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“Integrating Operability and Maintainability into Constructability Implementation in Petrochemical Projects”

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Abstract
Integrating Operability and Maintainability into Constructability Implementation in Petrochemical Projects is a multifaceted endeavor aimed at optimizing the efficiency and effectiveness of the petrochemical industry's infrastructure development. This study aimed to measure the amount of the study participants' awareness with Operability, Maintainability and Constructability concepts. A mixed-method approach has been adopted, combining qualitative and quantitative techniques. The first source is based on a survey of 54 project-experienced workers, while the second is based on four managers' accounts from petrochemical firms in Saudi Arabia gathered through semi-structured interviews. The findings demonstrated that the individuals involved possessed a keen understanding of the concepts of operability, maintainability, and constructability. Based on the findings, it is recommended to incorporate operability and maintainability into the early stages of project development in order to ensure a lucrative and efficient petrochemical complex. Involvement of process safety, operations, and process engineers is crucial in the early stages of any petrochemical project, and responses made it clear that process safety and operations should be involved from the beginning.
Key words: Constructability, Operability, Maintainability, Petrochemical Projects, Saudi Arabia.

Introduction

Since 1973, the building sector in the Kingdom of Saudi Arabia has experienced significant and widespread growth across all parts of the country. This significant surge in construction is a manifestation of various factors. The primary element is the enhancement of the economic condition resulting from the surge in oil income during that timeframe. The second aspect involves the government's implementation of residential and industrial projects to generate cash for the country. As a result, the incorporation of these components has helped to improve the progress of construction projects.

There are numerous stakeholders involved in the development of building projects in the petrochemical sector, including owners, designers, agents, subcontractors, and technology licensors. Consequently, it is critical to get the whole project team on the same page and make the most of the knowledge, lessons learned, and challenges encountered in past petrochemical projects.

Completeness within the allotted time and budget, as well as safety and continuous operation with little maintenance for the remainder of the facility's life, are all necessary for a project to be considered successful from every angle (Hauashdh et al., 2022). Including this idea in all project manuals will increase project scope, quality, and ROI. Also, the operation and maintenance team's experience are valuable (Pratap Chandran & K. Purayil, 2020).

Constructability practice, which centers on analyzing project procedures from start to finish during the pre-construction phase, may be extended to incorporate issues connected to operation and maintenance, making it an efficient way to implement this principle.

The notion of buildability, also known as constructability, refers to the process of maximizing the essential background experience during the feasibility planning and design phases of a project. This can be accomplished by the combined efforts of all team members (Osuizugbo et al., 2023). When construction operations are isolated from the planning and engineering phases, constructability offers a chance to shorten the project length, improve the final product process, and reduce the amount of expenditure that might be wasted (Xu et al., 2023). From inception to completion, constructability can improve numerous facets of a project. These include keeping an eye on the big picture, selecting the optimal design, preventing tasks from going over schedule, and keeping costs within the set budget (Shash & Almufadhi, 2021).

In essence, integrating operability and maintainability into constructability implementation in petrochemical projects represents a holistic approach to infrastructure development. By aligning these critical components throughout the project lifecycle, stakeholders can achieve enhanced operational performance, reduced maintenance overheads, and improved project outcomes, thereby driving success and sustainability in the dynamic petrochemical industry.

Problem Statement

The problem that this study sought to address stemmed from was the fact that successful petrochemical projects were put at risk due to the absence of suitable integration of operations and maintenance and the involvement of varied partners throughout their lifecycle. Many reworks and claims for additional cost have resulted from changes in project scope due to the separation of operability, maintainability, and constructability. This is especially common in projects related to the petrochemical sector. While constructability has been discussed as a tool to address operability and maintainability, it has not been enough to resolve the research questions raised by its use to industrial projects.

Research Objectives

The main objectives of this study are as follows:

- To examine the project owner's comprehension of the significance of integrating operation and maintenance considerations throughout the first stages of a project.
- Incorporate operation and maintenance considerations during the first stages of a project by implementing constructability practices.

Research Hypotheses

H1: The implementation of operability & maintainability activities is independent of the years of experience.
H2: The implementation of operability & maintainability activities is independent of type of project.
H3: The implementation of operability & maintainability activities is independent of project budget.

Research Significance

Researching the integration of operability and maintainability into constructability implementation in petrochemical projects holds immense significance for the efficiency, sustainability, and long-term success of such endeavors. First and foremost, this research endeavors to address the complex challenges inherent in the petrochemical industry, where the construction, operation, and maintenance of facilities are intricately linked. By examining how operability and maintainability considerations can be seamlessly integrated into the constructability phase, researchers aim to optimize every stage of the project lifecycle.

One of the primary significances lies in the potential to enhance operational efficiency. Petrochemical facilities are intricate systems that require seamless operation to maximize productivity and minimize downtime. By incorporating operability considerations during the constructability phase, such as designing systems that are easy to operate and adapt to changing conditions, researchers can contribute to smoother startup processes and more efficient operations once the facility is operational. This can lead to increased throughput, reduced operational disruptions, and ultimately, improved profitability for petrochemical projects.

Moreover, the significance extends to the realm of maintenance optimization. Maintenance costs represent a substantial portion of the total lifecycle expenses for petrochemical facilities. By integrating maintainability principles into the

constructability phase, such as designing for accessibility and ease of maintenance, researchers can help mitigate these costs. Facilities that are easier to service, repair, and upgrade are likely to incur lower maintenance expenses over their lifespan, resulting in significant cost savings for project stakeholders. Additionally, improved maintainability can contribute to extended asset lifespan, increased reliability, and enhanced safety performance, further underlining the significance of this research.

Limitations of the study

The limitations of the study include:

Sample Size: The majority of participants were from engineering disciplines, with a smaller representation of project managers and facility managers. This limited sample composition might not fully capture the perspectives and experiences of other relevant stakeholders involved in petrochemical projects, such as regulatory authorities or environmental experts.

Methodological Constraints: The study utilized a mixed-method approach combining qualitative interviews and a quantitative questionnaire. While this approach allows for triangulation and deeper insights, it also presents challenges such as potential biases in participant responses, difficulty in ensuring consistency between qualitative and quantitative data collection, and limitations in the depth of qualitative analysis due to time and resource constraints.

Industry Context: Petrochemical companies in Saudi Arabia operate within a distinct industry context characterized by significant government involvement, large-scale production facilities, and strategic importance to the national economy. This context may shape the challenges, opportunities, and priorities related to operability, maintainability, and constructability in ways that are not fully captured by the study's findings. Consequently, the applicability of the study's conclusions to petrochemical industries in other countries or regions may be limited.

Definition of Key terms

- Operability: Ease of operation is the defining characteristic of operability. It involves designing systems and processes that enable smooth and efficient operation under various conditions, ensuring that production targets can be met while minimizing disruptions and maximizing productivity (Trigunarsyah & Skitmore, 2010).
- Maintainability: A product's maintainability can be defined as its ease of maintenance, which in turn can help to decrease the frequency and severity of defects, as well as to find new needs, make future maintenance easier, and adapt to changing environmental conditions (Thabet, 2000).
- Constructability: For a project to be constructible, it is necessary to incorporate construction-related knowledge and experience from the outset in order to accomplish the project's overarching goals throughout the planning, designing, logistics, and execution phases (Yustisia, 2014).
- Petrochemical Projects: Petrochemical projects involve the construction, operation, and maintenance of facilities that produce a wide range of chemical products derived from petroleum and natural gas. These projects can include refineries, chemical processing plants, petrochemical complexes, and other facilities involved in the production, processing, and distribution of petrochemical products (Speight, 2019).

Theoretical Framework

1. An Overview of Constructability

In order to improve the construction process, the concept of constructability might be considered at the outset of the project, either through a formalized method or informally (Barros & Sotelino, 2023). The use of the constructability principle is typically contingent upon the characteristics of the project and the type of contract. The primary importance of employing the constructability principle lies in its early implementation, which provides possibilities to impact cost savings and enhance the overall quality of the project's lifespan (Lao et al., 2023). Nevertheless, implementing the constructability idea frequently enhances the potential value of the project.

Furthermore, apart from achieving cost savings and improving work quality, the advantages might also encompass facilitating construction activities, prioritizing safety at the project site, and shortening construction timelines (Martínez & Miller, 2023).

The construction industry frequently faces difficulties in quantifying the advantages of implementing the constructability concept. This is because the installation of constructability necessitates a financial investment and increases the workload for project designers in reviewing design feedback (Shash & Almufadhi, 2020). Nevertheless, the savings in both cost and time during construction outweigh the expenses incurred for the review.

But there are two kinds of benefits that might come from using the constructability concept: quantitative and qualitative. The quantitative benefits include things like shorter project schedules and lower costs associated with design and field execution. Applying international standards, meeting owner requirements, taking regional and situational characteristics into account, having experience with material selection, and verifying the final design with software modules can all lead to a reduction in design cost (Mohsenijam et al., 2020).

Since reducing construction costs necessitates employing fewer fixed construction equipment and fewer workers, it varies from reducing design costs. In addition, cutting down on the project timeline can help save money by shortening the duration of activities, expediting tasks that could otherwise add more time to the project if not done in the right order, and concentrating on tracking the critical path activities, which are the primary factors in creating the project timeline (Nolan & Gibson Jr, 2021).

1.1. Concepts and Principle

Constructability is a fundamental concept in construction management that encompasses principles and practices aimed at optimizing the construction process to achieve project objectives efficiently and effectively. At its core, constructability emphasizes the integration of design, construction, and operation considerations from the early stages of project planning through to completion (Khan, 2018).

In the past, petrochemical projects followed a more conventional project lifecycle model. This model required the completion of the Front Engineering Package (FEEP), which covered the project's fundamental engineering and rough investment, before the construction agency, general contractor (GC), and subcontractors (Sub-C) could begin to actively participate in carrying out the work. Also, as seen in Figure 1 (Menegon & da Silva Filho, 2023), after communicating material and equipment specifications to suppliers, you should place a purchase order for a Long Lead Item (LLI).

The owner, agency, designer, engineers, and execution contractor all work together as a cohesive unit from the very beginning of a project in an integrated project lifecycle. The constructability concept is defined by this project lifecycle approach, which aims to maximize efficiency, minimize waste, and optimize project outcomes in order to increase the owner's value. It also helps in identifying and narrowing the gap between the design and construction phases. In keeping with the petrochemical sector's expansion and the proliferation of projects of all types, there is an urgent need to maximize the application of constructability and make use of its benefits, the most important of which are cost reductions.

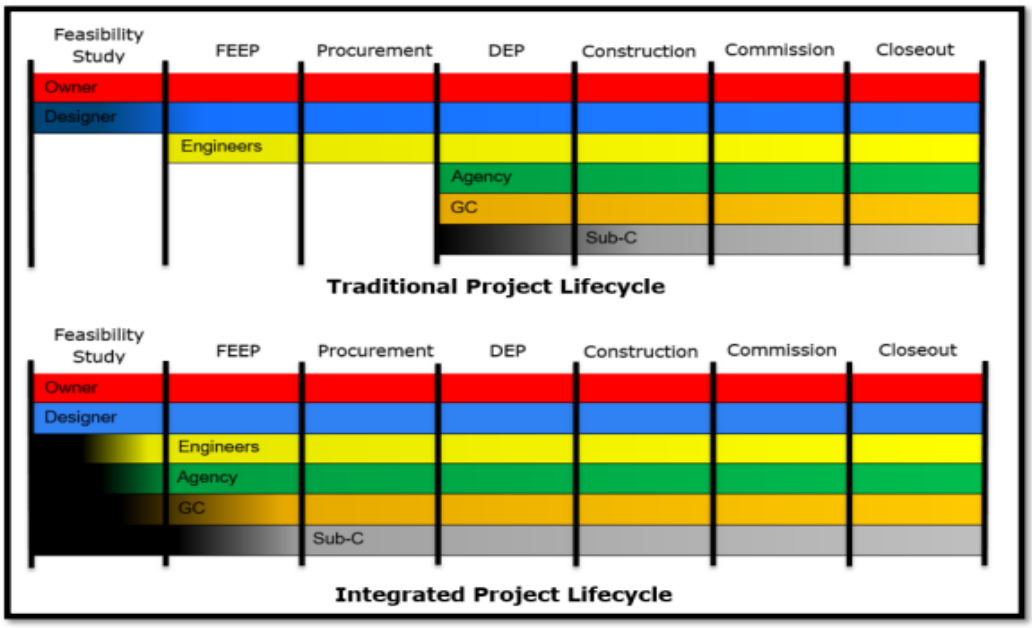

Figure 1: The Difference Between Project Lifecycles

1.2. Current Implementation

The current method for implementing constructability is a workshop or review process that aims to find difficulties, disputes, or barriers that may arise throughout the design and building phases of a project.

Four evaluation points make up the constructability review procedure as shown in figure 2. According to Samimpey & Saghatforoush (2020), the first review, known as a primary review, is carried out during the preliminary engineering phase after the Project Definition Report (PDR) has been prepared. Its major purpose is to ensure that all team members have a clear grasp of the project's scope and are committed to achieving its goal.

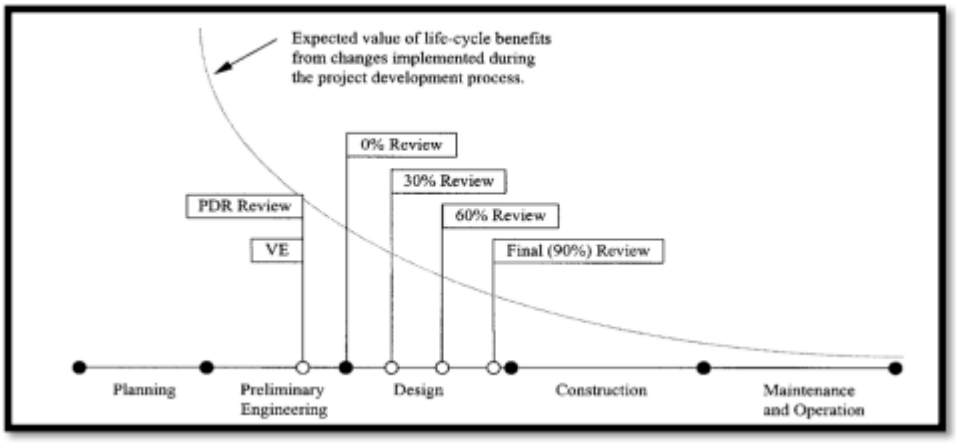

Figure 2: Procedure for Constructability Reviews

2. Overview of Operability and Maintainability

Operability and maintainability are two critical aspects of engineering design and facility management that play integral roles in ensuring the long-term success and efficiency of industrial projects.

The capacity of a business to run its operations smoothly and without incident is known as operability. According to Rossini et al. (2023), the end goal of facility operability is to build a structure that can be used safely, efficiently, and affordably for its entire lifetime.

Similarly, maintainability is described as the actions performed during the creation, design, and installation of a manufactured product to decrease the need for maintenance, minimize the amount of time, tools, and resources necessary, and lower the skill level needed. Therefore, at the design stage of any equipment & system, the team responsible for approving the design must consider the possibility of maintaining equipment & system with a minimal cost. Furthermore, it is noteworthy that there are minimal impacts on the environment (Ghalenoei et al., 2021).

Maintainability and operability are integral to the effective operation of industrial facilities and are inextricably linked. Even with a functional system, one that is challenging to maintain may incur expensive disruptions and reduced dependability. A system that is both maintainable and inadequately operable can result in inefficiencies and operational errors. Determining optimal performance and sustainability thus necessitates the implementation of a comprehensive strategy that takes maintainability and operability into account throughout the facility's lifecycle.

2.1. Concepts of Operability and Maintainability

Operability refers to the simplicity and efficiency with which the intended function of a system or facility can be accomplished. This concept entails the development of systems that feature intuitive controls, user-friendly interfaces, and streamlined processes, enabling operators to effectively monitor, regulate, and modify operations (Kordestani Ghaleenoe et al.,2017). A system that is exceptionally operable empowers operators to promptly adapt to evolving circumstances, reduce inaccuracies, and maximize the output of production. Organizations can achieve several benefits by placing operability as a forefront in both design and operation: increased productivity, diminished training needs, and enhanced overall operational performance.

In contrast, maintainability pertains to the simplicity and efficiency of servicing and maintaining a facility or system throughout its entire life cycle. This notion entails the development of systems that incorporate easily obtainable components, standardized processes, and streamlined maintenance workflows to facilitate the activities of inspection, repair, and replacement. Preventive maintenance, corrective maintenance, and predictive maintenance are all components of system maintenance, which are performed to ensure the system's continued functionality and dependability (Asmone et al., 2019). By minimizing outage, lowering maintenance expenses, and prolonging equipment lifespan, a maintainable system is achieved. Organizations can enhance asset performance, prolong uptime, and reduce lifecycle expenses by integrating maintainability considerations into their design and maintenance procedures.

The relationship between Operability and Maintainability (O&M) arises from the impact of effective maintainability on achieving sustainable operation and attaining the desired production (Kordestani Ghaleenoei et al., 2022). Immediate action to address operational issues can lead to great maintainability, allowing the system to quickly return to normal operating circumstances (Ogunbayo et al., 2022).

Operation and maintenance concerns account for 50% to 80% of the overall project expenditure as shown in figure 3. This demonstrates the need of considering the ultimate objective of achieving smooth operation and maintenance after project initiation, rather than solely prioritizing the building schedule and budget (Ogunbayo et al., 2022).

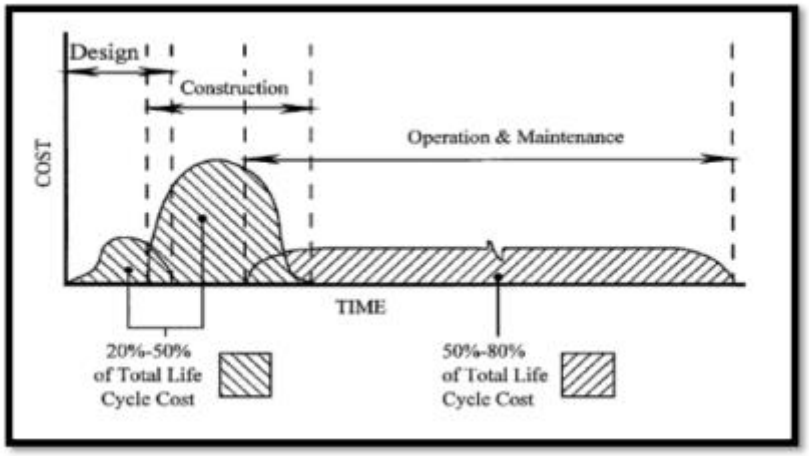

Figure 3: Life-Cycle Costing Profile

2.2. Current Implementation

Utilizing the knowledge and experience of individuals working in operation fields was traditionally the source of field operability. In a nutshell, operational dependability and performance are factors that should be considered throughout the engineering and construction phases of an asset's lifecycle. In order to accomplish this, the operability review process must be implemented by the design team and the project throughout its development. This will ensure that the designer is aware of the commonly observed hazards, their impact on the environment, and any unsafe conditions, and will prevent any major accident that could result in massive losses (Yang et al., 2022).

In order to guarantee the quality and availability of enterprise systems, an operability assessment is conducted as part of an intense project analysis. This study focuses on utilizing operation experts. To ensure a cost-effective strategy that takes into account economic, environmental, and financial issues, it is important to incorporate the operability idea early on in the project (Barozzi et al., 2020). This will help the designer choose the right technology system.

2.3. The incorporation of maintainability and operability into the implementation of constructability

Problems arising during project development are a direct result of misalignment that arises when constructability, operability, and maintainability concepts are implemented independently. On the other hand, new issues may arise following the facility's commissioning and restart, which can interrupt regular operations and necessitate repairs to get things back to normal (Castro-Lacouture, 2023).

Conversely, certain proprietors opt to expedite the design phases and achieve immediate financial savings through the omission of operability and maintainability requirements during the design phase. Subsequently, upon reaching the post-commissioning phase, they are taken aback by the substantial surge in operational and maintenance expenses that were accrued throughout the operational phase (Frank & Brisibe, 2021) as shown in figure 4.

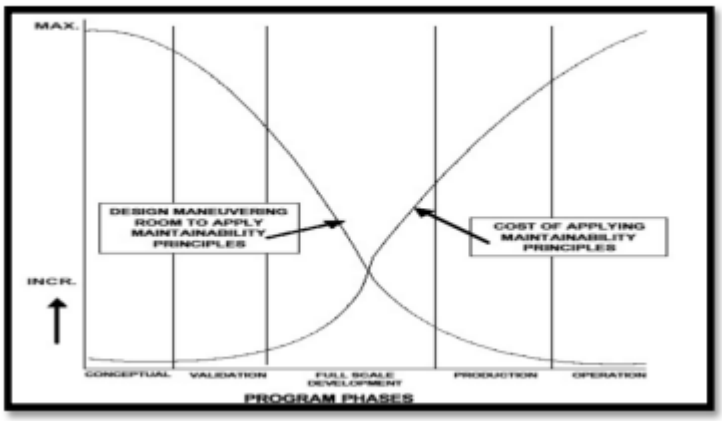

Figure 4: Impact of Implementing a Maintainability Program

Previous Studies

According to (Kordestani Ghaleenoe et al., 2017) project managers continue to encounter challenges related to time, money, and quality even after allotting substantial funds to civil engineering projects, engaging in thorough planning, and using human resources. The majority of these problems stem from the fact that the various parts of the project aren't working together and because construction and maintenance contractors can't be present at the beginning of the project. When you apply the

principles of constructability, operability, and maintainability (COM), you can fix a lot of issues that arise from things like poor communication, unnecessary repetition of tasks, and ineffective management. You can also save time and money by bringing in contractors for both construction and maintenance at the beginning of the project. Several studies have looked at the positive aspects of using these ideas, but none have compared the pros and cons of COM. Project managers can enhance their performance and efficiency by utilizing these concepts and strategies to implement them. This is achieved by focusing on the benefits of implementation and evaluating the effect of each strategy and benefit from different perspectives and time periods. Examining recent studies that have focused on the positive effects of constructability, operability, and maintainability on the construction sector is the primary goal of this research. For that, we employ the strategy of doing a comprehensive literature study. Qualitative examination of the data collected has made use of descriptive analysis. The importance of paying close attention to what is helping the construction process has been better appreciated than in the past, according to this study's conclusions. What this means is that the building industry's professional community is paying attention and is interested in replacing outdated practices with more modern ones, like COM principles.

According to (JadidolEslami et al., 2018) given the ever-increasing global population, infrastructure projects are receiving unprecedented levels of focus and funding as they constitute the backbone of national economies and social welfare systems. There is a greater need to address post-design issues due to the high stakes involved, the negative consequences of early destruction, and the availability of duplicates in these projects. A project management strategy for analyzing post design processes from beginning to end is to incorporate constructability, operability, and maintainability elements from the first pre-construction stage. This helps to reduce problems that arise throughout the post design stages of infrastructure projects. In order to minimize issues caused by a lack of application of expertise and experience in the early stages of a project, these concepts stress the importance of construction, operation, and maintenance contractors being present early on in the project. This inquiry has categorized these benefits at different stages of the project life cycle using the meta-synthesis approach and the qualitative analysis program NVIVO. Its purpose is to evaluate the benefits of adopting these concepts in infrastructure projects. Not only were there many advantages throughout the design and implementation phases, but we also saw that some of those advantages were repeated throughout the project. In order to ensure the project's success, it is crucial to comprehend and use all of the COM ideas; this case proves that doing so is necessary at various points in the process.

Methodology

1. Research Plan

An overview of the operationalizing procedures and analyses utilized in this study is illustrated in Figure 5.

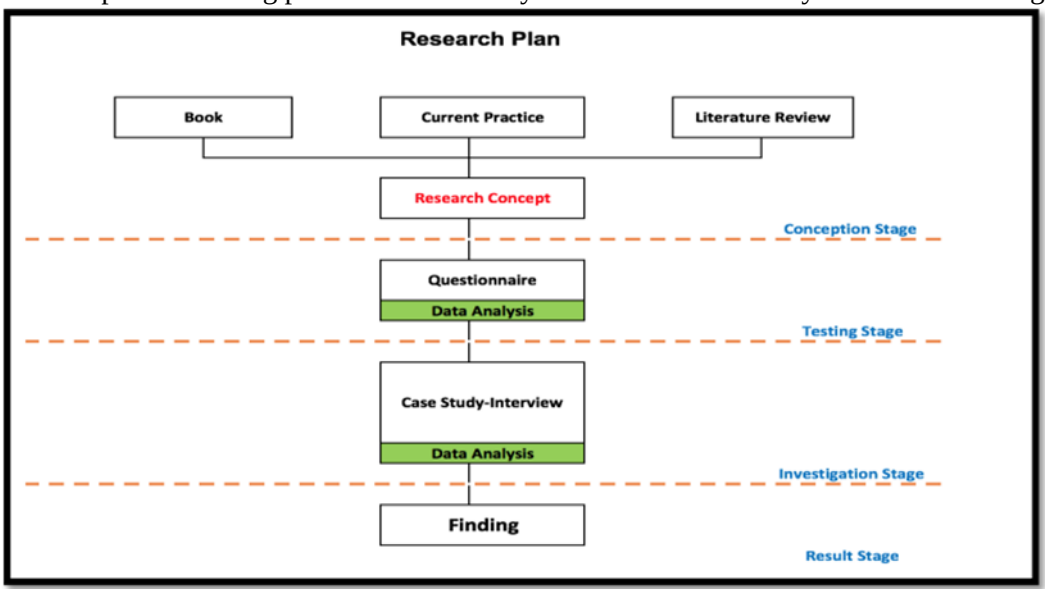

Figure 5: Research Plan

2. Research Approach

A research approach refers to the overarching strategy or methodology adopted by researchers to conduct a study and achieve its objectives (Opoku et al., 2016). It outlines the systematic process and techniques used to collect, analyze, and interpret data in order to address research questions or hypotheses.

- Qualitative Approach: According to Hennink & Kaiser (2022) The primary tenet of the qualitative research method is investigation. The foundation of qualitative research is an examination of a social phenomenon through the eyes of the people who take part in it. According to Fischer & Guzel (2023), qualitative research is an effective model because it takes place in the actual world, where the researcher can gain specifics by taking part in the events.
- Quantitative Approach: Based on data collected from the study population, quantitative research either confirms or refutes the research hypotheses (Fischer et al., 2023). According to Nasir & Sukmawati (2023), a quantitative method involves gathering information based on theories or hypotheses, and then analyzing this data using descriptive or deductive statistics.

In order to accomplish the goals of this research, a combination of qualitative and quantitative methodologies, known as a mixed method approach, has been employed. The theoretical framework of this research was developed using the qualitative research method, which involved conducting interviews and reviewing relevant literature, including studies, books, and articles related to the subject of the study. Additionally, a pre-designed questionnaire was used as the quantitative approach. The mixed-methods approach allows for the collection of data from a large sample of people, provides answers to the research question from multiple angles, and guarantees that the data is complete and accurate; all of this could lead to a deeper comprehension of the study's topic and goals.

3. Data Collection Methods

Data collection is a fundamental component of research methodology, essential for gathering information and evidence to support the research objectives (Igwenagu, 2016). It involves the systematic process of obtaining, recording, and analyzing data from various sources and methods to address specific research questions. The primary purpose of data collection is to generate empirical evidence that can be used to draw meaningful conclusions and insights.
In order to achieve the objectives of the study; All data and information were based on two types of sources:

- **Secondary Sources**

Secondary sources are vital references and materials that provide existing data, information, or knowledge that has been collected, analyzed, and documented by someone other than the researcher. These sources serve as a valuable resource for researchers to support their studies and investigations, as they offer pre-existing data or insights, often in the form of published literature, or reports (Ajayi, 2017).
The information was gathered from a variety of secondary sources, including published books and articles.

- **Primary Sources**

Primary sources are foundational elements of data collection that provide original, firsthand information or evidence directly related to the research topic. These sources are essential as they offer data that has not been interpreted, summarized, or filtered through the lens of previous researchers or intermediaries (Pandey & Pandey, 2021).
The research has employed both primary and secondary sources to fill its data bucket, as these are the two most common ways for researchers to gather information for a study. The main data for this study were provided by survey respondents who are employees of Petrochemical Projects.
Conducting semi-structured interviews is another method for gathering primary data. The researchers in this study gathered their information through in-person interviews with managers at petrochemical companies. The interview questions aimed to clarify the selected topic, gather data that would answer the research questions and objectives adequately, and make the study more convenient for the participants. The maximum amount of time each interview took for this study is fifteen to twenty minutes.

4. Study Population

The study population refers to the entire group or collection of individuals that share common characteristics or attributes and are of interest to the researcher for a specific study (Sileyew, 2019). It is a fundamental concept in designing and conducting research as it defines the scope and boundaries of the investigation. The study population is central to determining which individuals or units will be the focus of data collection and analysis.
The study population comprised employees and managers employed in Petrochemical Companies in Saudi Arabia. Although we sent out the survey to over 120 people working for Saudi Arabian petrochemical companies, we only got 54 back from employees with project experience. The second source relies on semi-structured interviews with four managers from Saudi Arabian petrochemical companies.

5. Data analysis

The term "data analysis" is used to describe the methodical and structured procedure of examining, cleaning, manipulating, and analyzing data acquired for the purpose of drawing conclusions, answering research questions, or putting hypotheses to the test. At this stage, researchers use a variety of statistical and computational methods to interpret the collected data (Davidavičienė, 2018).

An examination of the following two primary areas was said to be the purpose of this study: (1) Conduct an investigation into the extent to which project owners comprehend the significance of incorporating concerns regarding operation and maintenance at an early stage in the project. (2) Constructability technique should be utilized in order to incorporate concerns of operation and maintenance into the early phases of the project.

6. Research Instrument (Questionnaire)

There were 54 participants from 22 different companies included in the study sample.
The responses were collected from a range of experience levels. The majority of participants (about 35.2%) have five to ten years of experience in their current position. Following that, 29.6% have less than five years of experience, 22.2% have eleven to fifteen years, 9.3% have a large amount of experience (more than 20 years), and 9.3% have two or more years of experience (between 16 and 20 years).

Based on the participant's role within the organization, the distribution was as follows:
Among the participants, 40% hold positions in fields outside of engineering, such as mechanical, electrical, instrument, chemical, maintenance, or engineering. Of the remaining participants, 34.55% are project engineers, 16.36% are facility managers, and 9.09% are project managers.

Results

There will be five main sections to the presentation of the results.

1. The characteristics of the company will be discussed in the first section. The results of this section were derived from the survey questions numbered three through four.
2. Questions 5–13 and 16–18 make up the second portion of the survey and reveal how people feel about the incorporation of operability and maintainability into constructability tasks.
3. The results on the benefits of performing the constructability study at early stages of the project design are shown in the third part enclosed beneath question 14.
4. Results regarding the benefits of relating operability and maintainability (O&M) ideas inside constructability practice are shown in the fourth part enclosed beneath question 15.
5. Part five, which is covered under questions 6–10, displays the outcomes pertaining to the early phases of petrochemical project stages addressing operability and maintainability (O&M) ideas.

The First Section: Organizational Features

The question regarding years of experience in the current position was answered by all participants. Of those, 52 (96.30%) provided the name of their company, while just 35 (64.81%) provided their own name. The majority of participants (approximately 38.18%) stated that their company's project budgets range from less than SR50,000,000. On the other hand, 29.09% indicated that their company's project budgets range from more than SR500,000. Alternately, 16.36% of respondents said that their company's project budgets fall anywhere between SR100,000,000 and SR500,000,000. The majority of the participants (approximately 61.82%) said that their organization uses turnkey/design and build to involve operation and maintenance experts during the planning, conceptual, and detail design phases of a project. This approach shifts the risk and keeps the total scope under the contractors' responsibility. On the other hand, 21.82% said that their company uses traditional (separate design and build) project delivery. On the other hand, 10.91 percent said that their company uses the Build-Operate-Transfer methodology for project delivery, while 5.45 percent said something else but didn't specify.

The Second Section: How Participants Feel About Operations and Maintenance Being Incorporated Early on in Petrochemical Projects

This section aims to assess participants' comprehension of the significance of including operation and maintenance considerations during the initial stages of a project. This will be achieved by examining their understanding of how operability and maintainability concepts are integrated into the implementation of constructability in petrochemical projects. To accomplish this goal, it is important to gather the viewpoints of the participants in the subsequent stage: The activities encompassed in your organization during the project planning phase, project conceptual design phase, project detail design phase, project construction phase, and project during and after closeout phase. Therefore, this section will provide a comprehensive explanation of these phases:

Table 1 presents a comprehensive description of the participants' viewpoints about the early integration of operating and maintenance concerns.

Table 1: Respondents' Views on the Early Integration of O&M Issues

Q		Percentage (%)
5	**How often do your organization engage operation and maintenance experts at planning, conceptual and detail design project phases: Check all that apply**	
5a	Commonly	49.09
5b	Depend on type of project	36.36
5c	Depend on importance of equipment	10.91
5d	Never	3.64
11	**Do you agree that the participation of operation and maintenance experts during the planning and design phases can help to produce better specifications, safe operation and minimum repair?**	
11a	Yes	88.68
11b	Sometimes	7.55
11c	Depends on another factor	3.77
11d	No	0.00
12	**"Operability is the ability of an organization to operate a facility in a safe and efficient manner. The ultimate goal of facility operability is to design and construct a facility that will remain safe, efficient and cost effective throughout its lifetime use" Have you heard this term before?**	
12a	Yes	90.57

Q		Percentage (%)
12b	No	9.43
13	**"Maintainability is the measures taken during development, design and installation of a manufactured product that reduce required maintenance, man-hours, tools, and logistic cost" Have you heard this term before?**	
13a	Yes	83.02
13b	No	16.98
16	**Do you think operability and maintainability should be included as a task during planning and design phases of the project?**	**Percentage (%)**
16a	Complex Projects	3.70
16b	Large Projects	3.70
16c	Certain types of Projects	5.56
16d	Small Projects	0.00
16e	All Projects	87.04
16f	Not required	0.00
17	**Do you think operability and maintainability should be included as a task during planning and design phases of the project**	
17a	Yes	83.33
17b	Sometimes	5.56

Q				Percentage (%)
17c	Depends on another factor			7.41
17d	No			3.70
18	**Based on your experience, please rate the following list relate to operation and maintenance issues result from petrochemical Projects**	ALWAYS–	SOMETIMES–	NEVER–
		%	%	%
18a	Your organization realize the benefit of integrating operability and maintainability at early project phases	59.26	38.89	3.70
18b	Consider having convenient accessibility for repair major plant equipment	64.81	31.48	3.70
18c	Look for innovation to solve operation and maintenance issues	48.15	40.74	11.11
18d	Allow some flexibility in design to treat operation and maintenance issues	48.15	44.44	7.41
18e	Provide enough authority for operation and maintenance to contribute their input within the design phases	48.15	48.15	5.56
Total		100		

Table 1 question 5 shows that 50% of respondents think these are typical things for their company to do when they're planning a project. This implies that it should be included in all projects. On the other hand, half of the respondents said that it depends on the project type or the significance of the equipment. If it doesn't happen, it will never be a part of their organization.

The majority of participants (approximately 47) acknowledge that involving operation and maintenance professionals throughout the planning and design phases can lead to a smooth operation with minimal repair needs in question 11 of the same table. Thus, it is clear that the individuals involved comprehend the significance of the operation and are prepared to do what is necessary to ensure its continued safety.

Similarly, the majority of respondents to question 12 attests to being familiar with these operability words and their significance in ensuring the facility can be operated in a safe and sustainable manner. On the other hand, some of them may be unfamiliar with the word and have never heard it used before. This could be due to a lack of awareness of the significance of safe and continuous operation following construction or another factor entirely.

With 83.02% of the response indicating that participants are familiar with the words, maintainability is just as important as operability.

Respondents to question 16 generally agree that operability and maintainability should be considered throughout the whole project lifecycle, not just during the planning and design stages. Choosing a precise project size is only done by a small proportion of the total.

When asked about the importance of adding operability and maintainability in early project stages, 83.33% of participants agreed. The significance of considering operability and maintainability cannot be overstated. Neglecting these aspects during commissioning can lead to major problems that disrupt or halt the facility's functioning.

As illustrated in Figure 6, participants drew on their prior knowledge to respond to questions 18 and 19 on operating and maintenance concerns, respectively.

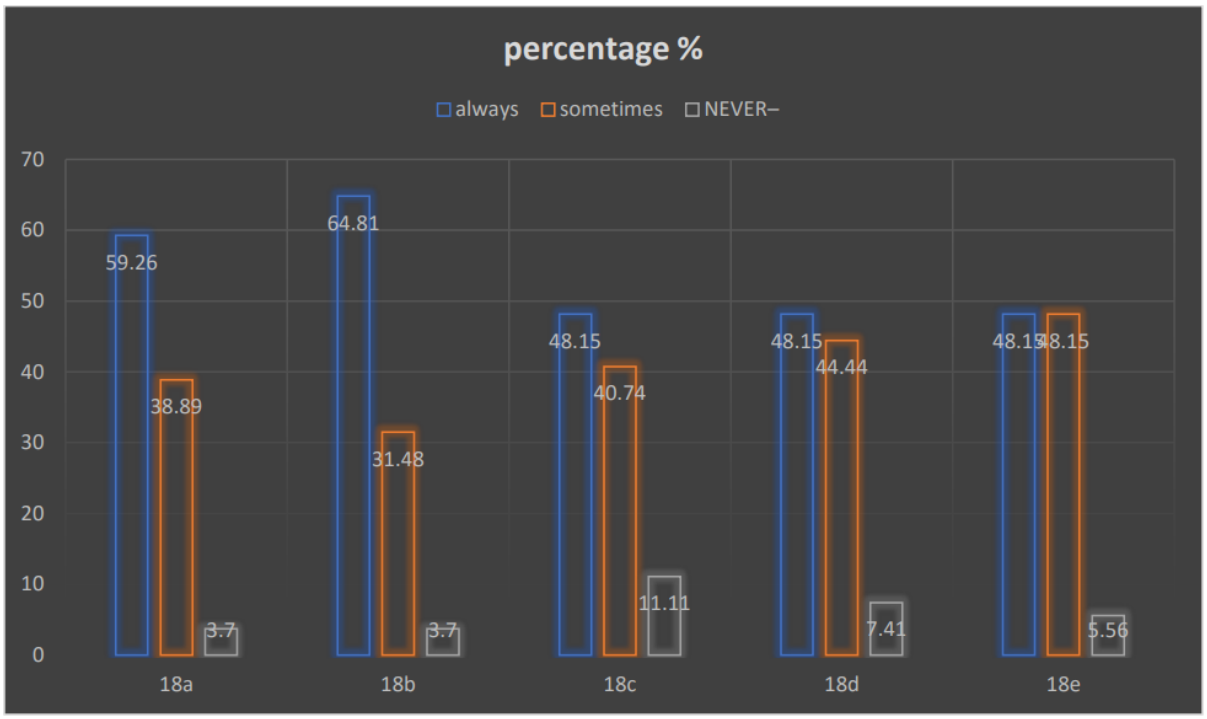

Figure 6: The Experiences of Participants Regarding Operation and Maintenance Concerns

This chart shows how important it is to resolve any concerns or issues with operation and maintenance as soon as possible in the project life cycle, before moving on to the specifics and construction.

The Third Section: Opinions of Participants Regarding the Use of the Constructability Review in the Early Stages of Design

Figure 7 shows that most people involved are adamant that constructability, when applied early in the design process, may reduce project risk. Due to the fact that it utilized to assess the building process throughout the development stage of a project, long before the detailed design was created. Second, keeping costs in check is essential; this will help you determine how much money you'll need at the outset by taking into account all the factors that can drive up the budget. Compared to the two elements mentioned earlier, time growth receives the least amount of attention from the participants, at 75.93%. Just because cutting corners to speed up the process can end up costing more than just cutting corners in the first place. As far as the participants are concerned, one of them claims there are no advantages.

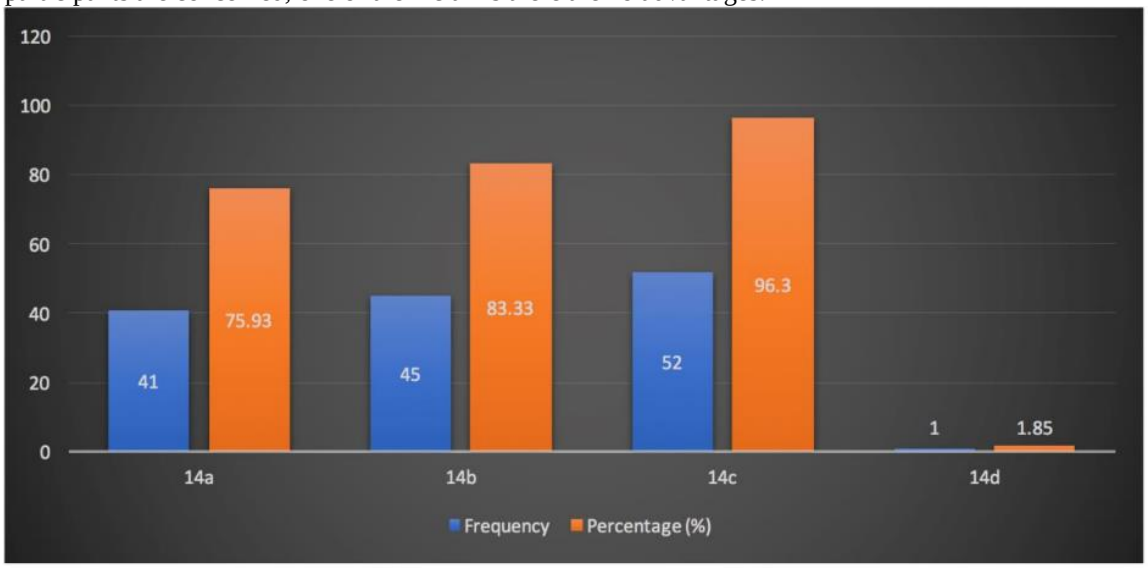

Figure 7: Advantages of Conducting the Constructability Review During the Initial Design Phases

The Fourth Section: Opinions of Participants Regarding the Advantages of Integrating Operability and Maintainability Principles into Constructability Practice

Incorporating Operability and Maintainability into constructability practice has several advantages, and this section will demonstrate that participants comprehend these benefits. Table 2 provides a comprehensive overview of the participants' views regarding the advantages of incorporating Operability & Maintainability principles into constructability practice.

Table 2: Views of Respondents on the Use of O&M Principles in Constructability

15	What are the benefits from involving Operability & Maintainability (O&M) concepts within constructability practice: Check all that are right	Percentage (%)
15a	Having a smooth operation	92.59
15b	Having a minimum maintenance	88.89
15c	Monitoring the project budget	40.74
15d	Monitoring the project schedule	37.04
15e	Ensuring safety considerations in all project phases	81.48
15f	Does not have any benefits	1.85
Total		100

Incorporating notions of operability and maintainability into constructability practice is crucial for achieving smooth operation and minimal repair, as acknowledged by more than 48 participants. This is in line with the constructability implementation guide's emphasis on these topics. Some participants, on the other hand, prefer to keep constructability separate from operability and maintainability. As an added bonus, including operability and maintainability principles into constructability practice helps with project budget monitoring to the tune of 40.74 percent. Last but not least, 37.04 percent of respondents felt that including operability and maintainability principles into constructability practice improved project schedule monitoring. However, one of them claimed that there are no advantages.

The Fifth Section: The Stages of Petrochemical Projects That Address Operability and Maintainability (O&M)

a. Descriptive Analysis

What follows is a discussion of "How the organizations participate during various stages of a project" in questions 6–10. Table 3 shows the researcher's understanding of the implementation of the Operability & Maintainability (O&M) concept throughout the project lifecycle, from planning to conceptual design to detail design to building and finally after closeout.

Table 3: Views of Respondents on O&M Concepts in the Early Stages of Petrochemical Projects

Q		Percentage (%)
6	**Has your organization in the project planning phase include following activities: Check all that apply**	
6a	Develop understanding of project goals and objectives among stakeholder	83.64
6b	Identify resources needed and available personnel	81.82
6c	Begin discuss operation and maintenance preliminary requirement	76.36
6d	Review lessons learned relate to operation and maintenance failure	63.64
6e	Specify required technical standards to be follow during engineering design phases	89.09
6f	None of the above	0.00%
7	**Has your organization in the project conceptual design phase include following activities: Check all that apply**	
7a	Identify opportunities for use of operability and maintainability concepts	64.15
7b	Involve operation and maintenance experts for selection of major system and equipment	75.47
7c	Provide enough authority to operation and maintenance leaders to make a decision	67.92
7d	Discuss the concerns about accessibility of huge equipment	69.81
7e	Prepare formal checklists to ensure addressing maintainability objectives	47.17
7f	None of the above	11.32

8	**Has your organization in the project detail design phase include following activities: Check all that apply**	
8a	Ensure implementation of operability and maintainability concepts	77.78
8b	Identify essential tools and training requirements about operation and maintenance of equipment	77.78
8c	Specify and communicate operability and maintainability requirements to supplier	75.93
8d	Assurance of having updated specifications to allow easy operation and maintenance	75.93
8e	Using innovation idea to resolve many operation and maintenance issues	53.70
8f	None of the above	5.56
9	**Has your organization in the project construction phase include following activities: Check all that apply**	
9a	Assure desired level of maintainability objectives built into constructed project	76.47
9b	Evaluate implementation of operability and maintainability of constructed project by operation and maintenance experts	78.43
9c	Conduct training for operation and maintenance for having smoother start-up	80.39
9d	Conduct maintainability assessment	58.82
9e	None of the above	5.88
10	**Has your organization in the project during and after closeout phase include following activities: Check all that apply**	
10a	Review all aspects of project to assure equipment meets requirements	79.25

10b	Record maintainability ideas generated and implemented on the project	66.04
10c	Data collection and information generated during this stage forward to future projects	60.38
10d	Assure availability of complete and up-to-date documentation relate to operation and maintenance of equipment	83.02
10e	None of the above	1.89

Table 3 shows that in response to question 6, over 80% of participants said that their organization would specify necessary technical standards for the design purpose, develop mutual understanding of project goals among project parties, and identify necessary resources during the project planning phase.

More than 64 percent of respondents to question 7 said that their company included operation and maintenance specialists in major equipment selection during project conceptual design, began discussing accessibility concerns with large equipment, gave operation and maintenance leaders sufficient authority to make decisions, and found ways to apply operability and maintainability concepts to reduce risk and get a safe, reliable design.

Answering question 8, over three quarters of participants said that their organization makes sure that concepts of operability and maintainability are implemented during the project detail design phase. They also said that their organization identifies essential tools and training requirements for equipment operation and maintenance, specifies and communicates these requirements to suppliers, and ensures that specifications are updated to make operation and maintenance easy.

With regard to question 9, Experts in operation and maintenance have given the implementation of operability and maintainability a similar 77% grade to the assurance of having the necessary degree of maintainability objectives built into the completed project. Although when compared to other tasks, 58.82% of respondents highlight the significance of conducting maintainability assessments.

The majority of respondents to question 10 are certain that the necessary paperwork for equipment operation and maintenance is readily available and current. Additionally, to ensure that the equipment satisfies standards, over 75% of the reposes confirm that they review all parts of the project.

Statistical Analysis

This section of the research seeks to identify links between organizational features and the application of operability and maintainability (O&M) concepts. Work kind, years of experience, and project budget are some of the parameters that can be examined using a chi-square test to determine their independence. Furthermore, the Operability & Maintainability (O&M) Concepts are applied at many points in a project's lifecycle, including the planning, conceptual, detail, building, and post-closeout phases.

Before collecting data, the researcher set the α value (which stands for degree of significance) at 0.05 because it is a common value and is based on tradition. If the produced P value is greater than 0.05, the study hypothesis will be rejected; conversely, if the P value is less than 0.05, the study hypothesis will be accepted. This process is carried out by calculating the α value, which is used in conjunction with sig. (P: observed significant).

H1: The implementation of operability & maintainability activities is independent of the years of experience.

Null hypothesis: The implementation of operability & maintainability activities is independent of years of experience.

Table 4 shows that there was no correlation between years of experience and any of the operability and maintainability implementation activities.

Table 4: The Implementation Of O&M Activities Is Independent of Years of Experience

Stage	Q	Survey measures	Chi-square	DF	P-value
planning phase	6a	Develop understanding of project goals and objectives among stakeholder	5.253	3	0.154
	6b	Identify resources needed and available personnel	5.313	3	.150
	6c	Begin discuss operation and maintenance preliminary requirement	2.563	3	.464
	6d	Review lessons learned relate to operation and maintenance failure	5.013	3	.171
	6e	Specify required technical standards to be follow during engineering design phases	2.959	3	.398
	6f	None of the above	1.782	3	.619
conceptual design phase	7a	Identify opportunities for use of operability and maintainability concepts	3.257	3	.354

	7b	Involve operation and maintenance experts for selection of major system and equipment	3.575	3	.311
	7c	Provide enough authority to operation and maintenance leaders to make a decision	1.696	3	.638
	7d	Discuss the concerns about accessibility of huge equipment	2.539	3	.468
	7e	Prepare formal checklists to ensure addressing maintainability objectives	2.110	3	.550
	7f	None of the above	1.882	3	.597
detail design phase	Q8a	Ensure implementation of operability and maintainability concepts	4.401	3	.221
	Q8b	Identify essential tools and training requirements about operation and maintenance of equipment	1.295	3	.730
	Q8c	Specify and communicate operability and maintainability requirements to supplier	2.124	3	.547
	Q8d	Assurance of having updated specifications to allow easy operation and maintenance	.770	3	.857
	Q8e	Using innovation idea to resolve many operation and maintenance issues	1.995	3	.573
	Q8f	None of the above	1.494	3	.684
construction phase	Q9a	Assure desired level of maintainability objectives built into constructed project	.382	3	.944
	Q9b	Evaluate implementation of operability and maintainability of constructed project by operation and maintenance experts	2.580	3	.461
	Q9c	Conduct training for operation and maintenance for having smoother start-up	7.131	6	.309
	Q9d	Conduct maintainability assessment	1.917	3	.590

	Q9e	None of the above	.307	3	.959
during and after closeout phase	Q10a	Review all aspects of project to assure equipment meets requirements	1.799	3	.615
	Q10b	Record maintainability ideas generated and implemented on the project	.938	3	.816
	Q10c	Data collection and information generated during this stage forward to future projects	No statistics are computed because Q10c is a constant.		
	Q10d	Assure availability of complete and up-to-date documentation relate to operation and maintenance of equipment	2.716	3	.438
	Q10e	None of the above	2.716	3	.438
operation and maintenance experts	Q11a	Yes	.762	3	.859
	Q11b	Sometimes	.506	3	.918
	Q11c	Depends on other factor	1.254	3	.740
	Q11d	No	1.254	3	.740
Operability	Q12	"Operability is the ability of an organization to operate a facility in a safe and efficient manner. The ultimate goal of facility operability is to design and construct a facility that will remain safe, efficient and cost effective throughout its lifetime use" Have you heard this term before?	1.760	3	.624
Maintainability	Q13	"Maintainability is the measures taken during development, design and installation of a manufactured product that reduce required maintenance, man-hours, tools, and logistic cost" Have you heard this term before?	2.183	3	.535
the benefits of performing the constructability	Q14a	Controlling time growth	2.880	3	.410
	Q14b	Controlling cost growth	.991	3	.803
	Q14c	Minimize the project risk	3.632	3	.304
	Q14d	Does not have any benefits	3.632	3	.304
the benefits from involving	Q15a	Having a smooth operation	1.760	3	.624
	Q15b	Having a minimum	3.308	3	.347
Operability & Maintainability (O&M)		maintenance			
	Q15c	Monitoring the project budget	2.163	3	.539
	Q15d	Monitoring the project schedule	.234	3	.972
	Q15e	Ensuring safety considerations in all project phases	.850	3	.837
operability and maintainability	Q15f	Does not have any benefits	1.254	3	.740
	Q16a	Complex Projects	3.632	3	.304
	Q16b	Large Projects	2.205	3	.531
	Q16c	Certain types of Projects	3.129	3	.372
	Q16d	Small Projects	.896	3	.826
	Q16e	All Projects	No statistics are computed because Q16e is a constant.		

Note: *: Statistically Significant P< 0.05

H2: The implementation of operability & maintainability activities is independent of type of project.

Null hypothesis: The implementation of operability & maintainability activities is independent of type of project.
Table 5 shows that the following activities—the amount of maintainability objectives built into the constructed project,

Table 5: The Implementation Of O&M Activities Is Independent of Type of Project

minimizing the project risk, doing constructability without benefit, and monitoring the project schedule—influence the relationship between operability and maintainability implementation and the type of project.

Stage	Q	Survey measures	Chi-square	DF	P-value
planning phase	6a	Develop understanding of project goals and objectives among stakeholder	5.358	6	.499
	6b	Identify resources needed and available personnel	1.190	2	.552
	6c	Begin discuss operation and maintenance preliminary requirement	1.691	2	.429
	6d	Review lessons learned relate to operation and maintenance failure	1.390	2	.499
	6e	Specify required technical standards to be follow during engineering design phases	1.012	2	.603
	6f	None of the above	1.310	2	.519
conceptual design phase	7a	Identify opportunities for use of operability and maintainability concepts	2.277	2	.320
	7b	Involve operation and maintenance experts for selection of major system and equipment	1.784	2	.410
	7c	Provide enough authority to operation and maintenance leaders to make a decision	1.066	2	.587
	7d	Discuss the concerns about accessibility of huge equipment	1.784	2	.410
	7e	Prepare formal checklists to ensure addressing maintainability objectives	1.601	2	.449
	7f	None of the above	1.778	2	.411
detail design phase	Q8a	Ensure implementation of operability and maintainability concepts	.350	2	.840
	Q8b	Identify essential tools and training requirements about operation and maintenance of equipment	3.017	2	.221
	Q8c	Specify and communicate operability and maintainability requirements to supplier	5.464	2	.065
	Q8d	Assurance of having updated	.974	2	.615

		specifications to allow easy operation and maintenance			
	Q8e	Using innovation idea to resolve many operation and	186	2	911
		and construct a facility that will remain safe, efficient and cost effective throughout its lifetime use" Have you heard this term before?			
Maintainability	Q13	"Maintainability is the measures taken during development, design and installation of a manufactured product that reduce required maintenance, man-hours, tools, and logistic cost" Have you heard this term before?	3.262	2	.196
the benefits of performing the constructability	Q14a	Controlling time growth	2.648	2	.266
	Q14b	Controlling cost growth	3.268	2	.195
	Q14c	Minimize the project risk	12.986	2	.002
	Q14d	Does not have any benefits	13.872	2	.001
the benefits from involving Operability & Maintainability (O&M)	Q15a	Having a smooth operation	.590	2	.745
	Q15b	Having a minimum maintenance	2.600	2	.272
	Q15c	Monitoring the project budget	.609	2	.737
	Q15d	Monitoring the project schedule	12.744	2	.002
	Q15e	Ensuring safety considerations in all project phases	2.808	2	.246
	Q15f	Does not have any benefits	.396	2	.820
operability and maintainability	Q16a	Complex Projects	.396	2	.820
	Q16b	Large Projects	1.095	2	.578
	Q16c	Certain types of Projects	.122	2	.941
	Q16d	Small Projects	.577	2	.750
	Q16e	All Projects	No statistics are computed because Q16e is a constant.		

Note: *: Statistically Significant P< 0.05

experts	Q11c	Depends on other factor	3.949	2	.139
	Q11d	No	1.095	2	.578
Operability	Q12	"Operability is the ability of an organization to operate a facility in a safe and efficient manner. The ultimate goal of facility operability is to design	4.287	2	.117

H3: The implementation of operability & maintainability activities is independent of project budget
Null hypothesis: The implementation of operability & maintainability activities is independent of project budget.
Table 6 shows that the following activities—not having any organization-wide involvement in the project planning phase and monitoring the schedule—are ways in which the project budget affects the implementation of operability and maintainability.

Table 6: The Implementation of O&M Activities Is Independent of Project Budget

Stage	Q	Survey measures	Chi-square	DF	P-value
planning phase	6a	Develop understanding of project goals and objectives among stakeholder	1.760	3	.624
	6b	Identify resources needed and available personnel	1.498	3	.683
	6c	Begin discuss operation and maintenance preliminary requirement	1.884	3	.597
	6d	Review lessons learned relate to operation and maintenance failure	3.549	3	.314
	6e	Specify required technical standards to be follow during engineering design phases	1.229	3	.746
	6f	None of the above	12.986	3	.005
conceptual design phase	7a	Identify opportunities for use of operability and maintainability concepts	3.549	3	.314
	7b	Involve operation and maintenance experts for selection of major system and equipment	1.720	3	.633
	7c	Provide enough authority to operation and maintenance leaders to make a decision	1.436	3	.697
	7d	Discuss the concerns about accessibility of huge equipment	5.433	3	.143

	7e	Prepare formal checklists to ensure addressing maintainability objectives	3.476	3	.324
	7f	None of the above	1.198	3	.754
detail design phase	Q8a	Ensure implementation of operability and maintainability concepts	1.760	3	.624
	Q8b	Identify essential tools and training requirements about operation and maintenance of equipment	3.818	3	.282
	Q8c	Specify and communicate operability and maintainability requirements to supplier	1.941	3	.585
	Q8d	Assurance of having updated specifications to allow easy operation and maintenance	3.429	3	.330
	Q8e	Using innovation idea to resolve many operation and maintenance issues	1.817	3	.611
	Q8f	None of the above	3.995	3	.262
construction phase	Q9a	Assure desired level of maintainability objectives built into constructed project	3.957	3	.266
	Q9b	Evaluate implementation of operability and maintainability of constructed project by operation and maintenance experts	3.794	3	.285
	Q9c	Conduct training for operation and maintenance for having smoother start-up	11.165	6	.083
	Q9d	Conduct maintainability assessment	11.277	3	.010
	Q9e	None of the above	3.655	3	.301
during and after closeout phase	Q10a	Review all aspects of project to assure equipment meets requirements	1.986	3	.575
	Q10b	Record maintainability ideas generated and implemented on	4.077	3	.253

		the project			
	Q10c	Data collection and information generated during this stage forward to future projects	No statistics are computed because Q10c is a constant		
	Q10d	Assure availability of complete and up-to-date documentation relate to operation and maintenance of equipment	2.707	3	.439
	Q10e	None of the above	.913	3	.822
operation and maintenance experts	Q11a	Yes	1.373	3	.712
	Q11b	Sometimes	1.112	3	.774
	Q11c	Depends on other factor	6.043	3	.110
	Q11d	No	.494	3	.920
Operability	Q12	"Operability is the ability of an organization to operate a facility in a safe and efficient manner. The ultimate goal of facility operability is to design and construct a facility that will remain safe, efficient and cost effective throughout its lifetime use" Have you heard this term before?	1.952	3	.582
Maintainability	Q13	"Maintainability is the measures taken during development, design and installation of a manufactured product that reduce required maintenance, man-hours, tools, and logistic cost" Have you heard this term before?	2.776	3	.427
the benefits of performing the constructability	Q14a	Controlling time growth	2.405	3	.493
	Q14b	Controlling cost growth	1.018	3	.797
	Q14c	Minimize the project risk	1.861	3	.602
	Q14d	Does not have any benefits	6.043	3	.110
the benefits from involving Operability & Maintainability (O&M)	Q15a	Having a smooth operation	1.883	3	.597
	Q15b	Having a minimum maintenance	1.198	3	.754
	Q15c	Monitoring the project budget	5.178	3	.159
	Q15d	Monitoring the project schedule	15.813	3	.001
	Q15e	Ensuring safety considerations in all project phases	3.345	3	.341
	Q15f	Does not have any benefits	1.861	3	.602
	Q16a	Complex Projects	6.644	3	.084
	Q16b	Large Projects	.494	3	.920
	Q16c	Certain types of Projects	4.349	3	.226
	Q16d	Small Projects	1.373	3	.712
	Q16e	All Projects	10.627	12	.561

Note: *: Statistically Significant P< 0.05

Discussion

The answers clarified that the contractor is responsible for executing the operability and maintainability policies. Additional participants elucidated that the functioning of the facility is contingent upon the instructions provided by the vendor. Furthermore, others emphasized that the individuals best suited to identify potential risks are experts in operation, process safety, and maintenance. Lastly, respondents indicated that communication occurs between the project engineer and the focal point for operation and maintenance.

The study's findings demonstrated the need of doing the constructability review early in the project's design phase. Additionally, the results showed that conducting the constructability review early in the design phase of a project has several advantages, such as reducing project risk, managing cost increase, and regulating time growth.

In order to successfully implement petrochemical projects in Saudi Arabia, the results showed how operability and maintainability concepts may be combined with constructability practice. According to the responders, a HAZOP analysis is the best way to integrate constructability with operability and maintainability. Additionally, it was made clear by the respondents that this approach needs to be implemented early on in the project development stage, specifically at the scope definition stage.

Due to the favorable effect that operation and maintenance's engagement and participation have on the project's development and commissioning, the participants agreed that operability, maintainability, and constructability are strongly related. Incorporating operability and maintainability principles into constructability practice has many advantages, as highlighted by the participants. These include, among other things, a smooth operation, minimal maintenance, safety considerations throughout the project, budget and schedule monitoring, and so on.

Conclusion

Included in constructability are all the components that aid in identifying and addressing operation and maintenance difficulties from the very beginning of a project. To reduce facility downtime and optimize long-term maintenance costs, it is recommended to emphasize operation and maintenance throughout the design and engineering process, which extends constructability to include operability and maintainability ideas. To what extent do project owners recognize the significance of addressing operation and maintenance concerns early on in the project lifecycle? That was the primary goal of this study. To ensure a petrochemical facility in Saudi Arabia runs smoothly and makes a profit, it is important to address operation and maintenance concerns early on in the project using constructability principles.

According to the results of the surveys, most people think that having O&M specialists on board during the design and planning stages can lead to safer operations, better specifications, and less maintenance needs. The concepts operability, maintainability, and constructability were clearly understood by the participants. They reached a consensus that designing and building a facility that is safe, efficient, and cost-effective during its lifetime use is the ultimate goal of facility operability.

The interview results showed that operability and maintainability should be implemented early in the project development stage. Respondents mentioned several advantages to implementing these concepts early on, including assistance with material selection, increased operational availability due to failure possibility identification, reduced life cycle costs, and additional expenditure after start-up. As a result of the good effect that operation and maintenance's engagement and participation have on the project's construction and commissioning, the participants also agreed that operability, maintainability, and constructability are strongly related. It is essential to have process safety, operation, and process engineers involved in the early stages of any petrochemical project, according to interview results, so that operations and process safety may be considered from the very beginning.

Recommendations

Based on the key findings of this study, various suggestions have been put forward to:

- With the operation and safety procedure involved from the beginning of the project, potentially dangerous situations can be identified.
- It is the duty of upper management to have a plan for adopting operability and maintainability, complete with a checklist.
- Insisting that businesses incorporate operability and maintainability into constructability implementation, as doing so can lead to more valuable projects with fewer O&M issues.
- To help managers enhance the operability and maintainability of petrochemical projects through early integration processes, we have developed a helpful guideline.
- Managers will be taught how to apply operability and maintainability through training programs.

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