + T_J + T_K + T_L$

Constraints

- $T_A - T_S >= t_S$
- $T_B - T_S >= t_S$
- $T_D - T_S >= t_S$
- $T_C - T_B >= t_B$
- $T_E - T_D >= t_D$
- $T_E - T_C >= t_C$
- $T_F - T_E >= t_E$
- $T_G - T_F >= t_F$
- $T_H - T_G >= t_G$
- $T_I - T_H >= t_H$
- $T_I - T_A >= t_A$
- $T_J - T_I >= t_I$
- $T_K - T_J >= t_J$
- $T_L - T_K >= t_K$ Non-Negativity $T_i \geq 0$

Solving Method Using EXCEL

- **EST (Earliest Start Time)**

	A	B	C	D	E	F	G	H
1		Linear programming model for EST						
2								
3	OBJECTIVE				Constraints			
4	Activities	Time	EST		From	To	Between Starts	minimum time Between Starts
5	S	0	0		S	A	0	0
6	A	52	0		S	B	0	0
7	B	18.2	0		S	D	0	0
8	C	20.8	18.2		E	F	62.4	62.4
9	D	49.4	0		B	C	18.2	18.2
10	E	62.4	49.4		C	E	31.2	20.8
11	F	36.4	111.8		D	E	49.4	49.4
12	G	85.8	148.2		A	I	289.9	52
13	H	55.9	234		F	G	36.4	36.4
14	I	72.8	289.9		G	H	85.8	85.8
15	J	84.5	362.7		H	I	55.9	55.9
16	K	62.4	447.2		I	J	72.8	72.8
17	L	36.4	509.6		J	K	84.5	84.5
18		MinZ	2171		K	L	62.4	62.4

Modeling of Earliest Start time of each activity

Latest Start Time Linear Model

Decision Variables

$T'_i = LST_i$ – Latest Start Time of the i^{th} Activity,

$t_{i=}$ Time Duration of Each Activity i   where i = A,B,C,D,...,L

Objective Function

- Max $Z = T'_A + T'_B + T'_C + T'_D + T'_F + T'_G + T'_H + T'_I + T'_J + T'_K + T'_H + T'_I + T'_J + T'_K + T'_L$

Constraints

- $T'_A - T'_S >= t_S$
- $T'_B - T'_S >= t_S$
- $T'_D - T'_S >= t_S$
- $T'_C - T'_B >= t_B$
- $T'_E - T'_D >= t_D$
- $T'_E - T'_C >= t_C$
- $T'_F - T'_E >= t_E$
- $T'_G - T'_F >= t_F$
- $T'_H - T'_G >= t_G$
- $T'_I - T'_H >= t_H$
- $T'_I - T'_A >= t_A$
- $T'_J - T'_I >= t_I$
- $T'_K - T'_J >= t_J$
- $T'_L - T'_K >= t_K$ Non-Negativity $T'_i \geq 0$.

- **LST (Latest Start Time)**

	A	B	C	D	E	F	G	H
1		linear programming model for LFT						
2								
3	Objectives						Constraints	
4	Activities	Time	LST		From	To	Between Starts	minimum time Between Starts
5	S	0	0		S	A	237.9	0
6	A	52	237.9		S	B	10.4	0
7	B	18.2	10.4		S	D	0	0
8	C	20.8	28.6		E	F	62.4	62.4
9	D	49.4	0		B	C	18.2	18.2
10	E	62.4	49.4		C	E	20.8	20.8
11	F	36.4	111.8		D	E	49.4	49.4
12	G	85.8	148.2		A	I	52	52
13	H	55.9	234		F	G	36.4	36.4
14	I	72.8	289.9		G	H	85.8	85.8
15	J	84.5	362.7		H	I	55.9	55.9
16	K	62.4	447.2		I	J	72.8	72.8
17	L	36.4	509.6		J	K	84.5	84.5
18		Max Z	2429.7		K	L	62.4	62.4
19								

Modeling of Latest Start time of each activity

Summary of the Project

Activity	Description	Time	EST	EFT	LST	LFT	slack	
	Project Summary							
Activity	Description	Time	EST	EFT	LST	LFT	slack	
A	Sleeve hem	52	0	52	237.9	289.9	237.9	NOT
B	join the collar rib	18.2	0	18.2	10.4	28.6	10.4	NOT
C	Open the seam and track	20.8	18.2	39	28.6	49.4	10.4	NOT
D	join shoulder	49.4	0	49.4	0	49.4	0	**
E	Attach the collar rib to body	62.4	49.4	111.8	49.4	111.8	0	**
F	Attach the main label	36.4	111.8	148.2	111.8	148.2	0	**
G	attach tape to collar, fold &cut tap	85.8	148.2	234	148.2	234	0	**
H	close the neck tape	55.9	234	289.9	234	289.9	0	**
I	Attach sleeve	72.8	289.9	362.7	289.9	362.7	0	**
J	Side seam with care label	84.5	362.7	447.2	362.7	447.2	0	**
K	Bottom hemming	62.4	447.2	509.6	447.2	509.6	0	**
L	Track sleeve	36.4	509.6	546	509.6	546	0	**
	** =>denotes Critical Activity							

Critical Activities:

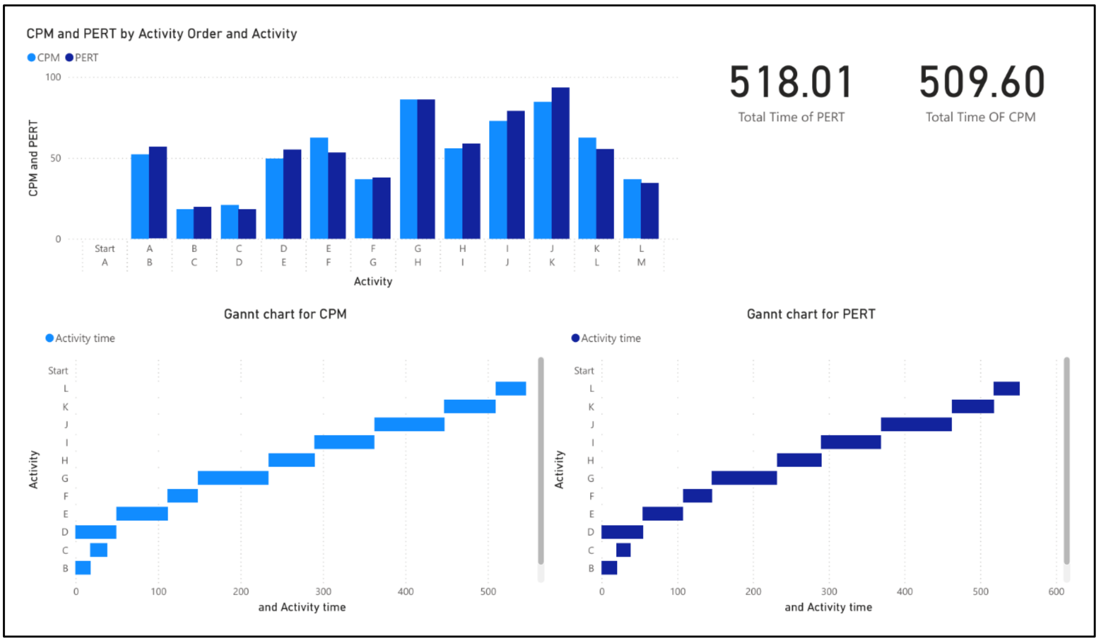
A **critical activity** in project management is a task that directly affects the project's timeline. It lies on the **critical path**, meaning that if the activity is delayed, the entire project will be delayed by the same amount unless corrective action is taken.

Critical path:

Start -> D -> E -> F -> G -> H -> I -> J -> K -> L

Start -> Join shoulder -> Attach the collar rib to body -> Attach the main label -> Attach tape to collar fold & cut lap -> Close the neck tape -> Attach sleeve -> Side seam with care label -> Bottom hemming and Tack sleeve.

Results and Discussions



Power BI Dashboard

Overview

The project management problem was solved using two standard techniques: the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT). The results were analyzed to compare the key metrics, such as Early Start Time (EST), Early Finish Time (EFT), Late Start Time (LST), Late Finish Time (LFT), and Slack, for each activity in the project.

CPM Results

In the CPM method:

- The critical path was determined by identifying activities with zero slack, indicating they are on the critical path and cannot be delayed without affecting the project's completion time.
- Activities D, E, F, G, H, J, K, and L were found to be critical.
- The project completion time was calculated to be 546 units.

PERT Results

In the PERT method:

- Probabilistic time estimates were used to incorporate uncertainty into activity durations.
- Activities D, E, F, G, H, J, K, and L were identified as critical.
- The project completion time was estimated to be 565 units, slightly higher than in the CPM approach due to PERT's focus on expected durations and risk.

Comparison of CPM and PERT

- **Slack Differences**: CPM assumes deterministic durations and assigns zero slack to critical activities, while PERT incorporates variability, which results in slightly adjusted slack values for non-critical activities such as A, B, and C.
- **Completion Time**: The CPM method yielded a shorter project duration compared to PERT, highlighting PERT's consideration of uncertainty in duration estimates.
- **Visualization**:
  - The bar chart comparing CPM and PERT times for each activity shows that while most activities have similar durations, differences are evident for non-critical tasks, reflecting PERT's adjustment for uncertainty.
  - The Gantt chart effectively illustrates the sequential and overlapping nature of the tasks, providing insights into dependencies and scheduling flexibility.

Key Insights

1. **Critical Path**: Both methods identified the same set of critical activities, confirming the robustness of the CPM and PERT approaches in identifying bottlenecks.
2. **Risk Management**: PERT provided a more conservative project timeline, making it suitable for scenarios with high uncertainty or when the cost of delays is significant.
3. **Scheduling Flexibility**: The slack values highlighted opportunities for resource reallocation to optimize project execution without affecting deadlines.

Conclusion

The CPM method is ideal for deterministic projects with well-defined durations, while PERT is better suited for projects with inherent uncertainty. Both methods complement each other in providing a comprehensive understanding of the project schedule and risks.

Effective Worker Reallocation Strategies for Continuous Production Line Operation

In production lines, activities from A to L are carried out by workers, with each worker assigned to a specific activity. If a worker assigned to an activity is absent, the entire production line may stop because every activity is critical for smooth operation. To address this, we have two options: either halt the production line or reassign a worker from the same production line or another production line.

Reassigning Workers Within the Same Production Line

When a worker is absent from a critical activity, it is essential to quickly reassign a worker from a non-critical activity within the same production line. For this, activities A, B, or C (non-critical activities) can be considered for reassignment. However, these workers typically have lower efficiency. To make an informed decision, we must analyze the slack time of the non-critical activities and compare it with the time required for the critical activity. This ensures minimal disruption while maintaining productivity. A Python program has been developed to streamline this process.

Reassigning Workers from Another Production Line

If there are insufficient slack times in the current production line to reallocate workers, we may need to assign a worker from a non-critical activity in another production line. This approach ensures continuity of the critical activity without significantly impacting the performance of the other production line. This scenario is particularly important when there are multiple worker absences, making it impossible to reassign workers internally.

By adopting these strategies, production lines can continue operating efficiently despite worker absences, ensuring minimal downtime and maximum productivity.

Conclusions and Future Directions

Challenges Identified

While implementing these methodologies, the following challenges were observed:

- **Data Dependency:** Accurate data collection was essential for both CPM and PERT. Inconsistent or incomplete data could lead to suboptimal results.
- **Human Factors:** Variability in worker efficiency and skill levels introduced deviations in task durations.
- **Machine Reliability:** Unanticipated breakdowns affected the accuracy of the projected timelines.

Despite these challenges, the combined use of CPM and PERT demonstrated significant potential in optimizing the production process, making it more efficient, predictable, and adaptable.

Future Directions

From CPM method the critical path was determined as:

Start → Join Shoulder → Attach Collar Rib to Body → Attach Main Label → Attach Tape to Collar → Close Neck Tape → Attach Sleeve → Side Seam with Care Label → Bottom Hemming → Tack Sleeve → End

PERT required obtaining three-time estimates for each activity in the assembly line process. The time estimates were derived from historical data collected over a six-month period (180 days)

Then we solved the problem by generating random numbers several times. Therefore, we got several critical activities but within those activities we got some of the same critical activities (Attach Main Label, Attach tape to collar, Close the neck tape, Attach sleeve, Side seam with care Label, Bottom hemming, Track sleeve) which means we have to give more priority to these activities.

In project scheduling, near-zero slack doesn't always correlate with being on the critical path. Activities Join shoulder and attach the collar rib to body can have minimal slack due to their dependencies, resource sharing, or changes in the project's timing, but they may not always be classified as critical tasks. The key takeaway is that these activities should still be carefully monitored because their tight schedule could make them near-critical, and delays in them could potentially affect the overall project completion.

To ensure the timely completion of the production process, it is crucial that critical activities are carried out without delays. However, in cases where the assigned personnel with specific expertise for these tasks are unavailable, these activities may need to be performed by other workers.

Since these substitute workers may not be fully skilled in the required tasks, the quality of the output could be compromised. This can lead an increase in product defects, resulting in wasted time and resources, ultimately affecting overall production efficiency and goals.

Conclusion

The integration of both the PERT and CPM methodologies in the optimization of the assembly line processes for garment production provides a comprehensive framework for managing time, resources, and uncertainties. The CPM method focuses on deterministic scheduling by identifying critical tasks and minimizing delays through optimal resource allocation. On the other hand, PERT incorporates variability and uncertainty in task durations, enabling better risk assessment and contingency planning.

Through this study:

1. CPM effectively reduced the production time by 91 seconds compared to traditional methods, highlighting its capability in streamlining critical activities in the assembly process.

2. PERT provided a probabilistic approach to project completion, offering insights into the best-case, most-likely, and worst-case scenarios for activity durations.

3. Combining these methods ensures both efficient scheduling and robustness against delays, enhancing the overall reliability and efficiency of the production process.

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