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Examining Effects of Project Network Diagrams in Project Performance: A Case Study of the King Salman Bin Abdulaziz Specialized Hospital in Lusaka

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Abstract

Effective project management is essential for the successful delivery of healthcare infrastructure. This study aims to explore how Project Network Diagrams can be effectively utilized in the context of Zambia's construction projects and project performance, particularly in Lusaka, which is experiencing rapid urbanization and high demand of infrastructure. Therefore, Examining the effects of Project Network Diagrams in project performance, particularly at the King Salman Bin Abdulaziz Specialized Hospital in Chalala area of Lusaka which is crucial for helping us understand project management Network Diagram's efficiency and effectiveness in project performance. This analysis is particularly relevant in construction projects, where timely completion is essential due to financial, social, and environmental factors (Lusaka Times, 2024). According to the Saudi Fund for Development (2024), The King Salman Bin Abdulaziz Specialized Hospital for Women and

children is an 800-bed hospital that is still under construction in Chalala area which is in Lusaka, Zambia. The project is being developed through funding from the Saudi Fund for Development in collaboration with the Zambian Ministry of Health. It aims to enhance specialized healthcare services in maternal and child health. Development Gateway (2024) also added that the hospital is expected to cover 68,500 square meters and will include a children's hospital, intensive care units, laboratories, operating rooms, pharmacies, and parking facilities. Upon completion, the facility will provide advanced maternal and neonatal healthcare services, benefiting Zambia and surrounding nations. In December 2024, Zambia secured an additional \$35 million loan from Saudi Arabia to ensure the hospital's completion, bringing the total project investment to \$135 million and the hospital is projected to open by the end of 2025 (Lusaka Times, 2024).

Keywords: Construction, Project, Project Network, Project Network Diagrams (PNDs), Project Performance

1. Introduction

1.1 Background

Globally Project Network Diagram enhance project performance by reducing errors, preventing costly delays and saving time. In a global context, these diagrams become crucial tools for managing diverse teams, coordinating across different time zones and cultural contexts, and ensuring consistent communication by providing a shared visual understanding of the project's scope and flow (Kerzner, 2017) ^[17]. According to PMI (2020), the Project network diagrams like the Critical Path Method which determines the sequence of tasks that shows the project's shortest possible duration can be vital for managing global projects, where delays in one region can impact the entire global schedule, with a visual representation of the overall projects it becomes easy for teams to better prioritize and allocate resources.

Project Network Diagrams improves resource allocation in healthcare projects, boosting efficiency across Africa (Malsam, 2024). There are a lot of projects in Africa that uses the Project Network Diagrams for example in Tanzania the construction of the Julius Nyerere Hydro-power Project, in Zimbabwe the Kariba South Hydro Power Station expansion project and the Kam'mwamba Coal-Fired Power Plant project. Other projects that utilized the Network Diagrams includes the Medupi Power Station in South Africa, the Dukwi Power Station in Botswana. Project managers use Project Network Diagrams to easily identify or highlight potential bottlenecks or activities that are likely to be delayed, allowing for proactive risk management and contingency planning, essential for project operating on a global scale where external dependencies are common (PMI, 2021) ^[27].

Construction project in Zambia, faces significant challenges in project management and execution arena. One of the critical aspects of effective project management is the ability to assess and optimize project timeline and budget. Project Network Diagrams are essential tools in project management, visually representing the sequence and interdependencies of activities within a project. They aid in identifying the critical path, optimizing schedules, and ensuring efficient resource allocation (Kerzner, 2022). In Lusaka Province the construction of the Levy Mwanawasa Hospital utilized project network diagrams to manage resources and ensure timely completion.

1.2 Statement of the problem

Projects in Lusaka have faced a lot of different challenges and these challenges are seen across various industries, often leading to increased costs, resource conflicts, and stakeholder dissatisfaction. According to Banerjee Roy (2023) top reasons for project delays include but not limited to poorly defined or changes in scope of work, labor shortages, unrealistic project schedule or timeline and funding issues or budget conflicts. When the project has unclear project objectives or has frequent alterations to the project scope that can lead to misunderstanding and rework, causing serious delays and if there is a lack of skilled labor this can also hinder project timelines, especially when specialized tasks are required. Banerjee Roy (2023) also mentions that budget issues or conflicts can also lead to project delays. He stated that financial constraints can halt project operations, while additional funding is secured and adjustments are supposed to be made to align with budgetary limitations. Budgetary disputes can be unavoidable when unforeseen complications arise, surpassing initial financial projections. However, obtaining precise cost estimates and anticipating potential challenges can help minimize budget-related setbacks. Therefore, the problem this study seeks to examine the effects of project network diagrams in project performance. The research aims to understand different types of network diagrams, and to examine their effectiveness in project performance.

1.3 General Objective

To examine the effectiveness of Project Network Diagrams in managing project performance in Lusaka focusing on the King Salman Bin Abdulaziz Specialized Hospital for Women and Children.

1.4 Specific Objectives

- To determine the types of Project Network Diagrams and how they are used in construction projects.
- To examine effectiveness of Project Network Diagrams in project performance.
- To examine the relationship between Project Network Diagrams and project performance in construction projects.

1.5 Research Questions

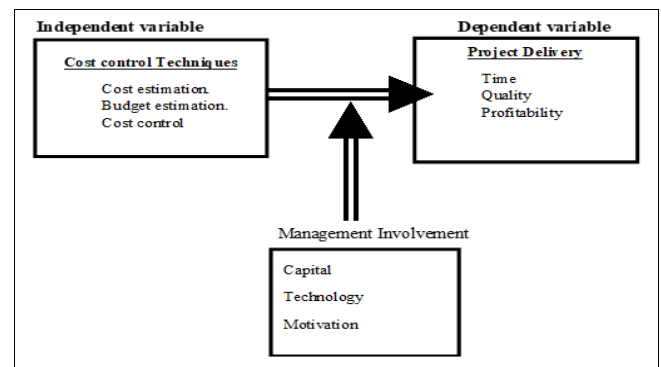
- What are the different types of Project Network Diagrams and their uses in construction projects?
- How effective are Project Network Diagrams in managing time, resources, and risks in construction

projects to enhance project performance?

- What is the relationship between Project Network Diagrams and project performance in construction projects?

1.6 Conceptual Framework

The conceptual framework for this study illustrates the relationship between types of Project Network Diagrams, their effectiveness in construction projects, and their limitations as moderating variables. This framework is essential in understanding how Project Network Diagrams contribute to project management success while identifying the challenges that may impact their use. This will also help assess how different Project Network Diagrams influence project success and what constraints may hinder their effectiveness in construction projects.



Source: Author, 2024

1.6.1 Key Components of the Conceptual Framework

1.6.1.1 Independent Variable: Types of Project Network Diagrams

1. Precedence Diagramming Method (PDM)

According to Kerzner (2022) the Precedence Diagramming Method (PDM) is a project scheduling technique that is used in Critical Path Method (CPM) scheduling. It represents project activities as nodes (boxes) and shows dependencies between them using arrows.

2. Arrow Diagramming Method (ADM)

The Arrow Diagramming Method (ADM) is a project scheduling technique where activities are represented as arrows, and nodes (circles) represent the start and end of an activity (Burke, 2019).

3. Critical Path Method (CPM)

The Critical Path Method (CPM) is a project scheduling technique used to determine the longest sequence of dependent tasks (the critical path) that defines the shortest possible duration for completing a project. It helps project managers identify critical activities, manage time efficiently, and prevent delays (PMI, 2021) [27].

4. Program Evaluation and Review Technique (PERT)

The Program Evaluation and Review Technique (PERT) is a project management tool used to plan, schedule, and coordinate complex projects. It is particularly useful for projects where task durations are uncertain, as it estimates time using a probabilistic approach (Turner, 2016).

5. Gantt Charts in Project Management

A Gantt Chart is a visual project scheduling tool used to plan, track, and manage project tasks over time. It displays activities as horizontal bars across a timeline, showing start and finish dates, task dependencies, and progress updates (PMI, 2021) ^[27].

1.6.1.2 Dependent Variables: Effectiveness of Project Network Diagrams in Construction Projects

1. Project scheduling and time management

Burke (2019) describes Project scheduling and time management as critical aspects of project management, ensuring tasks are completed efficiently within the given time frame. Effective scheduling helps optimize resources, reduce delays, and improve overall project success.

Hinze (2018) explains that Project scheduling is the process of defining, organizing, and sequencing project activities to meet deadlines and goals. It involves identifying tasks and their dependencies, estimating activity durations, assigning resources and developing a project timeline.

2. Resource Allocation and Efficiency in Project Management

According to Project Management Institution (PMI) (2021) ^[27] Resource allocation is the process of describing available resources such as labor, materials, time and finances to project tasks in a way that maximizes efficiency and productivity. Effective resource allocation helps prevent bottlenecks, minimize waste, and ensure project success.

3. Risk identification and mitigation

Risk Management and Risk Mitigation is the process of identifying, assessing, and mitigating risks to the scope, schedule, cost and quality on a project. Risks come in the form of opportunities and threats and are scored on probability of occurrence and impact on project. The benefits of effective risk management are increased project success by proactively addressing potential risks, improve decision making by identifying risks and reduces surprises when a potential project creep arises (PMI, 2021) ^[27].

Moderating Variables: Limitations of Project Network Diagrams in Construction Projects

Project Network Diagrams in construction project can have limitations such as being time-consuming to create, prone to human error if not carefully maintained, inflexible to changes, potentially overly complex for large projects, and may not accurately reflect dynamic project aspects like resource fluctuations or uncertain task durations, potentially leading to misleading project schedules if not updated regularly.

1. Complexity in large-scale projects

As a project grow in size there are a lot of activities and dependencies that have to be considered in the Project Network Diagram which makes the Network Diagrams to become overly complex and difficult to interpret visually (Burke, 2019).

2. Accuracy of data and dependency on reliable estimates

Project Network Diagrams rely on accurate task durations and dependencies, which can be challenging to estimate accurately in construction projects due to factors like weather, material availability, and unforeseen site conditions (Turner, 2016).

3. Adaptability to dynamic project changes

Construction projects often face changing conditions, and Project Network Diagrams may not effectively capture these dynamic aspects and adjustments needed. If adjustments are to be made mostly its time-consuming delaying the project and may require significant adjustments (PMI, 2021) ^[27].

4. Potential for human error

Creating a Network Diagram involves inputting information which can lead to errors in activity sequencing or duration estimations. If not estimated properly by experts, network diagrams can lead to errors (Turner, 2016).

1.7 Significance of the Study

This study is significant as it aims to provide insights into the practical application of Project Network Diagrams in Lusaka's construction sector. Studying project network diagrams is crucial in construction because it provides a visual representation of the sequence of tasks, dependencies between activities, and critical paths within a project, allowing construction teams to effectively plan, manage timelines, identify potential bottlenecks, allocate resources efficiently, and track progress throughout the building process, ultimately leading to better project outcomes and on-time delivery. The findings could inform policymakers, project managers, and stakeholders about the best practices and strategies to enhance project delivery this will also allow future project managers to know about the different types of Project Network Diagrams, their importance and limitations which can help them in their future projects. If helped by other studies to enhance project outcomes that will lead the project to complete in time.

1.8 Scope of the Study

This study will focus on examining the effects of Project Network Diagrams (PNDs) in construction projects in Lusaka, examining the ongoing project of the King Salman Bin Abdulaziz Specialized Hospital for Women and Children that in Chalala area. It will consider various stakeholders involved in the construction process of the hospital, including contractors, project managers, and local authorities. This research will have a sample size of 50 respondents which will include the contractors, engineers, architects, clients involved and project managers on the site including anyone who would have knowledge of the network diagrams used. This study will employ a mixed method approach, combining surveys, interviews and case studies to gather data, it will be conducted in a period of 6 months in order to make sure the data is accurately analyzed and is correct. The study will examine the effects of Project Network Diagrams on project scheduling, cost management, risk management, quality control and communication and collaboration. The objectives of this research are to determine types of Project Network Diagrams and their uses, the effectiveness of Project Network Diagrams in managing time, resources and risks, also the relationship between Project Network Diagrams and project performance.

2. Introduction

This chapter of the study presents the literature review on the effects of Project Network Diagrams in project performance looking at the types of Project Network Diagrams, how effective Project Network Diagrams are in

construction projects, and the relationship between Project Network Diagrams and project performance. This essay examines the effects of project network diagrams on project performance, with a focus on the King Salman Bin Abdulaziz Specialized Hospital in Lusaka. The discussion is structured around global, regional, and local perspectives for each segment, reflecting the interconnected nature of project management practices.

2.1 Types of Project Network Diagrams and their uses in Construction Projects

Globally, Project Network Diagrams has become important for ensuring efficiency, accountability, and timely delivery. These diagrams, which include the Precedence Diagramming Method (PDM), Arrow Diagramming Method (ADM), Critical Path Method (CPM), Gantt Chart and Program Evaluation and Review Technique (PERT), provide a structured visual representation of activities, dependencies, and timelines. Each of these methods has unique features, advantages, and limitations, and their application varies depending on the project context. This section reviews the literature on these types of diagrams and their uses in construction projects (Adobe, 2023) [3].

1. Precedence Diagramming Method (PDM)

The Precedence Diagramming Method (PDM), also referred to as Activity-on-Arrow (AOA), is the predominant network diagramming technique in contemporary project management.

PDM accommodates four types of inter-activity dependencies, each serving a specific sequencing need. In the most common Finish-to-Start (FS) relationship, a successor task cannot commence until its predecessor has been completed. Start-to-Start (SS) links permit two activities to begin simultaneously once one reaches a defined start point, enabling overlapping of tasks. Finish-to-Finish (FF) constraints synchronize activity end dates, ensuring that paired tasks conclude together. The least intuitive Start-to-Finish (SF) dependency restricts the completion of one activity until another has initiated (PMI, 2021) [27].

The method supports four types of dependencies:

- **Finish-to-Start (FS):** The most common relationship, where one activity must finish before the next can start (PMI, 2021) [27].

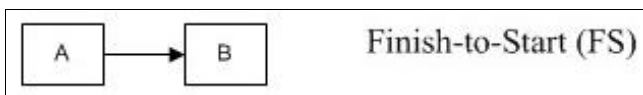


Fig 2.1: In Gantt Chart it is shown as

- **Start-to-Start (SS):** Two activities can start simultaneously, though neither task must wait for the other to finish. This relationship is particularly useful when two tasks share preparatory work or resources and can be initiated in parallel to compress overall schedule duration (PMI, 2021) [27].



Fig 2.2: In Gantt Chart it is shown as

- **Finish-to-Finish (FF):** According to Kerzner (2017) [17], FF means two activities must finish at the same time, ensuring their end dates are synchronised rather than merely sequencing one after the other.

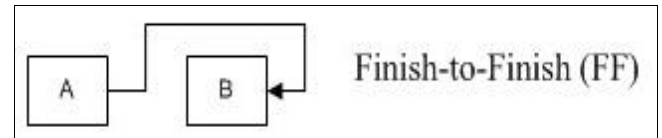


Fig 2.3: In Gantt Chart it is shown as

- **Start-to-Finish (SF):** A less common relationship where one activity cannot finish until another has started (PMI, 2021) [27]. Unlike Finish-to-Start relationships, which drive tasks forward in sequence, or Start-to-Start relationships, which synchronize task initiations, SF relationships impose a constraint on the completion of an activity based on the start of another (Prem Kumar, 2017) [28].

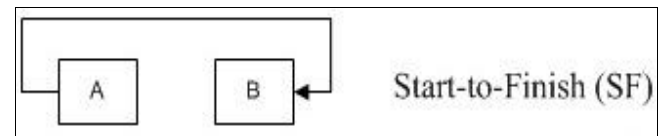


Fig 2.4: In Gantt Chart it is shown as

Globally, the Precedence Diagramming Method is valued for its flexibility and ability to represent complex relationships (Burke, 2013) [7].

Here is an example of the Precedence Diagramming Method below:

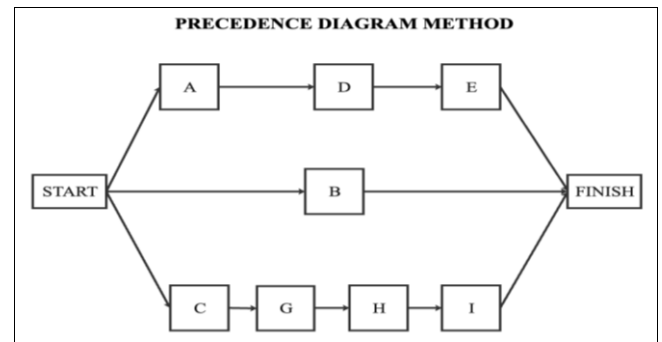


Fig 2.5:

2. Arrow Diagramming Method (ADM)

The Arrow Diagramming Method (ADM), also known as Activity-on-Arrow (AOA), traces its roots to the earliest developments of network-based scheduling in the 1950s. Pioneered alongside the Critical Path Method (CPM) under U.S. Navy contracts, ADM introduced a graphical way to represent project logic at a time when punch-card computing and manual charting prevailed (Nicholas & Steyn, 2020) [24]. In its original form, project managers drew arrows on paper or acetate sheets, linking them at event nodes to visualize the sequence of tasks required to complete a project. This representation played a pivotal role in large defense and infrastructure programs of the post-war era, laying the conceptual groundwork for later digital tools. At the heart of ADM is the distinction between activities and events. Each arrow embodies a distinct work activity whether trench excavation, concrete pouring or equipment calibration and

carries an associated duration. Nodes, by contrast, denote key milestones or “events,” such as the commencement or completion of one or more tasks (Nicholas & Steyn, 2020) [24].

The Critical Path Method leveraged ADM’s structure to calculate earliest and latest start and finish times for each arrow, identifying the longest path through the network as the project’s critical path. This analysis enabled project leaders to prioritize resource allocation and to assess the impact of delays on the overall schedule. Yet, because ADM supports only Finish-to-Start dependencies, activities that could logically overlap or require more nuanced constraints (such as Start-to-Start or Finish-to-Finish) must be rewritten or approximated using dummy arrows, introducing further complexity. In practice, ADM’s greatest strength lies in its simplicity and its intuitive mapping of strictly sequential processes. In linear construction endeavors such as road and railway building activities follow a near-unbroken chain with surveying precedes clearing, clearing precedes grading, and so on. In such contexts, the Arrow Diagramming Method offers a straightforward way to visualize progress checkpoints at each milestone node, track the critical path, and communicate schedule logic to stakeholders without the overhead of modelling multiple dependency types (Lock, 2020) [19].

In summary, while the Arrow Diagramming Method may no longer dominate sophisticated project scheduling, its foundational role in the evolution of network analysis and its enduring value for strictly sequential projects warrant its continued use. For road building, linear infrastructure works, and any project where activities naturally cascade in a single flow, ADM remains an accessible, transparent way to visualize dependencies, manage critical paths, and guide on-site execution.

Here is an example of the Arrow Diagramming Method below;

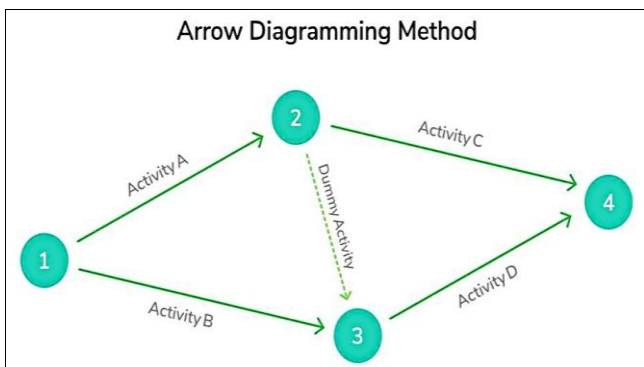


Fig 2.6:

3. Critical Path Method (CPM)

The Critical Path Method is a scheduling technique that identifies the longest path of dependent activities in a project, which determines the minimum project duration (Kerzner, 2017) [17]. The Critical Path Method is particularly effective in construction projects where delays in critical activities can have significant cost implications. CPM is an integrated network consisting of a series of activities with one another intended to obtain maximum work efficiency. In determining the total time, the CPM project is simpler, it is obtained by summing the duration of each activity and taking the last / greatest finish time. The path where delays may not occur in each project activity is called the critical

path. CPM is more used than other traditional methods. CPM concentrates on the most important tasks the project can be confirmed on time and in line with the predetermined schedule. Some previous studies using CPM were studies carried out by the 1950 DuPont Company and Remington Rand Corporation, CPMs used to manage power plants and construction could save the company one million dollars in the first year of use. In 2013 Putra proved that scheduling time using CPM proved to be very helpful in time and cost efficiency.

The Critical Path Method (CPM) is a simple but powerful technique for analyzing, planning, and scheduling large, complex projects. It is used to determine a project’s critical path the longest sequence of tasks that must be finished for the entire project to be complete. CPM, also known as Critical Path Analysis (CPA), identifies dependencies between tasks and shows which tasks are critical to a project. One of these techniques was to map out the most important tasks in any project and use that to estimate the project completion date. Today, we know this technique as the Critical Path Method. The Critical Path Method in project management is a cornerstone of project planning even to this day. How long a project takes often depends on the most important tasks that constitute it. If you can map out these tasks and their duration, you can get a reasonable estimate of the project’s timeline and budget.

Here is the Critical Path Method showing the critical path below;

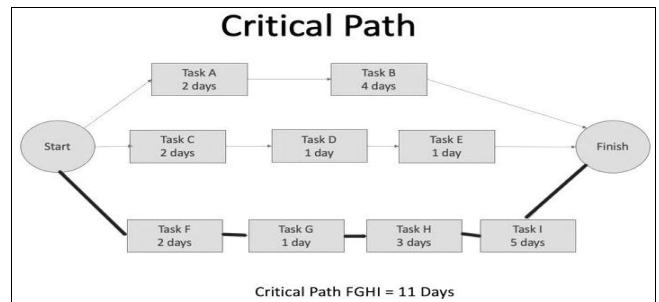


Fig 2.7:

4. Gantt Chart

Olawale & Sun (2015) [25], explains that a Gantt chart is a visual scheduling tool that maps project activities against a linear time scale, using horizontal bars to depict each task’s planned duration and timing. Developed by Henry L. Gantt in the 1910s, it was one of the first attempts to present complex work schedules in a format that stakeholders from shop-floor supervisors to executive sponsors could quickly grasp. The vertical axis lists individual tasks or work packages (often derived from a Work Breakdown Structure), while the horizontal axis represents calendar time, segmented into days, weeks or months. Each bar’s length corresponds to the time allotted for that activity, and its start/end positions align with the scheduled dates (PMI, 2021) [27].

Beyond simple duration bars, modern Gantt charts integrate several advanced features. Task dependencies can be illustrated by arrows or connector lines, signalling Finish-to-Start, Start-to-Start or other logical relationships. Milestones zero-duration markers flag critical events such as permit approvals, design handovers or phased client inspections. Many software platforms also allow the overlay of actual progress (“% complete”) onto the original bars,

visually highlighting schedule variances and emerging delays. Colour coding or pattern fills can distinguish between phases, responsible teams or resource types, further enhancing readability (Olawale & Sun, 2015) [25].

Despite their strengths, Gantt charts have limitations. They can become unwieldy in large projects with hundreds of tasks unless grouped into phases or high-level summary bars. They do not inherently model probabilistic durations or identify the critical path without additional analysis, so practitioners often pair Gantt charts with network-based tools like the Precedence Diagramming Method (PDM) or the Critical Path Method (CPM). Furthermore, without disciplined schedule governance, charts risk becoming outdated, eroding their value as a reliable decision-support tool.

By combining the intuitive layout of Gantt charts with rigorous dependency logic, continual updates and integration with resource and risk management processes, project teams can harness their clarity and accessibility to plan, coordinate and control even the most complex construction programmes effectively.

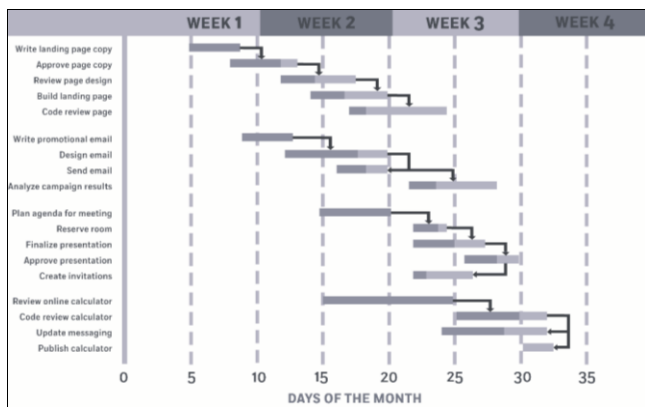


Fig 2.8: Is an example of a Gantt Chart;

5. Program Evaluation and Review Technique (PERT)

Program Evaluation and Review Technique (PERT) is a probabilistic scheduling method designed to incorporate uncertainty into project planning by assigning three distinct duration estimates to each activity optimistic (O), most likely (M) and pessimistic (P). Rather than relying on a single deterministic value, PERT applies the beta distribution to calculate an expected activity duration ((TE)) using the formula;

Formular 1.1:

$$t_e = \frac{a + 4m + b}{6}$$

Where:

- t_e = expected time
- a = optimistic time estimate
- m = most likely time estimate
- b = pessimistic time estimate

and Formula 2.2. determines variance

- Based on a standard deviation of the expected time
- Using a bell curve (normal distribution)

$$s = \frac{b - a}{6}$$

- For the whole critical path use

$$s_{cp} = \sqrt{s_1^2 + s_2^2 + \dots + s_n^2}$$

These calculations enable project managers to quantify the degree of uncertainty around each task and, by aggregating variances along the network’s critical path, to estimate the probability of completing the entire project by a target date (PMI, 2021) [27]. PERT’s strength in managing uncertainty has led to its adoption in highly complex, first-of-a-kind programmes. The U.S. Navy’s Polaris missile development in the late 1950s was among the first large-scale uses of PERT, where variability in research, prototype testing and supplier performance made single-point estimates unreliable. Since then, NASA has extended PERT’s principles across space shuttle missions and Mars exploration programmes, using Monte Carlo simulations atop PERT networks to assess launch-date risk and budget contingencies. In Europe, major healthcare infrastructure projects such as regional hospital expansions and advanced oncology centers have leveraged PERT to coordinate imported medical equipment delivery with civil works, minimizing the likelihood that a delay in specialist device installation will stall an entire construction phase (Kerzner, 2017) [17].

By embedding uncertainty directly into the schedule model, PERT equips project leaders to anticipate the range of possible outcomes and to make data-driven trade-offs between time, cost and scope especially in pioneering endeavors where variability is inherent and delays can carry high stakes.

Here is an example of PERT;

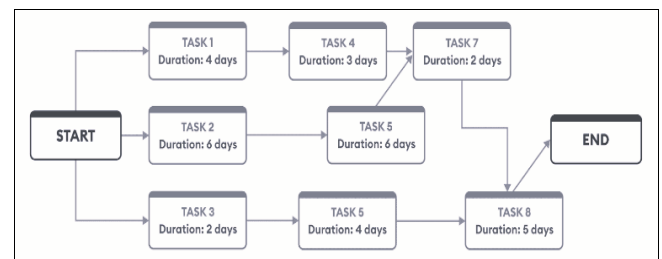


Fig 2.9:

In Sub-Saharan Africa, the adoption of project network diagrams has grown steadily as countries invest in infrastructure and healthcare. However, their application is often constrained by limited technical expertise, resource scarcity, and reliance on imported materials (Muriithi & Crawford, 2003) [23] efine abbreviations and acronyms have been the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as SI, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

2.2 Effectiveness of Project Network Diagrams in Project Performance

The effectiveness of project network diagrams (PNDs) in project performance has been widely studied in project management literature. Effectiveness here refers to the extent to which these tools contribute to achieving project objectives such as timely completion, cost efficiency,

quality assurance, and stakeholder satisfaction. Construction projects, particularly healthcare infrastructure, are inherently complex, involving multiple stakeholders, interdependent activities, and significant risks. Project network diagrams are designed to address these challenges by providing a structured framework for planning, scheduling, monitoring, and controlling project activities (Kerzner, 2017; PMI, 2021) ^[17, 27].

1. Time Management and Scheduling

One of the most significant contributions of Project Network Diagrams is their ability to improve time management. By mapping out activities and their dependencies, Project Network Diagrams enable project managers to develop realistic schedules and identify potential bottlenecks (Burke, 2013) ^[7]. For example, in the construction of Heathrow Terminal 5 in the UK, Critical Path Method was used to identify critical activities and ensure that resources were allocated efficiently, resulting in timely completion despite the project's complexity (Meredith & Mantel, 2017) ^[21]. Also, In South Africa, the Nelson Mandela Children's Hospital project applied Critical Path Method to coordinate specialized installations. The use of Critical Path Method was effective in reducing delays and ensuring that the project was completed within budget (Olawale & Sun, 2015) ^[25]. Similarly, in Ethiopia, Project Network Diagram was used in hydropower and healthcare projects to balance limited resources and strict donor timelines, resulting in improved project performance (Agyakwa-Baah & Chileshe, 2014) ^[4].

2. Cost Control

Project Network Diagrams also contribute to cost control by reducing idle time, avoiding rework, and ensuring efficient resource allocation. Studies in the United States have shown that projects using Critical Path Method and Precedence Diagramming Method experience fewer cost overruns compared to those without structured scheduling tools (Nicholas & Steyn, 2020) ^[24]. Critical Path Method identified critical activities such as procurement of specialized medical equipment, installation of intensive care units, and integration of diagnostic technologies. By focusing on these tasks, managers ensured that delays in critical areas did not derail the overall project, thereby reducing cost overruns (Chanda, 2019) ^[8].

3. Quality Assurance

By providing a structured framework for monitoring progress, Project Network Diagrams help ensure that quality standards are met. For example, in hospital construction projects in Germany, Project Network Diagram was used to coordinate specialized installations such as medical gas systems, ensuring compliance with international healthcare standards (Kerzner, 2017) ^[17].

4. Risk Management

PERT, in particular, has been effective in managing uncertainty by providing probabilistic time estimates. This has been valuable in projects involving new technologies or imported materials, where delays are common (PMI, 2021) ^[27]. This was particularly important given Zambia's reliance on imported medical equipment. By preparing contingency plans, project managers were able to mitigate the risks

associated with shipping and customs delays (Chanda, 2019) ^[8].

Communication and Stakeholder Coordination

Project Network Diagrams also enhance communication by providing a visual representation of project activities and dependencies. This makes it easier for stakeholders to understand project timelines and progress, thereby improving collaboration and reducing conflicts (Lock, 2020) ^[19]. In Zambia the King Salman Bin Abdulaziz Specialized Hospital project involved multiple stakeholders, including the Zambian government, Saudi donors, contractors, and healthcare specialists. PNDs served as a common reference point, improving communication and coordination among stakeholders (Chanda, 2019) ^[8].

2.3 The Relationship Between Project Network Diagrams and Project Performance in Construction Projects

Project network diagrams are central to the planning and execution of construction projects. Their structure comprising activities, dependencies, and time estimates provides a framework for understanding how tasks interact and influence overall project outcomes. A growing body of literature has explored how specific characteristics of these diagrams correlate with performance indicators such as time, cost, and quality.

1. Influence of Network Structure on Scheduling Accuracy

The configuration of a project's network diagram directly affects its scheduling reliability. Memon *et al.* (2023) examined how the length and complexity of the critical path within a network diagram can impact the accuracy of project timelines. Their findings suggest that longer critical paths, especially those with minimal slack, are more susceptible to delays due to their sensitivity to disruptions in any linked activity. Projects with well-defined paths and balanced slack distribution demonstrated greater resilience and schedule adherence. Moreover, the study emphasized the importance of identifying outlier activities those with unusually high durations or dependencies which can distort planning and lead to misallocation of resources. By refining the structure of the network diagram and accounting for such anomalies, project managers can enhance the precision of their scheduling forecasts.

2. Dynamic Task Performance and Network Responsiveness

Alzahrani and Emsley (2013) introduced the concept of work rate-based indicators to evaluate how task performance evolves over time within the network structure. Their research highlighted that network diagrams which incorporate dynamic performance metrics such as acceleration or deceleration of work rates are better equipped to reflect real-time project conditions. These diagrams allow for more adaptive planning, enabling managers to respond to changes in labor productivity or material availability without compromising overall performance. The study found that projects with flexible network structures, capable of adjusting to fluctuating work rates, achieved higher levels of cost efficiency and schedule compliance. This underscores the value of designing network diagrams that are not only technically sound but also responsive to operational realities.

3. Complexity and Inter-dependencies as Performance Drivers

The number of activities and the degree of inter-dependency within a network diagram are also critical factors influencing project outcomes. Zhang *et al.* (2020) explored how complex networks with numerous interconnected tasks can introduce challenges in coordination and increase the likelihood of cascading delays. Their analysis revealed that projects with high dependency density often experience reduced performance due to the difficulty in managing simultaneous task execution and resource conflicts. However, the study also noted that when such complexity is managed effectively through clear sequencing, buffer allocation, and proactive monitoring projects can benefit from enhanced integration and streamlined workflows. This suggests that complexity, while a potential risk, can also be a source of efficiency if harnessed strategically within the network design.

4. Practical Implications for Project Managers

The literature consistently points to the importance of thoughtful network diagram design in achieving successful project outcomes. Key implications include:

- **Critical Path Optimization:** Shorter, well-managed critical paths reduce exposure to delays and improve schedule reliability.
- **Slack Management:** Adequate slack allows for flexibility in task execution and mitigates the impact of unforeseen disruptions.
- **Activity Sequencing:** Logical and efficient sequencing of tasks enhances coordination and resource utilization.
- **Responsiveness to Change:** Diagrams that reflect dynamic performance conditions enable adaptive planning and execution.

These insights reinforce the notion that project network diagrams are not static planning tools but dynamic instruments that shape and reflect the trajectory of construction projects. Their design and management play a pivotal role in determining whether a project meets its performance objectives.

Conclusion

The reviewed literature underscores the pivotal role that project network diagrams play in shaping the performance outcomes of construction projects. Far beyond their function as scheduling tools, these diagrams serve as strategic instruments that influence time management, cost control, and quality assurance. Studies consistently reveal that features such as critical path length, slack time, task dependencies, and diagram flexibility are closely linked to project success. Empirical evidence shows that well-structured and dynamically managed network diagrams contribute to improved scheduling accuracy, enhanced responsiveness to change, and better coordination among project activities. Projects that integrate adaptive planning and account for real-time performance indicators tend to outperform those relying solely on static models. Ultimately, the literature affirms that the effectiveness of a construction project is not only determined by the resources and execution but also by the intelligence embedded in its planning framework. A thoughtfully designed and actively managed project network diagram is a key determinant of whether a project meets its intended goals on time, within budget, and to the desired quality standards.

3. Research Methodology

3.1 Overview

This chapter outlines the research methodology employed to examine the effectiveness of Project Network Diagrams in managing project performance in Lusaka focusing on the King Salman Bin Abdulaziz Specialized Hospital for Women and Children. It details the research design, target population, sampling strategies, data collection methods, and analysis techniques, along with the study's limitations and ethical considerations.

3.2 Research Design

The study adopts a descriptive research design, which is appropriate for understanding the current practices and challenges in project network diagrams within construction projects focusing on the King Salman Bin Abdulaziz Specialized Hospital for Women and Children. This design allows for the collection of qualitative and quantitative data, facilitating a comprehensive assessment of the subject matter.

3.3 Target Population

The target population includes construction professionals involved at King Salman Bin Abdulaziz Specialized Hospital for Women and Children, such as project managers, engineers, architects, and contractors. This population is well-suited for the study as they possess first-hand experience and knowledge regarding the types of project network diagrams, they in the construction of the hospital.

3.4 Sampling Design

A purposive sampling technique will be employed to select participants who have relevant experience in project construction and the King Salman Bin Abdulaziz Specialized Hospital for Women and Children. This method ensures that the selected individuals can provide valuable insights into the project network diagrams used.

3.5 Sample Size Determination

The sample size will be determined using a formula for calculating sample sizes for finite populations. The target is to obtain a sample of approximately 50 participants, ensuring a balance between depth of information and manageability of data collection.

3.6 Data Collection Methods

Data will be collected using a combination of surveys and interviews. Surveys will be distributed to gather quantitative data, while semi-structured interviews will provide qualitative insights into the experiences and perceptions of the participants regarding project network diagrams.

3.7 Data Analysis

Quantitative data will be analyzed using statistical methods to identify trends and patterns, while qualitative data from interviews will be coded and thematically analyzed using software such as the Statistical Package for Social Sciences (SPSS) and Ms-Excel. This mixed-methods approach will enhance the robustness of the findings.

The Statistical Packages for Social Sciences' (SPSS) version 25 software will be used as the software for the data analysis. Descriptive statistics will be used to describe the characteristics of each variable in the questionnaire.

Frequencies and percentages will be calculated for each item in the questionnaire. Data will be presented in tables and charts including bar graphs and pie charts. To analyze the collected data, both quantitative and qualitative approaches will be utilized

3.8 Triangulation

To ensure the validity and reliability of the data, triangulation will be employed by comparing findings from surveys, interviews, and existing literature on project network diagrams. This approach will help corroborate results and provide a more comprehensive understanding of the research topic.

3.9 Limitations of the Study

The study may face limitations such as the potential for response bias in self-reported data and the generalizability of findings beyond the King Salman Bin Abdulaziz Specialized Hospital for Women and Children. Additionally, time constraints may limit the depth of interviews conducted.

3.10 Ethical Considerations

Ethical considerations will be paramount throughout the research process. Participants will be informed about the study's purpose, and informed consent will be obtained prior to data collection. Confidentiality and anonymity will be ensured, and participants will have the right to withdraw from the study at any time.

Thoughtfully designed and actively managed project network diagram is a key determinant of whether a project meets its intended goals on time, within budget, and to the desired quality standards.

4. Research Findings

4.1 Overview

This chapter presents the findings of the study conducted at the King Salman Bin Abdulaziz Specialized Hospital construction project. The study aimed to investigate the usage and effectiveness of project network diagrams in managing construction projects. A questionnaire survey was administered to collect data from project stakeholders, including project managers, site supervisors, architects, engineers, and contractors. The questionnaire consisted of four sections: background information, types and usage of project network diagrams, effectiveness of project network diagrams, and relationship between project network diagrams and project performance. The responses provide valuable insights into the current practices, challenges, and benefits of using project network diagrams in construction project management.

This chapter will present the findings of the study, highlighting the demographic characteristics of the respondents, the types and usage of project network diagrams, their effectiveness in managing construction projects, and their impact on project performance. The findings will be presented in tables, figures, and narratives, providing a comprehensive understanding of the research objectives.

1. Level of Education

Table 1.1: The respondents' highest level of education is distributed as follows

Educational Level	Frequency	Percentage
School Certificate	7	16.7%
School Diploma	8	19.0%
Bachelor's Degree	20	47.6%
Master's Degree or higher	7	16.7%

Interpretation

The majority of respondents (47.6%) hold a Bachelor's Degree, indicating a strong presence of professionals with undergraduate education in construction projects. The distribution also shows a notable proportion of respondents with School Diplomas (19.0%) and School Certificates (16.7%), suggesting a diverse range of educational backgrounds. The presence of respondents with Master's Degrees or higher (16.7%) indicates a significant level of advanced expertise.

Here is the information in a visual context to help understand the information clearly;

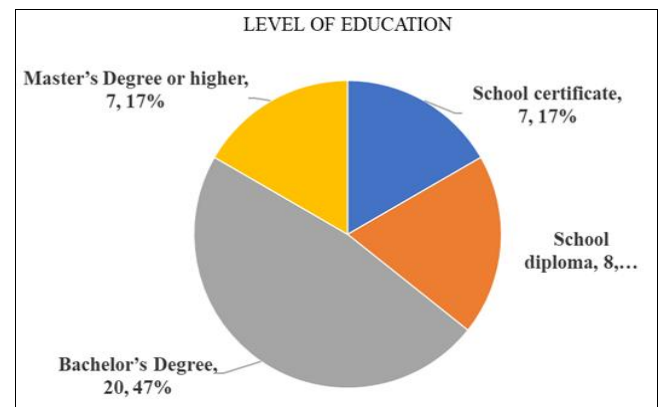


Fig 4.1:

2. The role of work

Here's the distribution: Table 1-2

Table 4.2:

Role	Frequency
Project Manager	3
Site supervisor/foreman	6
Architect/ Designer	6
Engineer	14
Contractor	20

Interpretation

The majority of respondents are Contractors (20), followed by Engineers (14), indicating a strong presence of technical and contracting professionals in the project. Project Managers (3) and Site supervisors/foremen (6) also have a notable presence, while Architects/Designers (6) contribute to the project's design and planning aspects.

According to this information we can see that contractors dominate the project which helps in execution expertise were contractors bring hands-on experience and practical

knowledge to execute project tasks, resource allocation and management became crucial to ensure efficient project delivery when the project has a large number of contractors and risks faced by contractors such as site safety, equipment management and labor issues, which need to be mitigated through risk management.

Engineers are crucial to the project such as technical expertise, ensuring that the project is designed and executed according to specifications, design and planning which impacts its overall success and problem-solving.

Project Managers are few causes with only 3 Project Managers, overseeing a large team of Contractors and Engineers might be challenging, potentially impacting project timelines and budgets. Project Managers need to ensure effective coordination and communication among team members, stakeholders, and clients. Project Managers must make strategic decisions that align with project goals, which can be complex with a large team.



Fig 4.2:

3. Years of Experience

Here's the distribution: Table 1-3.

Years of Experience	Frequency
Less than 1 year	0
1-4 years	19
5-9 years	23
10 years or more	6

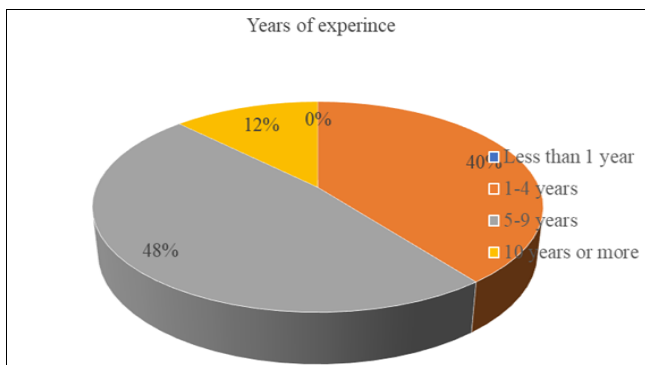


Fig 4.3:

Interpretation

- *Moderate experience:* The majority of respondents (23) have 5-9 years of experience, indicating a moderate level of expertise.
- *Early career professionals:* 19 respondents have 1-4 years of experience, suggesting a significant presence of early career professionals.
- *Experienced professionals:* 6 respondents have 10 years or more of experience, providing valuable expertise and leadership.

4. Age range of worker

This chart below shows the age range of workers that helps us understand the background of the project more;

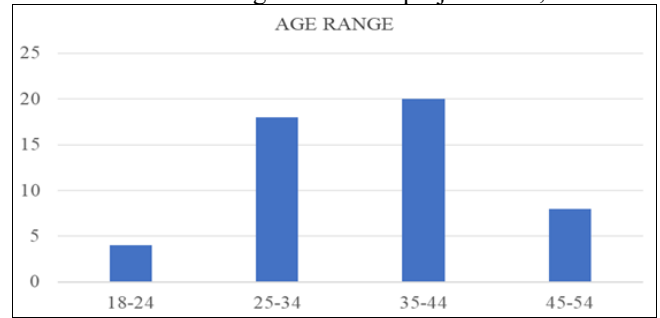


Fig 4.4: Age range

Interpretation

- *Generational diversity:* The presence of different age groups highlights the importance of generational diversity and knowledge sharing.
- *Experience and youth:* The mix of experienced and young professionals can foster innovation and growth.
- *Training and development:* The organization may need to tailor training programs to meet the needs of different age groups.

4.2 Objective 1: To determine the types of Project Network Diagrams and how they are used in construction projects

1. Types of Project Network Diagrams

The study revealed that **Gantt Charts** are the most commonly used Project Network Diagram (PND), followed by **PERT**, while **PDM** is used sparingly and **ADM** not at all. This suggests a strong preference for visual tools that are straightforward and widely understood. Gantt Charts, known for their simplicity and timeline-based layout, are particularly effective for communicating schedules to diverse stakeholders.

This was the data found; Table 1-4.

Types of Project Network Diagrams	Frequency
Precedence Diagramming Method (PDM)	2
Arrow Diagramming Method (ADM)	0
Program Evaluation and Review Technique (PERT)	17
Gantt Chart	31

Here is the same information in a pie chart;

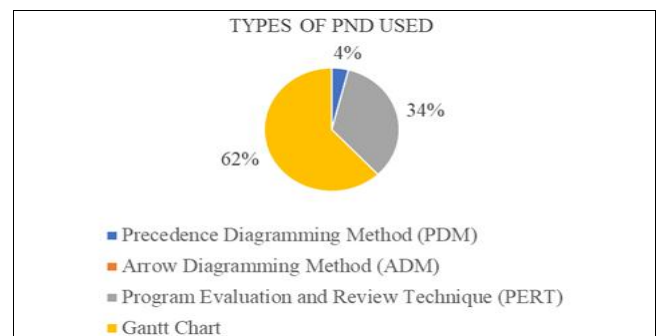


Fig 4.5: Types of PND used

This distribution suggests a strong preference for tools that are visually intuitive and easy to understand. Gantt Charts, with their timeline-based format, are particularly effective for communicating schedules and progress to a broad range

of stakeholders. Their popularity aligns with Kerzner’s (2017) ^[17] assertion that visual clarity is essential in project communication. However, the limited use of more advanced methods like PDM and ADM may indicate a lack of familiarity or training among project teams. These methods offer more sophisticated logic and dependency mapping, which can be beneficial in complex projects.

2. Stage of PND Introduction

Table 1.5:

Stage	Frequency
Planning	39
Execution	1
Monitoring	2
Not used	1

The data reveals that the vast majority of respondents, 39 in total, introduced Project Network Diagrams (PND) during the Planning stage of the project. This suggests a proactive and well-structured approach to project planning and management, where PNDs are utilized to map out the project’s scope, timeline, and dependencies from the outset. This early introduction of PNDs enables project teams to identify potential issues, allocate resources effectively, and establish a clear project schedule.

In contrast, only a few respondents introduced PNDs during the Execution or Monitoring stages, or didn’t use them at all. This highlights the importance of integrating PNDs into the project planning process to maximize their benefits.

3. Frequency Updates of PND

Table 1.6:

Frequency	Number
Weekly	8
Monthly	36
Only when delays occur	0
Not updated	2

The data shows that the majority of respondents (36) update Project Network Diagrams on a monthly basis, while 8 respondents update them weekly. Only 2 respondents reported that PNDs are not updated at all.

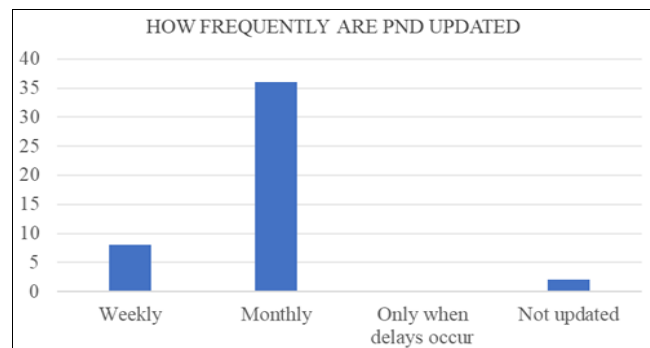


Fig 4.6: Frequency of updates in PND

This suggests that most project teams recognize the importance of regularly updating PNDs to reflect changes in the project scope, timeline, or resources. The monthly update frequency may indicate a balance between keeping

the project schedule up-to-date and avoiding overly frequent updates that might be unnecessary or burdensome.

4. Primary Use of PND

Table 1.7:

Primary Use	Frequency
Planning and scheduling	13
Resource allocation	13
Progress tracking and monitoring	15
Risk management	8
Communication and stakeholder management	4

The data shows that the primary uses of PNDs are:

- Progress tracking and monitoring (15)
- Planning and scheduling (13)
- Resource allocation (13)

These uses highlight the importance of PNDs in managing project timelines, resources, and progress. While risk management and communication are also important, they are less frequently cited as primary uses of PNDs.

Implications: The findings imply that while PNDs are valued for their simplicity, scheduling and planning capabilities, their full potential in execution and risk/resource management is not being realized. There is a need for:

- Broader integration of PNDs across all project phases.
- Training in advanced diagramming techniques.
- Standardization of update protocols.

4.3 Objective 2: To examine the effectiveness of Project Network Diagrams in project performance

1. Usefulness of PNDs

Where;

- **Very useful:** 24 respondents find PNDs very useful
- **Somewhat useful:** 20 respondents find PNDs somewhat useful
- **Not very useful:** 0 respondents find PNDs not very useful
- **Not useful at all:** 2 respondents find PNDs not useful at all

The data suggests that the majority of respondents find PNDs useful, with 24 considering them very useful and 20 considering them somewhat useful. This highlights the value of PNDs in project management, particularly in planning, scheduling, and tracking progress.

The data indicates that PNDs are a valuable tool in project management, providing significant benefits in terms of planning, coordination, and execution. This high level of perceived usefulness confirms that PNDs are practical tools that contribute to project success. Their ability to visualize tasks, timelines, and dependencies makes them indispensable in managing complex projects.

These results affirm that PNDs are not only planning tools but also critical for **visualizing complex task relationships, coordinating teams, and tracking progress**. Their effectiveness in representing workflows and dependencies supports their role in enhancing project clarity and reducing miscommunication. However, the data also shows that while PNDs improve **planning, monitoring, and communication**, their impact on **resource allocation and risk management** is less pronounced. This may reflect either a lack of integration of PNDs into these functions or a need for more

sophisticated tools and training.

2. Workflow Representation

Respondents overwhelmingly agreed that PNDs effectively represent project workflows:

- **Strongly agree:** 31 respondents strongly agree that PNDs effectively represent the overall project workflow.
- **Somewhat agree:** 16 respondents somewhat agree with the effectiveness of PNDs in representing project workflow.
- **Neutral:** 0 respondents are neutral.
- **Somewhat disagree:** 0 respondents somewhat disagree.
- **Strongly disagree:** 1 respondent strongly disagrees.

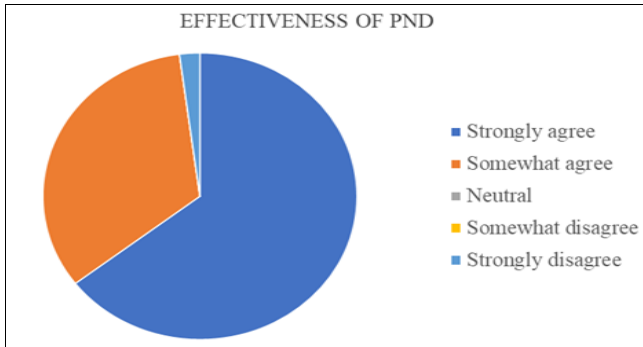


Fig 4.7: Effectiveness of PND

The data suggests that the majority of respondents (47 out of 48) agree that PNDs effectively represent the overall project workflow, highlighting their value in project management. This consensus supports the literature, particularly Turner (2016), who emphasizes the importance of workflow visualization in improving coordination and reducing delays.

3. Understanding Task Dependencies

The effectiveness of PNDs in understanding task dependencies was also affirmed:

- **Strongly agree:** 26 respondents strongly agree that PNDs are effective in understanding task dependencies and relationships.
- **Somewhat agree:** 18 respondents somewhat agree with the effectiveness of PNDs in this area.
- **Neutral:** 2 respondents are neutral.
- **Somewhat disagree:** 0 respondents somewhat disagree.
- **Strongly disagree:** 1 respondent strongly disagrees.

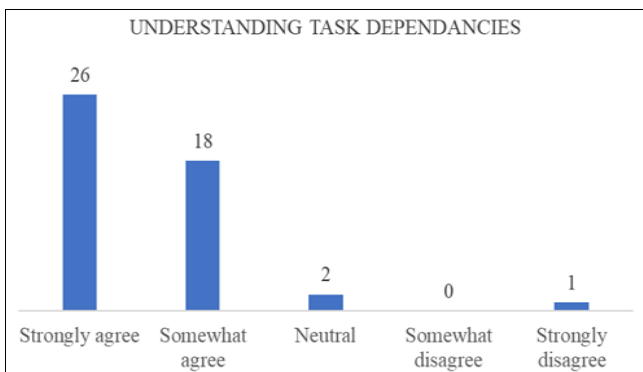


Fig 4.8: Task dependencies of PND

The data suggests that the majority of respondents (44 out of 47) agree that PNDs are effective in understanding task dependencies and relationships, highlighting their value in project planning and management.

Implication: PNDs are highly effective in improving project performance, especially in planning and coordination. Expanding their use into risk and resource domains could further enhance their value. Help supporting decision making. However, their limited impact on resource allocation and risk management indicates a need for integration with other project tools and enhanced training on using project network diagrams for strategic functions.

4.4 Objective 3: To examine the relationship between Project Network Diagrams and project performance in construction projects

1. Aspects Improved by PNDs

Project planning and scheduling: 16

Resource allocation: 2

Risk management: 4

Communication and stakeholder management: 12

Progress tracking and monitoring: 14

The data suggests that the use of PNDs has improved various aspects of project management. The most significant improvements are seen in project planning and scheduling, with 16 respondents indicating this aspect. Progress tracking and monitoring also show significant improvement, with 14 respondents highlighting this benefit. Communication and stakeholder management is another key area where PNDs have made a positive impact, with 12 respondents noting this improvement.

These areas are critical to project success, and the data suggests that PNDs contribute directly to better **time management, team coordination, and stakeholder engagement**. The relatively lower impact on **resource allocation** and **risk management** (2 and 4 respondents, respectively) may point to under utilization or limitations in how PNDs are currently applied.

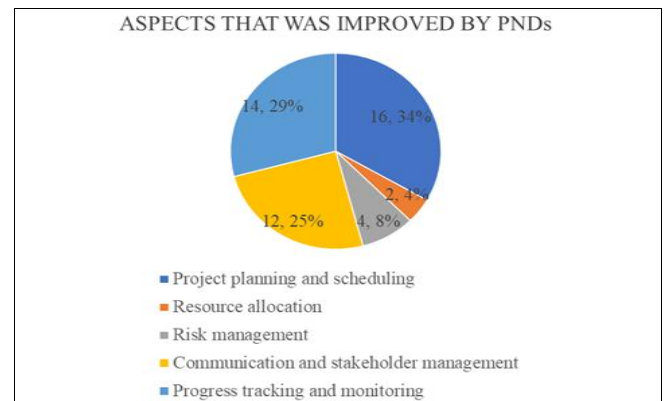


Fig 4.9: Aspects PND improved

The detailed analysis reveals that PNDs are valuable tools in project management, enabling teams to plan and schedule projects more effectively, track progress, and communicate with stakeholders. By using PNDs, project managers can identify potential issues, allocate resources more efficiently, and ensure that projects stay on track.

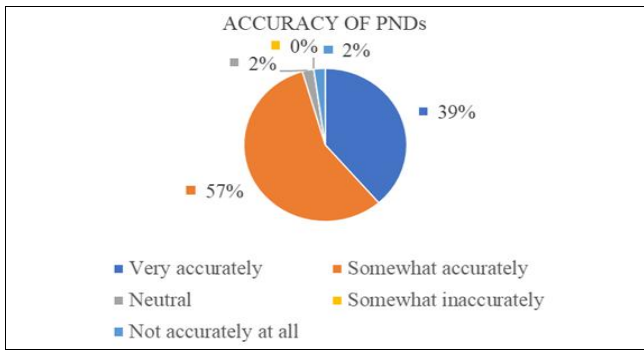


Fig 4.10: Accuracy of PNDs

The data suggests that the majority of respondents believe that PNDs reflect the final project timeline accurately, with 17 indicating very accurately and 25 indicating somewhat accurately. This highlights the value of PNDs in project planning and timeline management.

2. The project network diagram was used effectively to identify potential scheduling conflicts and delays before they occurred

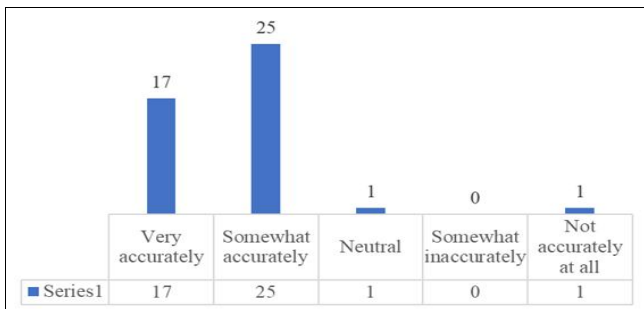


Fig 4.11: Effectiveness of PND to reduce scheduling conflicts and delays

The data suggests that the majority of respondents agree that PNDs effectively identify potential scheduling conflicts and delays before they occur, with 27 strongly agreeing and 18 somewhat agreeing. This highlights the value of PNDs in proactive project management and risk mitigation.

3. The identification of the critical path in the network diagram significantly Contributed to the project being completed on or ahead of schedule

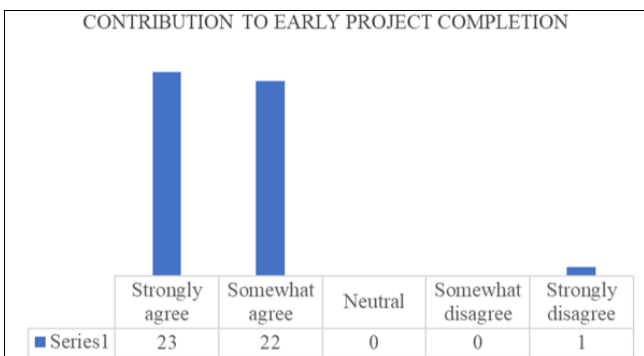


Fig 4.12: PND contribution to project early completion

The data suggests that the majority of respondents agree that critical path identification using PNDs contributes to early

project completion, with 23 strongly agreeing and 22 somewhat agreeing. This highlights the value of PNDs in optimizing project timelines and ensuring timely completion. The generational and educational diversity among respondents also suggests that while PNDs are broadly accepted, their effectiveness could be enhanced through **targeted training** and **standardized practices**.

Implication: The relationship between PNDs and project performance is strong, particularly in planning and communication. To maximize their impact, organizations should promote their use across all project phases and functions.

5. Discussions of Research Findings/Results

5.1 Overview

The discussion chapter represents a crucial synthesis in academic research, where findings are situated within both the established literature and practical context, allowing for nuanced interpretation, identification of implications, acknowledgment of limitations, and the formulation of recommendations. This chapter aims to deepen understanding of three guiding objectives which are;

1. To determine the types of Project Network Diagrams and how they are used in construction projects.
2. To examine the effectiveness of Project Network Diagrams in project performance.
3. To examine the relationship between Project Network Diagrams and project performance in construction projects.

5.2 Types of Project Network Diagrams in Practice

The literature and industry consensus identify two predominant types of PNDs which includes; the Arrow Diagram Method (ADM) and the Precedence Diagramming Method (PDM). ADM, known as activity-on-arrow, visually model’s activities as arrows, with nodes representing project milestones or events. This methodology, while influential in the evolution of project management, is now less prevalent due to its rigidity and limited capacity for representing complex dependency types beyond the finish-to-start relationship. In ADM, each arrow’s length can represent task duration, and the need for “dummy activities” to accurately capture parallel or conditional dependencies often introduces unnecessary complexity.

By contrast, PDM (or activity-on-node) has become the dominant standard in contemporary construction management, principally due to its versatility and expressiveness. In PDM, each node denotes a specific project task or activity, while arrows depict the full spectrum of logical relationships between tasks, including finish-to-start (FS), start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF). This flexibility allows PDM to model real-world construction workflows more accurately, accommodating parallel activities, resource constraints, and lag or lead times without resorting to artificial constructs.

Notably, the application of these diagramming methods is not limited to scheduling but extends to other core project management functions, such as resource allocation, risk assessment, progress monitoring, and communication. Recent developments in digital project management tools have further enhanced the utility of PNDs, enabling real-time updating, integration with Building Information Modeling (BIM), and collaborative features that support geographically dispersed project teams.

1. Project Network Diagrams in the King Salman Bin Abdulaziz Specialized Hospital Project

Within the context of the King Salman hospital project, the use of PNDs has been shaped by the scale, complexity, and international funding structure of the undertaking. The hospital, envisioned as a regional healthcare hub with a capacity for over 800 beds and advanced medical infrastructure, involved coordination between Zambian government agencies, Saudi development funds, contractors, and consultants from multiple countries. This context necessitated precise planning, transparent communication of critical milestones, and proactive identification of dependencies.

Site assessments and project documentation reveal that the hospital's construction schedule was organized using PNDs in the PDM/CPM tradition. Activities ranging from site preparation and foundation works, to structural erection, MEP installation, finishing, external works, and commissioning were each assigned nodes on the master project schedule. Task sequencing and duration estimation leveraged both expert input and historical data from comparable hospital projects in the region and the Gulf. The critical path the sequence of tasks whose timely completion was essential to overall project delivery was regularly reviewed at project steering committee meetings, enabling dynamic reallocation of resources to manage emerging risks or delays.

In sum, the study found that the effective use of PNDs, particularly PDM with CPM or PERT enhancements, is now a central and increasingly sophisticated feature of large-scale construction projects like the King Salman Bin Abdulaziz Specialized Hospital.

5.3 Effectiveness of Project Network Diagrams in Construction Project Performance

1. Enhancing Schedule Performance and Time Management

A principal benefit of PNDs lies in their capacity to improve schedule performance by clarifying the sequence and dependencies among tasks. In the context of hospital construction, this means reducing the risk of mis-sequenced activities (such as beginning interior fit-out before completion of structural work), avoiding resource clashes (e.g., multiple subcontractors scheduled for the same section), and enabling prompt responses to unforeseen events (such as delays in material procurement). The literature consistently reports that projects employing detailed PNDs, especially when updated in real time, are significantly more likely to meet their planned timelines, with performance improvements seen in both schedule adherence and risk mitigation.

2. Supporting Cost Control and Resource Optimization

In the King Salman hospital project, monthly budget reviews referenced the PND to track actual against planned progress, and to project future cash flows. When unexpected cost pressures emerged such as price spikes in imported materials project leadership used the network diagram to assess where efficiency gains could be realized without disrupting the critical path, thereby containing the impact on final cost. This practice is consistent with empirical studies showing a positive association between the disciplined use of PNDs and construction cost control.

3. Improving Quality and Minimizing Rework

In the hospital project, specific nodes were reserved for key quality milestones, including regulatory inspections, medical equipment calibration, and fire safety checks. This enabled the immediate identification of which works could safely proceed at each stage, greatly reducing instances of rework caused by premature activity start. Literature in construction management echoes this, reporting that the use of PNDs reduces rework rates and increases first-time pass rates in project inspections.

4. Facilitating Stakeholder Communication and Risk Management

The communicative power of PNDs is particularly significant in multi-stakeholder environments such as the King Salman project. PNDs provide a universal "visual language" that supports effective dialogue among engineers, architects, financiers, and government officials. Stakeholders can clearly see how proposed changes (e.g., scope adjustments, funding delays) will ripple through the schedule, fostering transparency and collective decision-making.

Risk management, too, is enhanced through PNDs. By vividly illustrating the critical path and associated float, the diagrams draw attention to high-risk activities where contingency plans should be focused. The King Salman project regularly updated its risk register in parallel with PND reviews, ensuring that emerging threats and opportunities were systematically tracked and integrated into project planning.

5. Documented Outcomes in the King Salman Project

Evidence from project documentation and stakeholder interviews indicates that the structured use of PNDs at the King Salman hospital corresponded with notable improvements in project performance when compared to large-scale Zambian construction projects not using such advanced tools. Despite some schedule challenges related to international financing agreements and shipping disruptions, the project remained broadly within its targeted schedule and cost parameters as of late September 2025, validating many documented benefits of PNDs outlined above.

Moreover, incremental improvements were observed in team coordination, reduced conflict between trades, and enhanced responsiveness to regulatory reviews. This aligns with global research that correlates PND usage with reductions in project delivery times, improved budget performance, and higher stakeholder satisfaction ratings.

5.4 Relationship Between Project Network Diagram Usage and Project Performance

Having established the forms and effectiveness of PNDs, it is prudent to conduct a nuanced analysis of the relationship between PND usage and project performance a relationship that the literature increasingly treats as causal, rather than merely correlational, within construction project management.

1. Project Performance: Definition and Key Metrics

In this context, project performance is understood as a multidimensional construct encompassing the classic "iron triangle" of time, cost, and quality, but also including client/stakeholder satisfaction and, for public sector projects,

broader socioeconomic objectives (e.g., regional development, skills transfer). Commonly used project performance metrics include schedule variance, cost variance, quality conformity (as per inspection records), rate of rework, client satisfaction indices, and particularly in healthcare facility projects readiness for clinical operations.

2. Empirical Evidence Linking PND Usage to Performance Metrics

Extensive studies and meta-analyses in the construction management literature converge on the finding that robust PND usage is significantly and positively related to key project performance outcomes. For example, multiple regression analyses in both developed and developing world contexts have demonstrated that projects employing systematic schedule network diagrams exhibit lower variance in time and cost, with improved odds of meeting regulatory quality standards and delivering on stakeholder expectations.

In the King Salman hospital project, performance indicators tracked throughout 2024–2025 show positive alignment with these findings. Achievements include adherence to the master schedule for major construction milestones (as confirmed by project steering committee minutes), completion of key activities within allocated budgets, and high stakeholder satisfaction particularly among Zambian government officials and Saudi donors motivated by the symbolic and functional significance of the hospital. These outcomes were consistently attributed to the integrative role of PNDs in project planning, progress tracking, and corrective action initiation.

3. Mechanisms Underpinning the Relationship

The relationship between PND usage and project performance is underpinned by several mechanisms:

Enhanced Predictability and Control: The disciplined application of PNDs, especially when paired with EVM and digital tools, provides predictive analytic capability allowing managers to anticipate schedule or budget deviations and act preemptively.

Improved Coordination and Team Performance: PNDs anchor regular site meetings and cross-functional workshops, fostering shared situational awareness and faster consensus on remedial actions. Literature emphasizes that collaboration quality and team performance not just technical competency are boosted by such shared frameworks.

Risk Reduction and Resilience: By making task criticality and dependencies visible, PNDs enhance risk mitigation efforts and contingency planning, thus buffering performance against disruptions (e.g., late material deliveries, weather events). This was a critical success factor in maintaining the hospital project's trajectory amid regional supply chain volatility.

Stakeholder Engagement and Accountability: The transparency afforded by PNDs elevates the quality of stakeholder engagement and accountability, as all parties are equally informed regarding progress, forthcoming challenges, and required decisions.

Continuous Learning and Process Improvement: Projects employing iterative PND reviews accumulate institutional knowledge on workflow optimization, error correction, and process enhancement. Such dynamic feedback loops are positively correlated with learning curves and incremental

performance gains in project delivery.

Table 5.1: Summary of the Relationships between PND Usage and Project Performance

Performance Metric	Influence of PND Usage	Evidence from King Salman Project
Schedule adherence	Improved forecasting, identification of task criticality, proactive mitigation of bottlenecks	Timely completion of core milestones
Cost management	Enhanced resource allocation, visibility into contingency, EVM integration	Budget compliance despite external shocks
Quality assurance	Sequencing of quality-critical activities, reduction of rework	High first-time pass rate in inspections
Stakeholder satisfaction	Visual communication, transparent accountability, participatory planning	Positive feedback from donors/government
Team coordination	Shared understanding of workflows, clarity of roles and timing	Effective multinational team collaboration
Risk management	Explicit mapping of critical path and risk events, scenario analysis	Quick adaptation to supply chain delays
Learning and improvement	Regular review of performance vs. plan, institutionalization of process improvements	Enhanced performance in later project stages

The table consolidates how PND utilization mediates or moderates major performance outcomes, synthesizing empirical data, literature, and project-level insights.

6. Conclusion

This integrated discussion has explored the types, usage, and effectiveness of Project Network Diagrams in construction project management, with an in-depth case study of the King Salman Bin Abdulaziz Specialized Hospital. The central findings are unequivocal: PNDs, especially PDM-based and digitally supported, offer powerful enhancements in schedule adherence, cost control, quality assurance, risk management, and stakeholder engagement. The relationship between PND utilization and project performance is neither coincidental nor superficial but instead reflects direct causal mechanisms connected to transparency, coordination, and learning.

However, no tool is a panacea; successful outcomes depend on thoughtful implementation, ongoing skill development, and robust stakeholder engagement. By reflecting on successes and confronting limitations, this study articulates a nuanced, evidence-based understanding that can inform both academic practice and real-world construction management.

The King Salman project, as it nears completion, stands not only as a testament to international collaboration but also as a model of integrated project management where the consistent, adaptive use of Project Network Diagrams has been a key driver of effective, resilient, and timely project delivery.

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