Lesson 5: Network Analysis: Critical Path Method (CPM)

Network analysis, also known as network theory or graph theory, is a field of study that deals with the analysis and interpretation of relationships and connections between various entities, often represented as nodes (vertices) and links (edges) in a graph. This field has applications in various domains, including social sciences, computer science, biology, transportation, telecommunications, and more.

In network analysis, the entities of interest can represent a wide range of things, such as people in a social network, computers in a communication network, molecules in a biochemical pathway, or even web pages on the internet. The connections between these entities (edges) could represent relationships, interactions, dependencies, or some form of association.

Key concepts in network analysis include:

1. **Nodes:** These are the entities being studied, and they can represent individuals, objects, concepts, or any other unit of interest.

2. **Edges:** These are the connections or relationships between nodes. Edges can be directed (pointing from one node to another) or undirected (bi-directional), weighted (carrying a value), or unweighted.

3. **Degree:** The degree of a node in a network is the number of edges connected to that node. In a directed network, nodes have both an in-degree (incoming edges) and an out-degree (outgoing edges).

4. **Centrality:** Centrality measures identify the most important nodes in a network. Nodes with high centrality often play crucial roles in the network's structure and function.

5. **Clustering and Communities:** Clustering involves identifying groups of nodes that are densely interconnected within themselves but have fewer connections between clusters. These clusters are often referred to as communities.

6. **Paths and Connectivity:** Paths are sequences of nodes connected by edges. Network connectivity studies whether there is a path between any pair of nodes in the network.

7. **Network Visualization:** Representing a network graphically can help in understanding its structure and relationships. Different layout algorithms are used to visualize networks effectively.

8. **Small-World Phenomenon:** This concept suggests that many networks in real-world systems exhibit short average path lengths and high clustering coefficients, leading to the idea that individuals in a network are connected by relatively few intermediaries.

Network analysis has found applications in various fields, such as identifying key players in social networks, understanding the spread of diseases, optimizing transportation and logistics networks, analyzing the internet's structure, studying biochemical pathways, and more. It provides a framework for understanding complex relationships and patterns that emerge from interactions between entities in various systems.

Construction of project networks

Constructing project networks involves creating graphical representations that outline the sequence of tasks or activities needed to complete a project. These networks are often used in project management to schedule, plan, and manage projects effectively. The most commonly used technique for constructing project networks is the Critical Path Method (CPM), which involves creating a network diagram known as a "project network" or "CPM network." Here's a step-by-step guide to constructing project networks using CPM:

1. Identify Activities: List all the individual tasks or activities required to complete the project. Each activity should be well-defined and have a clear start and end point.

2. Determine Precedence Relationships: Determine the dependencies between activities. Some activities must be completed before others can start. These dependencies can be categorized as:
- Finish-to-Start (FS): Activity A must finish before Activity B can start.
- Start-to-Start (SS): Activity A and Activity B can start simultaneously.

- Finish-to-Finish (FF): Activity A and Activity B must finish simultaneously.
- Start-to-Finish (SF): Activity A must start before Activity B can finish (less common).

3. Create a Network Diagram: Represent each activity as a node (or a box) in the diagram. Connect the nodes with arrows to indicate the sequence and dependency relationships between activities. The arrows show which activities must be completed before others can start.

4. Add Duration and Estimates: Assign a time estimate or duration to each activity. This estimate represents how long it will take to complete the activity.

5.Identify the Critical Path: Calculate the earliest start and finish times for each activity. The critical path is the longest path through the network that determines the shortest time needed to complete the project. Activities on the critical path have no slack or float and must be closely monitored to avoid project delays.

6. Calculate Float/Slack: For non-critical activities, calculate their float or slack time. Float represents the amount of time an activity can be delayed without affecting the project's overall duration.

7. Project Timeline: Once you've identified the critical path and estimated durations for all activities, you can create a project timeline. This timeline shows when each activity should start and finish, considering the dependencies and durations.

8. Monitor and Manage: Throughout the project, track the progress of activities against the planned timeline. If any critical path activity is delayed, it can impact the overall project completion time. Non-critical activities with available float can be delayed without affecting the project's end date.

Project networks help project managers visualize the project's flow, identify potential bottlenecks, allocate resources efficiently, and make informed decisions about project scheduling and resource allocation. Software tools like Microsoft Project, Primavera P6, and various online project management tools facilitate the construction and management of project networks.

Identifying critical path and float times

Identifying the critical path and calculating float times (also known as slack) is a crucial aspect of project management using the Critical Path Method (CPM). The critical path represents the sequence of activities that, when added up, determine the shortest time needed to complete the project. Activities on the critical path have zero float, meaning they cannot be delayed without affecting the project's overall duration. Activities with float can be delayed without impacting the project's completion time. Here's how to identify the critical path and calculate float times:

1. **Calculate Early Start (ES) and Early Finish (EF):**

For each activity, calculate the earliest start (ES) and earliest finish (EF) times based on the project's starting point (usually time zero). ES for the first activity is always zero, and EF is ES plus the activity's duration.

$$ES(activity) = \text{Maximum of } EF(predecessors)$$
$$EF(activity) = ES(activity) + Duration(activity)$$

2. **Calculate Late Finish (LF) and Late Start (LS):**

For each activity, calculate the latest finish (LF) and latest start (LS) times based on the project's completion time. The LF for the last activity is equal to the project's duration, and the LS is LF minus the activity's duration.

$$LF(last\ activity) = EF(last\ activity) = \text{Project Duration}$$
$$LF(activity) = \text{Minimum of } LS(successors)$$
$$LS(activity) = LF(activity) - Duration(activity)$$

3. **Calculate Total Float (TF):**

Total float (TF) is the amount of time an activity can be delayed without affecting the project's completion time. It's calculated as the difference between the late start (LS) and early start (ES) times of an activity:

$$TF(activity) = LS(activity) - ES(activity)$$

4. **Identify Critical Path:**

The critical path is the longest path through the network that has zero total float. Activities on the critical path must be completed as scheduled to avoid delaying the entire project.

5. **Calculate Free Float (FF):**

Free float (FF) is the amount of time an activity can be delayed without affecting the early start of the following activity. It's calculated as the minimum time difference between the early start of the successor and the early finish of the current activity (minus its duration):

$$FF(activity) = ES(successor) - EF(activity) - Duration(activity)$$

By identifying the critical path and calculating float times, project managers can effectively allocate resources, make informed decisions about schedule adjustments, and manage the project's progress. The critical path highlights activities that need close monitoring, while activities with float provide flexibility for resource allocation and potential adjustments. Project management software tools often automate these calculations and provide visual representations of the critical path and float times, simplifying the process for complex projects.

Using CPM for project scheduling

Using the Critical Path Method (CPM) for project scheduling involves a systematic approach that aids in planning, managing, and controlling project activities to ensure timely completion. This method is particularly advantageous for projects that possess clearly defined activities, interdependencies, and a requirement for optimal resource allocation. To apply CPM for project scheduling, follow these steps:

Firstly, identify all the tasks or activities necessary to bring the project to completion. Each activity should be well-defined, with distinct start and end points. This stage requires a careful breakdown of the project into manageable and measurable components.

Next, determine the relationships between these activities. Pinpoint which activities must be finalized before others can commence. This involves establishing finish-start, start-start, finish-finish, or start-finish relationships between various activities.

Construct a network diagram, often in the form of a graph, to visually represent the activities and their interdependencies. Nodes symbolize activities, and arrows signify the dependencies between them. This diagram provides a clear overview of the project's structure and flow.

Estimate the time required for each activity to be completed. These duration estimates can be informed by historical data, expert opinions, or other relevant sources of information.

Proceed to calculate the early start and early finish times for each activity using the forward pass technique. Start with the first activity and systematically move through the network, accounting for activity durations and dependencies.

Conduct the backward pass technique to calculate the late start and late finish times for each activity. Begin from the project's endpoint and work backward while considering the project's deadline and the dependencies between activities.

Identify the critical path, which consists of activities with zero float. These are activities where the early start matches the late start, and the early finish matches the late finish. The critical path represents the longest path through the project network and dictates the project's minimum completion time.

Calculate float (both total and free) for activities that aren't critical. Total float refers to the amount of time an activity can be delayed without extending the project's completion time. Free float denotes the amount of time an activity can be delayed without affecting the start time of its successor.

Compile the data from early start and early finish calculations to create the project schedule, illustrating when each activity will commence and conclude. Ensure this schedule considers resource availability and any other relevant constraints.

Continuously monitor and manage the project as it unfolds. Track actual start and finish times for activities and compare them against the planned schedule. If any deviations or delays occur, adjust the project schedule accordingly.

Utilize the project schedule to allocate resources optimally. This ensures resources are available when needed and resolves any potential conflicts.

Moreover, CPM assists in identifying potential risks and bottlenecks within the project. Any delays to activities on the critical path could affect the overall project timeline. Therefore, it's important to develop contingency plans to address potential setbacks.

In essence, the Critical Path Method offers a structured and effective approach to project scheduling and management. It provides a clear visualization of the project timeline, highlights critical activities, and facilitates resource optimization. Modern project management software often integrates CPM functionalities to automate calculations, generate visual representations, and streamline project scheduling and control processes.