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Identification and Weighting of Criteria for Assessing Project Complexity in the Oil and Gas Industry, A Specific Focus on Pipeline projects

Student: Fatemeh Ramzi

Supervisor: Alberto De Marco

Co- Supervisor: Filippo Maria Ottaviani

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Identificazione e Ponderazione dei Criteri per la Valutazione della Complessità dei Progetti nell'Industria Petrolifera e del Gas, Un Focus Specifico sui Progetti di Gasdotti

Candidato: Fatemeh Ramzi

Relatore: Alberto De Marco

Correlatore: Filippo Maria Ottaviani

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Abstract

The energy sector faces unmatched challenges from the global rise in demand, and the projects of pipelines become strategic and a core infrastructure in that direction. Oil and gas pipeline projects are pretty intricate to handle from a technical, regulatory, environmental, and stakeholder perspective. Most pipeline projects have high failure rates despite heavy investments due to their multidimensional complexities, and hence effective management practices become imperative.

This research study identifies and prioritizes, in a structured manner, the complexity factors influencing pipeline projects through a wide review of academic and industry sources. Seven key dimensions were identified, from technical and environmental challenges to regulatory and resource management complexities, each comprising a number of interconnected sub-factors. Advanced methodologies, such as Delphi and AHP techniques, were applied to this research study to develop a structured framework for evaluating and ranking these complexities.

The findings provide actionable insights for project managers and stakeholders by offering a holistic approach to address critical factors that affect time, cost, quality, and safety in pipeline projects. This research enhances the understanding of project complexity and establishes a foundation for implementing sustainable, risk-resilient management strategies that contribute to more efficient and compliant delivery of energy infrastructure.

Keywords:
Project Complexity Management, Pipeline Projects, AHP, Delphi, Complex Mega Projects

Chapter One: Overview of the Study

1.1. Introduction

Global demand for energy has increased over recent years due to increasing the demands of industries and societies. This surge underlines the strategic importance of the energy sector, which is determinant in nations' and industries' development. Among various energy megaprojects, oil and gas projects, especially pipeline projects, are considered critical infrastructure that delivers energy resources in an effective and reliable manner.

Pipeline projects are critical arteries through which oil and gas move over long distances, linking extraction fields with refineries and end users (Dao et al., 2016). These projects, though indispensable, involve immense complexity due to their scale, environmental sensitivity, and interdependencies. Investments in such projects often exceed billions of dollars, bringing about high levels of uncertainty, risks, and societal impact (Lee, 2021). In spite of their importance, energy megaprojects, pipelines included, have an alarmingly high failure rate, making effective management practices indispensable (Kızılkaya & Öztürk, 2017).

Governments and private institutions worldwide invest heavily in pipeline projects to meet growing energy demands. However, these projects face challenges beyond financial constraints, including intricate planning, execution, and management needs (Kianmaneshrad et al., 2017). The success of pipeline projects hinges on understanding and addressing project complexity—a multi-dimensional aspect that influences planning, coordination, resource allocation, and overall outcomes such as cost, time, and safety (Kermanshachi et al., 2016).

Pipeline projects are a balancing act between several factors that introduce different levels of complexities, such as regulatory compliance, environmental impact, stakeholder involvement, and technical uncertainties (Mitchell, 2009). These challenges mostly cannot be handled with traditional project management strategies, hence the call for innovative and adaptive ones. In addition, as the operating environment for pipeline projects continues to evolve, new layers of complexity add to the already difficult task of delivering a successful project successfully (Zabaleta et al., 2018).

Pipeline projects, as a part of oil and gas infrastructure, are specifically sensitive to the impacts of complexity. The level of risk, environmental concern, tight schedule, and interdependence between project activities raise the challenge for the project manager. These underpin the critical need to identify and weigh the dimensions of complexity that influence performance outcomes (Dao et al., 2016).

Energy companies, especially those dealing in oil and gas, acknowledge that the delivery of projects is one of the highest pipeline project risk areas. Therefore, it is paramount to have an accurate assessment of project complexity and develop appropriate management strategies (Rastegar, 2014). The inability of most pipeline projects to achieve their goals despite massive investments demonstrates that there is a need for deeper consideration of complexity factors and their impact on project performance (Kianmaneshrad et al., 2017).

The research will, therefore, be dedicated to identifying and weighting factors of complexity in relation to pipeline projects in the context of the oil and gas industry. This study underlines complex pipeline project issues and intends to consider strategies for effective management of the challenge in the delivery of pipeline projects amidst broader energy infrastructure.

1.2. The Importance of study

The pipelines are the lifeblood through which global energy infrastructure ensures optimum transportation of critical resources with safety ensured for oil and gas, among others (Rastegar, 2014). This aspect immensely affects energy security, economic development, and international trade. Because of their magnanimity and criticalities, pipeline projects are made through elaborate planning, much investments, and strong risk-mitigating mechanism.

However, pipeline projects are so complex, involving technical, financial, environmental, and operational aspects that their successful execution is really a challenge. Certain other factors contributing to increased complexity include geographical terrain, regulatory frameworks, environmental concerns, and interdependencies among components of the project (Paknahad et al., 2023). The ability to understand and manage such intricacies means understanding the realization of project objectives, avoiding delays, and assuring cost efficiency.

The emphasis of this study is that complexity factors need to be evaluated and managed systematically if pipelining is to achieve the best performance and value delivery. It therefore calls for targeted research on the most critical drivers of complexity and the development of effective strategies for mitigating their impact.

1.3. Aim and Research Questions

Weight and identify complexity factors in the projects of pipelining for a better understanding of how factors linked to the success in managing a project and events will fall in place is the main target of this study. In improving project execution and enhancing the general efficiency, this shall provide actionable insight by offering comprehensive solutions to the intrinsic indiscrimination of challenges related to pipeline projects.

Major research questions are as under;

- Which factors are at higher priorities in causing complexities within pipelining projects?
- How do these factors of complexity impact the project outcomes with respect to time, cost, quality, and safety?
- How can these complexity factors be weighted to assess their relative importance in pipeline projects?
- How can the findings contribute to better planning and management practices in future pipeline projects?

This research, therefore, tries to give a framework through which the identification, weighting, and addressing of complexity factors in pipeline projects are done to ensure successful delivery and long-term sustainability by carrying out a thorough analysis of these questions.

1.4. Method of research

The methodology employed in this thesis for weighting and identifying complexity factors in pipeline projects consists of the following structured steps:

- **Step 1: Literature Review and Development of Conceptual Framework**

The first step involved substantial library research and information analysis from sources. This will provide a fair idea about the general framework and the important concepts such as project complexity and their impact on project management success. Synthesizing data from various sources, we identified preliminary factors that contribute to pipeline project complexity and established an initial conceptual framework for further investigation.

- **Step 2: Collection of Practical Knowledge via Industrial Exposure**

The findings of this stage complement the theoretical understanding by practical insights. In order to get a deep insight into the complexities observed at real projects and to further refine the factors identified at Step 1, discussions and interviews with project managers and industry experts were conducted, more so those experienced in pipeline projects. These consultations have, in turn, helped in bridging the gap between the theoretical perspectives and the practical realities for comprehensive coverage of project complexities.

- **Step 3: Incorporating the Delphi Method to Achieve Consensus**

The complexity-factoring processes were defined and verified by making use of the Delphi method. It is an iterative method employing a panel of selected experts, in a structured mode, for the elicitation of their opinions through the successive rounds of surveys. This method imparted controlled feedback and analysis of opinions from the expert panel to reach a consensus upon the most significant factors affecting pipeline project complexity. This step would allow the framework to mirror expert judgment and industry relevance.

- **Step 4: Questionnaire Design and Data Collection**

The comprehensive questionnaire was formulated based on the findings of the literature review along with interviews and the Delphi method. This questionnaire aimed to quantify and prioritize the complexity factors as perceived by project managers and other industry stakeholders. The online survey was administered in order to gather a wide range of responses from diverse participants to ensure data validity and reliability.

- **Step 5: AHP for Weighting of Factors**

The data collected at this stage underwent analysis with the Analytic Hierarchy Process, a systematically developed decision-making tool. The AHP assigned weights to the identified complexity factors, indicating the relative importance and impact of each factor for the successful management of projects. Such quantitative analysis was able to favor one set of factors over another and hence provide input for developing pragmatic strategies for dealing with the complexities of projects.

- **Step 6: Establishing a Practical Management Framework**

The Delphi technique, the data collected from questionnaires, and the analysis through AHP were incorporated into a management framework so as to assist project managers in identifying, ranking, and addressing major complexity factors in pipeline projects. This framework ultimately favors viable solutions to improve projects through a synthesis of theoretical considerations and practical insights.

Upon completion of these phases, an extensive understanding was developed of the factors that affect the complexity of projects, the environmental influences, and project management success itself. Also contributing to the parameter of building a comprehensive framework in order to identify and evaluate these factors is the gainful practical knowledge acquired during consultations with project managers and other industry stakeholders. The full set of questionnaires and data analysis provides further insight into developing a practical management framework for projects.

1.5. The Gap of the Project and Innovative Solution

Pipeline projects, especially in the context of oil and gas, do bear unique complexities that are rarely discussed in extant literature. Although there is substantive research evidence relating to general oil and gas projects, data on those specific to pipeline project complexities remain uncoordinated and scant. Traditional studies and data sources often fall short in capturing the complexity of such projects, their geographical constraints, environmental sensitivities, interdependencies of activities, and the detailed coordination across multiple stakeholders.

This study fills this gap by moving beyond static data collection methods to integrate a dynamic approach: iterative interviews with experienced industry professionals and targeted questionnaires. These approaches gave a fuller and more comprehensive view of the determinants of complexity in pipeline projects. Besides providing an all-round understanding of pipeline-specific complexities, this study integrates theoretical knowledge with practical insight and presents tailored innovative solutions to improve project management outcomes in this critical domain.

1.6. Research framework and chapters

The paper, therefore, tries to make the readers understand the discussed topic in-depth. As such, the paper has divided into five chapters that are done in a manner that can enable the readers to have an overview.

- The first chapter introduces the project, stating the main question, aim, and significance of the focal point of the paper. It will also give the readers an overview of the structure of the paper and what to expect in each chapter.
- Chapter Two will present past research on the topic at hand and thereby present the principles and theoretical underpinning of the subject. This shall enable the readers to understand concepts related to the subject and to understand the gaps and areas in the previous research that need further exploration.
- The next section will detail the methodology that was selected in Chapter Three, providing a rationale and describing the process of research in detail. Finally, the

validity and reliability of the questionnaire will also be discussed to ensure that the readers understand the research methodology behind the work.

- The fourth chapter will present the data and figures of collection clearly and succinctly, using graphs and tables in building clarity. This shall provide a clear picture to the readers for them to draw their conclusion from such results.
- Chapter five is a summary of the findings from the research, showing the differences or distinctions with other works. It will contain a conclusion, future research recommendations and limitations of study. Additionally, suggestions on how to apply findings to work will be provided to the readers hence ensuring that they can use the knowledge gained from the paper and apply to their research.

Chapter Two: Literature Review

2.1. The Role and Scope of Literature Review in Understanding Pipeline Project Complexity

The concept of complexity has received much attention in the context of project management due to the unprecedented challenges modern industries face in navigating the intricacies of their environment. Complexity is an abstract and multifaceted concept that is everywhere but cannot be precisely defined (Remington et al., 2009). To explore this topic, Project Management Institute convened global discussions under the title "Complexity in Project Management and the Management of Complex Projects" to emphasize the great importance of complexity in shaping up project success (Manesh Rad, 2017). More than 80 % of all projects fail because of such factors as production rate, scheduling, or cost overrun, and most such failures can be attributed to improper management of complexity (Gate, 2016). These trends underscore the pressing need to address complexity, especially as industries grow more interconnected and dynamic (Proctor, 2005)

In the oil and gas sector, pipeline projects stand out as particularly complex, influenced by technical intricacies, environmental pressures, and sociopolitical factors (Floricel et al., 2015). These projects not only demand advanced technical expertise but also necessitate robust strategies to navigate volatile environments. This research investigates the complexity of pipeline projects by embracing chaos and complex systems theories for interpretation and management in an ever-changing challenge found within this important industry. The success of pipeline projects ensures the cascading effect within other industries and economies across the globe (Kızılkaya & Öztürk, 2017).

This chapter presents the origins, definitions, and theoretical explanations of project complexity, particularly the implications for pipeline projects in the oil and gas industry. It identifies the key facets of complexity, such as technical, organizational, and environmental, in relation to their impact on project outcome. The dynamic nature and competitiveness of pipeline projects have been underlined to delineate how internal and external constantly changing environments are configuring project dynamics.

The AHP and Delphi method are introduced as advanced analytical tools to deal with such challenges. AHP provides a structured framework for the evaluation and prioritization of complexity factors, while the Delphi method utilizes expert consensus in order to identify and address critical issues of concern in complex projects. By integrating these methodologies, the chapter provides practical insights into managing project complexity, setting the stage for deeper exploration in subsequent sections.

The development enhances not only a better understanding of the pipeline project complexity but also forms a base to work toward effective management frameworks that can ensure success in this critical sector.

2.2. Approach for Reviewing Relevant Studies and Frameworks

This chapter, therefore, systematically and structurally reviews related studies and frameworks that ensure comprehensive understanding in regard to project complexity and its management within pipeline projects in the oil and gas industry. The review combines an extensive review of the literature, identification of theoretical underpinnings, and the application of advanced analytical techniques for effective evaluation of complexity.

a) Systematic Literature Review

Extensive searches of relevant academic and industry sources are conducted for journal articles, conference papers, industry reports, and foundational books. The selection of the studies is guided by keywords such as project complexity, pipeline project, complex oil and gas systems, and complexity factors. More emphasis is given to recent research and seminal works in order to establish a sound theoretical and practical foundation.

b) Classification of Complexity Factors

The collected literature is analyzed to categorize the complexity factors into three dimensions:

- **Technical Complexity**: Includes technological uncertainties and system interdependencies.
- **Organizational Complexity**: It includes diversity in stakeholders, communication issues, and decision-making.
- **Complexity of Environment**: This considers regulatory demands, market turbulence, and socio-political demands.

Theoretical frameworks of chaos theory and systems thinking do help in providing a contextual lens to understand these dimensions in pipeline projects.

c) **Evaluation of Complexity Assessment Frameworks**

The chapter reviews key frameworks and methodologies used for assessing complexity, including:

- **Chaos Theory**: Offering insights into unpredictable and dynamic project behaviors.
- **Complex Systems Theory**: Helping to understand interconnectedness and nonlinear interactions within project environments.
- **Analytical Tools**: Highlighting the use of the Analytic Hierarchy Process (AHP) for prioritizing complexity factors and the Delphi method for consensus-driven evaluation.

d) **Identification of Research Gaps**

A critical analysis was done to identify gaps existing in literature, especially with regard to peculiar challenges that come with large-scale pipeline projects. This includes the inability to adapt general theories of complexity into the specific pipeline project requirements, and the lack of suitable framework adaptations for high-value oil and gas projects.

e) **Synthesis of Key Insights**

It synthesizes the findings from the reviewed studies into an exposition of how complexity manifests itself in pipeline projects. Guided by this synthesis, the paper sets out the criteria for assessing and weighting the factors of complexity to serve as a foundation for practical applications.

This chapter therefore connects the theoretical and the practical by adopting a rigorous approach to providing an overall road map of understanding and managing complexity at pipeline projects.

2.3. Understanding Complexity and Complex System

2.3.1. Complexity Theory

The world, in most contemporary discourse, is increasingly understood as a system in which complexity is an intrinsic and essential feature. In systems like this, outcomes cannot be related linearly to specific causes, while deterministic models often poorly explain the behaviors (Mancini & Derakhshanalavijeh, 2017). This transition in worldview from a simple to a complex one necessitates the development of Complexity Theory, which is a multidisciplinary attempt at understanding and managing intricacy in various domains (Mitchell, 2009).

Complex science stretches across multiple disciplines including neuroscience, social sciences, meteorology, chemistry, physics, computer science, psychology, artificial intelligence, evolutionary computing, economics, earthquake prediction and molecular biology. It focuses on how interactions among the parts of a system lead to emergent collective behaviours, examining how systems adapt to and interact with their environment (Holland, 2014). The field seeks to decode the dynamic interplay between system components and their surroundings, emphasizing relationships and interdependencies rather than isolated entities (Wood, 2010).

The Santa Fe Institute pioneered the establishment of complexity theory in the 1980s. The institute was set to work out solutions to complex problems in natural sciences, such as astronomy and biology, among others, and in social sciences, including economics, among others (Tsiga et al., 2017). Complexity theory is associated with chaos theory, that is a study of systems that are sensitive to initial conditions and unpredictable but deterministic behaviors. The theory was further conceptualized by early thought leading authors like Roger Lewin, Complexity: Life at the Edge of Chaos, and M. Mitchell Waldrop, Complexity: The Emerging Science at the Edge of Order and Chaos, making it a robust framework to explain how order and disorder interact (Waldrop, 1992).

The exact relationship between the two theories-chaos and complexity-remains a subject of debate among scholars. Some scholars consider complexity as a subset of chaos, whereas others regard them as distinct but related paradigms. There is also a third group that considers both theories as complementary; they represent different dimensions of the same phenomenon (Cilliers, 1998). Despite these differences, both theories emerged as a result of the development of human knowledge and the urge to solve fast changes in turbulent and unpredictable environments, especially in organizational and project management contexts (Remington et al., 2009).

Given the strong interrelations between chaos and complexity theories, any foray into complexity theory has to be appropriately grounded in the knowledge of chaos theory and its dimensions as they provide foundational insights into the principles of complexity.

2.3.2. Chaos Theory: Bridging Complexity and Predictability

Chaos theory also investigates how a simple rule-based system generates complex and perhaps quite unpredictable behavior. Chaos theory has turned our conventional notions of deterministic systems into new ways of thinking about the contest between chaos and order by nonlinear dynamics and sensitivity to initial conditions (Mitchell, 2009).

Historically, scientific inquiry was based on reductionism, the idea that systems could be fully understood by studying their individual components. This Newtonian perspective treated the universe as predictable and deterministic. However, phenomena such as turbulent weather, adaptive ecosystems, and economic fluctuations exposed the limitations of linear causality and deterministic modeling (Klijn & Teisman, 2008).

Chaos theory dates back to the late 19th century when Henri Poincaré first recognized irregular behaviors in deterministic systems. It wasn't until the 1960s, though, that the field came into its own with the discovery of what would be called the butterfly effect, by Edward Lorenz, in which small changes in initial conditions produce drastically different results. When this was first deduced from atmospheric models, it underlined the intrinsic unpredictability of complex systems (Galbchi & Faraji, 2013).

2.3.3. Core Principles of Chaos Theory

- **The Butterfly Effect**

Probably the most famous hallmark of chaos theory is that small changes in initial conditions may bring about drastically different outcomes over time; even slight variations in a system that is deterministic and nonlinear may produce an unpredictable result. Such sensitivity underlines the limitations of traditional modeling approaches as well as the new requirements for finding tools for understanding chaotic systems (Klijn & Teisman, 2008; Sharaborora, 2014).

- **Self-Organization**

Self-organization is defined as the ability of a system to change itself, rebuild its structure in line with changes in the environment. In chaotic systems, self-organization is how a system maintains order at the edge of chaos and stability. That is, for example, subsystems or groups in a system decide cooperatively what to do and when while overall coherence is maintained despite external disturbances (Kızılkaya & Öztürk, 2017).

- **Self-Similarity**

Self-similarity, or fractal behavior, in systems is repeating patterns at different scales. Separation of parts reflects the whole in chaos theory is unity. The same idea carries on over into organizations where specific goals naturally fit into larger objectives enabling everything to work together without them even trying, Tsang (1997).

- **Strange Attractors**

While chaotic systems appear to behave randomly, strange attractors give evidence of a hidden pattern that unfolds over time. Strange attractors are symbolic of long-term behavior and confirm that usually behind what appears disordered lies something more structured. A strange attractor is different from predictive patterns because it acts nonlinearly and in unsynchronized way and the shift in part of the system will have other unexpected parts changing and vice-versa, all in their unpredictable nature. (Marsick & Watkins, 1992).

2.3.4. Complex Systems and Chaos Theory

Complex systems are characterized by many independent components interacting in a complex way, such that emergent behaviors and multiple evolutionary paths are exhibited. The system is interdependent in such a way that the elements of the system individually contribute to properties that cannot be reduced to the sum of its parts (Birol, 2006).

Scientific investigations into complex networks, which are modeled by nodes and connections, explain the ways in which high levels of interaction determine system behavior. The different systems result in variations of the adaptability and intelligence of nodes, as well as connection density (Ziadat et al., 2017). Chaos theory completes the understanding with systems operating on nonlinear relationships with a minimum of three dimensions. Such systems often demonstrate stable yet seemingly disordered long-term behaviors, where patterns emerge among apparent unpredictability (Lou et al., 2016).

Chaos theory, initially developed to study unpredictability in deterministic systems, provides a very strong platform for understanding and dealing with the problems created by complex systems. It examines in detail how systems evolve from initial simplicity or randomness into large-scale complexity and thus provides very important insights into their dynamics and adaptability.

2.3.5. Core Characteristics of Complex Systems

- **Numerous Interconnected Components**

Complex systems consist of a large number of interacting components. The interactions are such that the internal relations and causalities among components are not fully accessible to outside observers. Although the removal of small components will generally not affect the behavior of the system, the removal of key components will often lead to significant disruptions in behavior (Sturmberg & Martin, 2014). The same phenomenon is observed in ecosystems and social systems, in which interdependencies determine resilience and fragility.

- **Feedback Mechanisms**

Dynamic complex systems are characterized by the presence of feedback loops, wherein the system reacts to and is influenced by its components. The state of such systems heavily depends on initial conditions and the history of their interactions. Feedback can stabilize systems by self-regulation or amplify disruptions through self-reinforcement (Sturmberg, & Martin, 2014).

- **Emergence**

Emergence refers to the higher-level properties and patterns that a system creates but which cannot be predicted from the behavior of its individual components. Synergy on the macro scale brings about collective behavior out of seemingly uncoordinated behavior of individuals (Kamaruzzaman et al., 2018).

- **Evolution and Adaptation**

Complex systems evolve through interaction of its elements. Cascading changes navigate down the system and induce changes within the system. In this process of co-evolution, the systems are at liberty to adapt and develop subsystems that introduce new dynamic properties. As an example, one can refer to technological innovations or biological evolution with regard to revealing how changes at one part of the system impact the entire network (Sturmberg & Martin, 2014).

2.4. Unraveling Project Complexity: Key Concepts and Factors

2.4.1. Nature of Complexity in projects

The systems thinking offers a spectrum of perspectives and grounds in a set of specific metaphors, hence providing an extremely useful framework for insight into different project types. In the provided typology, there are two main approaches to the subject: a traditional positivist approach and an anti-positivist approach (Vidal & Marle, 2008).

Traditional systems thinking of the positivist school focuses on stringent rationality and predictions according to empirical observation. In contrast, the anti-positivist school, usually associated with complex systems thinking, uses multiple perspectives in understanding the complexity of projects. This approach adapts to the level of project complexity and its nature. Therefore, project managers should focus on a holistic approach, deeply interacting with the environment in which the project exists rather than abstracting it from its context (Ziadat et al., 2017).

Most projects exist within larger systems and, in turn, form their own systems comprising interdependent subsystems. Complex projects are open, emergent, and adaptive systems with nonlinear and iterative feedback loops. These projects are highly sensitive to initial conditions; therefore, detailed long-term planning is not possible for them, and their execution becomes dynamic in nature (International Centre for Complex Project Management, 2014).

By their very nature, projects like these can best be modeled and analyzed using the complex systems theory that offers deep insights into behavior and performance.

2.4.2. Definition of Project Complexity

A critical review of the related literature indicates that there lacks a clear-cut definition of project complexity that is universally applicable. As an attribute, complexity is system-specific and varies according to the nature of the system. Complexity cannot be clearly defined because it is a spectrum that evolves depending on the peculiarities of each system (Ziadat et al., 2017). The concept of project complexity has been evolutionary; early foundational work was done by Cilliers in 1998, where project complexity was defined as a project's interconnectedness and diversity, focusing on differentiation variety of elements, and interdependency-their interrelationships. These dimensions apply across different project aspects, including organization, technology, environment, and decision-making processes (Cilliers ,1998).

Greater profundity into the meaning of project complexity is shed light by further studies. It was described as "a measure of interdependency level among the attributes, between the relations and about predictability of performance," a multidimensional definition thereby (Kermanshachi et al., 2016). In another explanation, the "extent of challenge to retain predetermined flows and the linked or imputed "cost in control, time, quality and conflict"" has also described project complexity (Gidado, 1996).

The concept is inextricably linked with the concepts of risk and uncertainty. It is defined as a project attribute that complicates comprehension, prediction, and control (Vidal & Marle, 2008) and can be characterized along two dimensions: project hardness to reach objectives and project risk (Dao et al., 2016). Complexity also encompasses high interconnectedness of components and the interplay of operating variables, both of which contribute to a great extent in determining its nature (Sbragia, 2000).

By its very nature, project complexity is a multidimensional phenomenon arising from dynamic interactions, uncertainties, and dependencies within a project system. It is a key source of risks impacting cost, performance, and management effectiveness (Jahanzaib & Ishtiaq, 2017; Floricel et al., 2015). As understanding evolves, it becomes evident that strategic measures are essential to address such complexities effectively across various project contexts.

The International Centre for Complex Project Management defines a complex project as an open, emergent, and adaptive system that is differentiated by non-linear feedback loops and recursion. According to the ICCPM, project complexity can also be perceived as the degree of familiarity on delivering the product, service, or outcome (International Centre for Complex Project Management, 2014). This distinction between complex and complicated projects is important. In complicated projects, the task is known along with the process, and although difficult it must be achievable with a defined process. However, in a complex project, the requirement is not clear and thus includes known-unknowns and unknown-unknowns. Uncertainty remains even after tools and methodologies are used (Herszon, 2017).

Five dimensions of project complexity includes: project size and cost, number and type of interactions, cultural outcomes, uncertainty, and stakeholder impacts (Kerzner & Belack, 2010). Moreover, complex projects must account for additional variables such as political factors, technology, organizational interactions, required information levels, new processes, and project management maturity levels (Herszon, 2017). However, according to the PMI definition, complexity "is a characteristic of the project, program, or project's environment that causes instability by human behavior, system behaviour, and/or ambiguity (PMI, 2014).

According to ICCPM, a complex project possesses a set of distinctive characteristics that make it fundamentally different from a traditional project. These include:

- **Adaptive Systems**: Complex projects often function as systems of systems that are adaptive and continuously evolving.
- **High Uncertainty**: Defining the scope of such projects involves a significant level of uncertainty.

- **Decentralized Structures**: They are usually decentralized, with decision-making distributed among various entities.
- **Internal and Environmental Turbulence**: There internal disruptions along with external environmental challenges for complex projects.
- **Rolling Wave Planning**: Iterative planning approaches are ways of execution, which keep on evolving during the project.
- **Indistinct Boundaries**: Components of complex projects cannot always be decomposed clearly to define distinct boundaries (ICCPM, 2014).

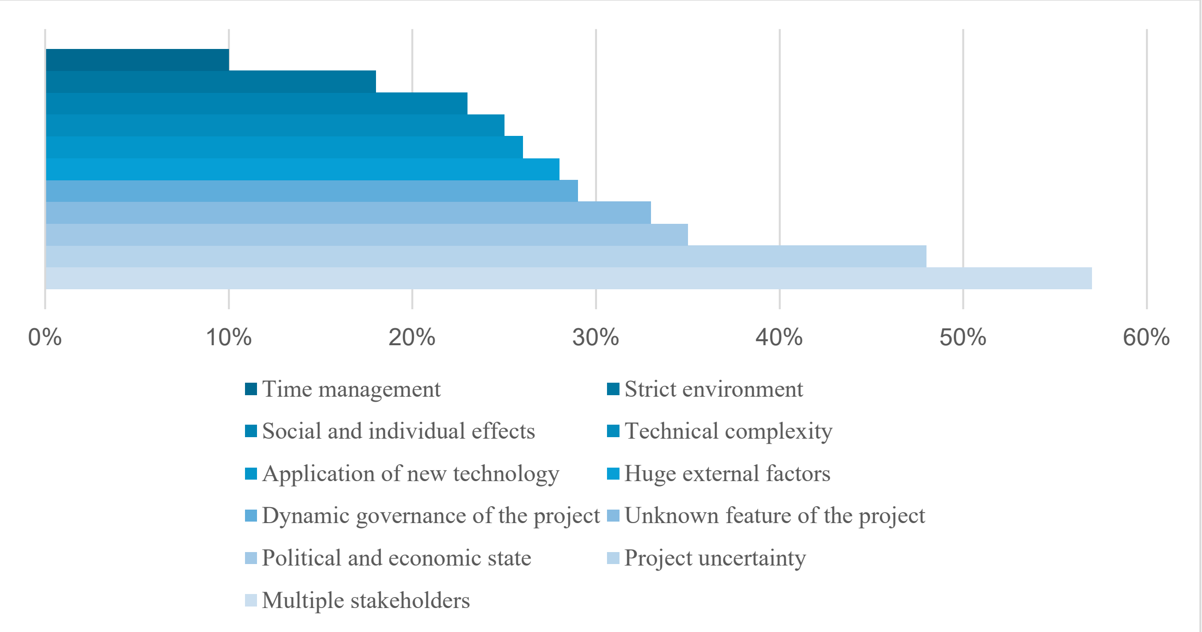

Chart 1: Project complexity characteristics (most prominent complexity features in projects) (PMI, 2014).

Further, ICCPM points out a number of dimensions that enhance the degree of complexity: multiple stakeholders, 57 percent; uncertainty over project characteristics, resources, and phases, 48 percent; strong political or influential power, 35 percent; and unknown project attributes, 33 percent. Other major factors include dynamic project governance, external influences, integrating new or evolving technologies, harsh regulatory environments, and social/interpersonal issues in the organization.

These attributes and dimensions underscore the need for an in-depth analysis of complexity factors, emphasizing that complex projects cannot be managed through conventional linear methods but require adaptive, flexible strategies to address emerging challenges (ICCPM, 2014).

2.4.3. Complex vs. Complicated Projects: Understanding the Key Differences

Projects have often been described as either complex or complicated, though the terms sound similar, they represent contrasting concepts with significant implications on approaches toward project management.

In a complicated project, there are many interrelated parts; however, the interactions of these parts take a logical and predictable pattern. To put it in another way, complicated project problems are solved with the knowledge of experts and by applying established processes and proven methods. For example, assembling a large industrial machine or designing a sophisticated IT system is complicated but doable because the steps can be specified and the results predicted. Projects that are merely complicated can be thought of as a puzzle that can be solved through analysis, technical expertise, and planning (Herszon, 2017).

By contrast, complex projects are fraught with uncertainty, dynamic interdependencies, and emergent behavior. A complex project involves the interaction between components in unpredictable ways without relying on pre- defined processes or traditional linear ways of doing things. At best, unclear objectives, changing requirements and various sometimes mutually conflicting stakeholders characterize the times. Examples of this kind will be the development of new infrastructure projects in a politically sensitive area or a disaster recovery operation. Unlike complicated projects, solutions in complex projects are discovered over time through adaptive strategies, iterative decision-making, and continuous learning (Kerzner & Belack ,2010). The key differences between these two types of project are:

- **Predictability**: Complicated projects are predictable, while complex projects involve significant uncertainty and evolving factors.
- **Solutions**: Complicated projects have known solutions that require expertise; complex projects demand experimentation, flexibility, and learning.
- **Interdependencies**: In complicated projects, relationships between components are linear and fixed; in complex projects, relationships are dynamic and nonlinear.
- **Management Approach**: Complicated projects benefit from detailed planning and control, while complex projects require adaptive management, collaboration, and continuous feedback loops.

While a project may be complicated in terms of its technical difficulty, a complex project is a challenging one because of its uncertainty, dynamic conditions, and emergent behaviors that demand continuous adaptation. Being cognizant of the existence of this distinction becomes imperative if project managers are to identify appropriate strategies and tools in the quest for success (Abifarin, 2018).

2.4.4. Complexity Factors in Projects and Their Importance

Project complexity is rooted in a variety of interdependent factors operating on each other dynamically, self-reinforcing with often imponderable results. Recognition of these different factors of complexity is important to assure successful project delivery, particularly for multidisciplinary projects when technical, organizational, and environmental challenges combine. Key complexity factor that can be seen in most of multi criteria projects can be mentioned as:

- **Technical Complexity**: Technical complexity refers to the number of components, interdependencies, and systems involved in the project. Complex Projects involve special solutions and high technical expertise to manage the uncertainties effectively (Herszon, 2017).
- **Organizational and Structural Complexity**: This dimension involves the project’s structure, governance, and stakeholder interactions. Complex projects often span multiple contracts, organizations, and disciplines, requiring advanced coordination and communication mechanisms. Projects of higher complexity may involve project management offices (PMOs) and specialized teams to ensure seamless execution across sub-projects (Belack & Kerzner, 2010).
- **Environmental and Political Complexity**: The environmental complexity is from uncontrollable, external factors such as adverse weather conditions, geopolitical instability, and regulatory requirements. In addition, remote site locations of projects, health and safety concerns, and environmental hazards due to ecological damage also create project complexity (Nguyen et al., 2015). Political and economic factors such as market fluctuation and government regulations consequently affect the schedule and cost of the project accordingly (Ziadat et al., 2017).
- **Human and Social Complexity**: Human factors are the most crucial factors for any project's success. Human values, perceptions, and team dynamics lead to various diversities, which often create barriers to communication and result in conflict. Such

social complexities are high in global projects due to cross-cultural collaboration; Understanding and controlling human aspects lead to better goal congruence and enhanced team performance (Rekveldt-Bosch et al., 2011).

- **Uncertainty and Ambiguity**: Uncertainty arises when project elements are unknown or unpredictable, making planning and forecasting difficult. Ambiguity in scope, resource allocation, or technology adoption increases risk and reduces clarity on project outcomes. Projects with high levels of uncertainty require adaptive and iterative planning methods, such as rolling wave planning (Sharaborova, 2014).

Understanding and managing complexity factors is important for a number of reasons:

- **Risk Mitigation**: By identifying and addressing sources of complexity, project managers can proactively mitigate risks and avoid catastrophic failures.
- **Value Creation**: Managing complexities effectively ensures projects deliver maximum value to stakeholders by optimizing resource allocation and decision-making processes (Sharaborova, 2014).
- **Adaptability**: Recognizing project complexity encourages flexible approaches and innovative solutions, especially in dynamic environments like oil and gas projects (Rekveldt-Bosch et al., 2011).
- **Improved Stakeholder Engagement**: Awareness of the factors of complexity allows for a balancing of stakeholder expectations to ensure coherence across diverse interests and priorities (Ziadat et al., 2017).

Recognition and management of project complexity are critical in handling the unpredictable nature of modern projects. Focusing on technical, organizational, environmental, and human factors, the project teams can build resilience and adaptation that would lead to better project outcomes under uncertain and challenging conditions.

2.4.5. Complexity and Project Success

The relationship between the two constructs of complexity and project success is deeply entangled in industries like oil and gas, where projects are imbued with technical difficulties, stakeholder diversity, and dynamic environments. While complexity often acts as a barrier to project success regarding traditional dimensions of time, cost, and quality, it fosters innovation and adaptability of project management approaches (Sjekavica & Radujković, 2017).

Gaining success from such complexity necessitates understanding its dimensions and the influence they exert upon project performance. In such a perspective, leadership is crucial to tackling such challenges; effective project managers are capable of adopting adaptation toward uncertainty, realignment with the stakeholder, and strategizing on risk/scope management (Cleveland, 2017).

Success with projects means achieving more than the deliverables of the "iron triangle" of time, cost, and quality but includes broader objectives as well as the satisfaction of one's stakeholders. However, traditional project management was only fitted for conditions of stability, being largely unequipped in practice to address such situations in complex projects. Their place is taken by complex project management operating in systemic thinking with iteration toward problem solving and requires for this process a dynamically enabling environment. This process has ensured that immediate objectives and long-term goals are achieved and also possible challenges have turned into strategic opportunities (PMI, 2014).

Research underscores the importance of integrating critical success factors, such as project manager competence, organizational support, and effective methodologies, to enhance project outcomes. In the oil and gas industry, where risk management and scope control are paramount, addressing complexity is essential for both management and product success (Smith et al., 2017). Ultimately, understanding and managing complexity is not just an operational necessity but a cornerstone for achieving sustained project success.

This understanding is even more significant in the context of the oil and gas sector, especially for pipeline projects, which are naturally complex given their scale, technical demands, and environmental considerations. An overview of the oil and gas industry provides insight into how these complexities manifest and the strategies employed to address them effectively.

2.5. An Overview on Oil and Gas Industry

2.5.1. Importance of the Oil and Gas Industry

The dependence of the global economy on oil and gas is such that they have become literally the lifeblood of transportation, the mainstay of industries, and the building blocks of many commodities. It is divided into three main sectors: upstream, which focuses on exploration and production; midstream, handling transportation and storage; and downstream, which covers refining and distribution. This industry, one of the most powerful and far-reaching worldwide, works in a continuous landscape of market fluctuation, geopolitical development, technological advancement, and environmental policy (Floricel et al., 2015).

Oil and gas are foreseen to be at the hub in driving modern civilization, taking up about 57% of the world's needs. These products will take over wide application, ranging from electric power generation to the manufacture of petrochemicals. Emerging economies depend on oil and gas for industrial growth and urbanization, while developed nations continue to rely on them as base sources of energy even as they make the transition to renewable energy alternatives. It fuels economic activities and creates huge employment and revenues, with great contribution to the national GDP of many countries of the world (Kraidi et al., 2021; Smith et al., 2017).

2.5.2. Oil and Gas Megaprojects

Oil and gas mega-projects are huge, capital-intensive projects of exploitation, processing, and transport of enormous deposits of hydrocarbon resources. Very large projects involving investments over one billion dollars in equally sophisticated planning, engineering, and execution may be called the examples such as an offshore drilling platform, the LNG terminals, and immense refinery complexes (Pitsis et al., 2018).

For example, such megaprojects are very important in ensuring a long-term supply of energy and satisfying the increasing global demand. However, they involve a number of risks and problems, including cost overrun, delays, and environmental objections. Their very complexity arises because of many reasons that may relate to technology, regulatory issues, stakeholders, or geopolitics. Their successful execution requires effective management strategies with profound understanding of their multivariate nature (Smith et al., 2017).

2.5.3. Oil and Gas Complex Projects

The intrinsic uncertainty, scale, and interdependencies make the projects in oil and gas industries more complex in nature compared to other traditional projects. Advanced technologies, multiple stakeholders, and mostly remote or challenging environments characterize such projects. The examples include deep-water exploration, shale gas extraction, and cross-border pipeline installations (Olaniran et al., 2015).

These projects are highly high-stake and bound by tight timelines; hence, agile management approaches have to be considered. The various issues of commodity price fluctuation, environmental sensitivity, and geopolitical tension build up the complexity. Navigating through these can ensure project success; therefore, managing complexity remains among the core competencies of industry leaders (Paknahad et al., 2023).

2.5.4. Pipeline Projects in the Oil and Gas Industry

A few vital pipeline projects stake their claim in the midstream sector as crisscrossing conduits carrying crude oil, natural gas, and refined products over long distances: most of these pipes cross international borders, linking remote production sites with refineries and markets. They are certainly the linchpins of the oil and gas industry, providing a much safer, convenient, and economically viable alternative to transport by rail or road (Paknahad et al., 2023).

Pipeline projects in oil and gas development include the designs for hydrocarbon pipelines, which may also include the compressor, pumping, and storage stations necessary to keep the system operational. An individual pipeline may be carrying crude oil, natural gas, or refined products depending on what material is being transported. In reference to their location, they may be onshore, offshore, or subsea.

Pipelines are critical to the global energy supply chain, permitting the mass movement of hydrocarbons while attempting to minimize environmental impacts as compared to other modes of transportation. Challenges faced in pipeline development and operation are technical issues, environmental concerns, and, of course, socio-political issues (Smith et al. 2017).

2.5.5. Technical Aspects of Pipeline Projects

Focusing on the precise engineering and high technology involved in making the procedure simple yet safe, pipeline projects basically consist of:

- **Material Selection**: Anticipating high pressures, temperatures, and corrosive substances, high-strength steel or other corrosion-resistant alloys are used.
- **Routing and Design**: To identify a suitable route, extensive studies in geospatial concerns, environmental impact studies, and stakeholder consultations take place. Design is greatly influenced by parameters such as terrain, geology, and land ownership (Sharaborova, 2014).
- **Construction Techniques**: Here, the techniques vary with the terrain, with HDD applied for river crossings while trenching is used for onshore pipelines. Offshore pipeline work involves the use of subsea welding and advanced laying techniques employed on vessels (Kraidi et al., 2021).

- **Monitoring and Maintenance**: Today, pipelines would be equipped with a real-time monitoring system made up of sensors- and SCADA (Supervisory Control and Data Acquisition)-based systems, thereby allowing for the fast detection of any potential leakages, pressure irregularities, or damages.

2.5.6. Challenges in Pipeline Projects

Various challenges add to the complication of pipeline projects, such as:

- **Regulatory and Environmental Compliance**: Meeting local and international regulations, including those on environmental protection, often requires very lengthy approval processes.
- **Cross-Border Coordination**: International pipelines would require agreements between governments on tariffs, security, and standards of operations.
- **Stakeholder Engagement**: Projects need to balance interests among governments, local communities, environmental groups, and private entities.
- **Geographical Constraints**: From dense urban areas to remote forests and deep seas, the varied terrain necessitates specific engineering solutions.
- **Security Risks**: Pipelines are targets of theft, vandalism, and geopolitical conflicts; hence, the security should be robust given these scenarios (Kraidi et al., 2021).

These make pipelines very important in the oil and gas industry, acting as the basis of their efficiency, safety, and capacity to transport volumes over long distances. As if all of that was not enough, they further contribute to this reduction in dependency from inefficient modes of transport, thus incurring costs and minimizing environmental impacts. Pipelines simply add grade to the strategic storage and distribution of energy resources, as they ensure the supply chain for both domestic and international markets.

Pipeline projects are the typical examples of the multifold challenge of the oil and gas industry, as they combine technical, regulatory, environmental, and economic dimensions of complexity. These challenges underline the need for detailed planning, the quest for innovative solutions, and adaptability in management approaches. Understanding such factors is important in guaranteeing project success. The next chapter shall identify factors of complexity: study how those elements affect the pipeline projects and their outputs using strategic management as a basis, finding creative solutions for handling such hurdles.

2.6. Identifying Complexity Factors in Pipeline Projects

In this context, extensive in-depth review of over 50 academic papers and industry reports was done to identify different factors that define pipeline projects as complex. From this in-depth study, some of the key themes and patterns that result in project complexities were found. A structured framework has been developed from this systematic investigation that showed seven major dimensions, capturing key challenges relating to pipeline projects.

1. Complexities of Project & Stakeholder Management
2. Complexities of Laws and Regulations
3. Project Resources Management Complexities
4. Market Complexities
5. Risks and Uncertainties
6. Environmental Conditions
7. Technical and Engineering Challenges

These dimensions cumulatively provide a strong definition of the critical challenges and are further elaborated into 41 sub-factors, representing the intricate and interconnected nature of complexities in pipeline projects. Each dimension represents one aspect of complexity that influences project performance, decision-making processes, and risk management strategies. In Chapter Three, this preliminary analysis will be revisited, and the main factors will be re-examined and ranked by experts to establish their relative significance.

In the next stage of the research methodology, the identified factors were assessed for priority with expert opinion. This was a collaborative effort to ensure the framework represents the real world and provides practical relevance to the management and mitigation of project complexities. The structured approach will not only enhance understanding but also provide actionable insights to stakeholders in effectively addressing challenges and improving project outcomes.

2.6.1. Project and stakeholder management complexities

The intricate interplay between project objectives, processes; and varied interests of an assortment of stakeholders creates the need for effective interlocutory management. The management of these stakeholders demands the balancing of rather high competing priority interests, on the basis of conflicting expectations, and the resolution of conflicts among parties on divergent objectives. The stakeholders of any complex project may actually include a mastermind mix of persons, organizations, governing bodies, and communities that add peculiar vistas, quite different levels of power, and different levels of influence to any project (Denni-Fiberesima & Abdul Rani, 2011).

Ever present within these are matters of culture, communication, level of engagement, and commitment. Unclear project definitions or conflicting stakeholder requirements, in turn, delay, cost increased down, and erode trust. The interdependence makes the management of project outcomes sensitive to stakeholder satisfaction, and reinforces a feedback system whereby iterative changes to project plans, in turn, are likely needed to satisfy evolving stakeholder demands. And they, in turn, increase the effort involved in their management (Abifarin, 2018).

A structured approach of stakeholder mapping and engagement strategies needs to be adopted. In complex projects, transparent communication, adaptive planning, and collaboration are important to align diverse interests and ensure stakeholder buy-in. As mentioned in earlier sections, proactive addressing of these complexities is important to maintain the momentum of the project and achieve the desired outcomes (Freeman, 1984; International Centre for Complex Project Management, 2014).

a) **Stakeholder diversity**: Diversity of stakeholders inevitably increases the complexities in pipeline projects due to the large number of persons, institutions, and communities that are affected by such projects (Abifarin, 2018). Pipeline projects typically traverse multiple and extensive geographic regions and so involve stakeholders with different interests such as local communities, government authorities, environmental activists, contractors, and financial institutions. Each stakeholder brings varied considerations to the table-from protection of the environment and compliance to regulative to economic benefits and operational efficiencies, and sometimes these considerations are in contention (Denni-Fiberesima & Abdul Rani, 2011). For instance, local communities would prioritize limiting entry cuts to their livelihood, while regulatory agencies are more concerned in ensuring that environmental standards are met. There are ownership rights and cultural preservation issues that the indigenous groups contend with, which creates further complexities.

   In addition, language and cultural differences, various levels of technical knowledge, and differences in legal regimes within the regions would be communication and coordination challenges (PMI, 2014). The nuances become more complicated through dominance, where an influential stakeholder group would be able to steer specific discussions, hence leaving out equally affected stakeholders engaged in that topic. Such diversity warrants strong stakeholder engagement strategies for a pipeline project, including effective and clear communication, early involvement by all parties, and mechanisms for conflict resolution. Trust and equity along the way in the decision-making processes are key to the emergence of these complexities and the success of the project (PMI, 2014; Freeman, 1984).

b) **Conflicts among key project parties**: The clients, contractors, subcontractors, and regulators represent a significant complexity factor in pipeline projects. These conflicts often arise due to differing objectives, priorities, and interpretations of project goals (Freeman, 1984). For example, clients may focus on cost control and timely delivery, while contractors might focus on risk management and ensuring profitability. Misaligned expectations, ambiguous contract terms, or inadequate communication can exacerbate these tensions, leading to disputes over scope changes, delays, or cost overruns (Abifarin, 2018).

   Besides, the regulatory agencies and interest groups may impose constraints that are against the operational strategies of the project implementers. This adds another layer of complexity. The hierarchical nature of many pipeline projects, added to the international stakeholders, often leads to cultural and communication barriers that further fuel misunderstandings.

   Such conflict can be sorted out by strong governance structures, contract management, and collaborative decision-making frameworks that align different interests and reduce adversarial relationships. Moreover, using proactive dispute resolution mechanisms like mediation or arbitration will also maintain the momentum of the project with minimal disruption (PMI 2014; Cleveland & Simon, 2017).

c) **Lack of team cooperation**: A lack of team cooperation is a critical complexity factor in pipeline projects, as these endeavors typically involve large, multidisciplinary teams with diverse expertise and responsibilities. Collaboration challenges often stem from unclear communication channels, misaligned objectives, or individual operations where teams prioritize their own tasks over the project's broader goals. For example, engineering teams focus on technical feasibility, whereas procurement teams focus on cost efficiency; these conflicting decisions contribute to delay; This is further exacerbated by geographical dispersion, with many pipeline projects extending across vast areas that require coordination across time zones and cultural backgrounds (Kian Manesh Rad et al., 2017)

Without strong leadership, a shared vision, and adequate conflict resolution mechanisms in place, the team members may doubt trusting and supporting each other in any respect, which reduces overall efficiency and increases the risks related to rework or failure to comply. A regularity of communication, joint sessions on planning, and activity aiming at team building will also favorably influence the successful management of such challenges (PMI, 2014; Denni-Fiberesima & Abdul Rani, 2011).

d) **Dynamic and evolving team structure**: Changing team structures are one of the key factors contributing to complexity in pipeline projects, whereby teams grow, shrink, or shift responsibilities according to the stage of the project or new challenges that come up.

This fluidity may interfere with continuity, communication, and even knowledge gaps due to changes in team members' roles or the addition of new ones. For instance, during the transition from the design to construction phase, the core team may shift from engineers to construction managers, requiring rapid onboarding and alignment of new team members to ensure project objectives remain clear (Kian Manesh Rad et al., 2017). Additionally, pipeline projects often span long durations and involve multiple subcontractors or joint ventures, each bringing their own work culture, standards, and priorities.

The latter structure calls for adaptive leadership and strong knowledge management systems to retain institutional memory, team cohesion, and prevent any miscommunication or duplicated effort. In the absence of such mechanisms, a project may be delayed, see cost overruns, or compromised on quality on account of lack of congruence between role and responsibilities of the ever-evolving teams. Such has been the arguments in (PMI 2014; Denni-Fiberesima & Abdul Rani, 2011).

e) **Cultural differences**: The cultural factors may be considered one of the forerunning complexity factors in pipeline projects, given the regional span or international players in that respect. There will be cultural differences concerning style of communication, the mode of decision-making, work ethic, and resolving disputes. For example, a project with team members from hierarchical cultures expects the decisions to flow down the chain, but an egalitarian culture is looking to decide by consensus, thereby slowing down major decisions through miscommunication or misunderstanding (Kardes et al., 2014).

In pipeline projects, cultural subtleties can come into play even in health, safety, and environmental compliance. The local workers may have different norms of safety or environmental standards, and the project managers will have to bridge those through clear communication, cultural sensitivity training, and unified protocols for the project. Linguistic barriers and comfort levels with regard to technology or documentation standards further complicate project coordination. Managing cultural diversity requires mutual respect, open communication, and common goals so that differences become a strength and not an obstacle to project success (PMI, 2014).

f) **Separate organization strategy**: The separate organizational strategies among stakeholders can significantly contribute to the complexity of pipeline projects. In fact, different stakeholders like owners, contractors, regulatory bodies, and local communities may work on different strategic objectives, which may not be aligned with the main project objectives. For instance, an organization that is focused on cost minimization may resist quality-driven or environmentally stringent measures proposed by others, thus causing tension in decision-making processes. This can lead to fragmentation of communications, misalignment in expectations, and delays either in approvals or allocation of resources (Floricel et al., 2015).

   Furthermore, there may be conflicting priorities in coordinating the supply chain, especially when different stakeholders operate under different standards or contracts. These issues, therefore, call for a proper governance framework that can integrate these different strategies into one project plan. The leadership should be well exercised in a manner that allows for open communication and a clear vision to help resolve these complexities and ensure that all parties are working together to achieve the success of the project (PMI, 2014).

g) **Inadequate Use of Project Management Practices**: Poor application of project management practices is one of the major factors in pipeline projects, where precision, coordination, and adaptability are a must for success (Abifarin, 2018). In most instances, pipeline projects involve large-scale operations with multiple stakeholders and intricate supply chains. The absence of structured project management frameworks might lead to poorly defined objectives, inadequate risk assessments, and ineffective communication across teams. Without clear guidelines, misaligned priorities, delays, and cost overruns may strike stakeholders (Layth, 2020).

   Moreover, the absence of robust practices like proper scheduling, resource allocation, and performance monitoring exacerbates challenges in adapting to unforeseen circumstances such as changes in regulations or environmental disruptions. The gap in project management maturity not only diminishes efficiency but also heightens the likelihood of conflicts among the parties to the project. In this vein, the adoption of internationally recognized standards such as PMBOK or PRINCE2 is considered (Paknahad et al, 2023).

h) **Diverse languages and nationalities**: Pipelines projects involve a high level of diverse languages and national practices, as most of the pipeline projects cover multiple countries and regions. It goes without saying that the differences in fluency can lead to misunderstanding in communication, delay decisions, or missing crucial information from documentation or instructions. National practices, including variations in labor laws, work ethics, safety standards, and business protocols, further compound these challenges by introducing inconsistencies in project execution (Ebtisam Mirza & Nadeem Ehsan, 2017).

   For example, teams of different cultural backgrounds may have different objectives regarding projects or methods of conflict resolution and problem-solving. This can affect cohesion and alignment in terms of project performance and deliverables. Such complexities call for the adoption of multilingual communication strategies, cultural sensitivity training, and standardized work practices that can help bridge the gaps and facilitate collaboration among multinational teams (Bosch-Rekveldt et al., 2011).

i) **Project Impact of Local Social and Political Groups**: In the complexity of pipeline projects, the local social and political groups have a highly decisive role. Pipelines pass across a number of diverse communities that may be differentiated socially, culturally, and by their political interests.

   Local opposition caused by environmental impact concerns, issues with land acquisition, or perceived project benefit inequities often causes substantial delay, which is difficult to handle with stakeholders. Political groups can influence the project through policy changes, regulatory requirements, or lobbying, further complicating project planning and execution (Hare et al., 2016).

   Local protests or opposition to a construction site, for example, interfere with the construction schedule, whereas upheaval or the change of guard in politics leads to changed permitting or changed contracting. Being able to deal with such complexities requires proactive stakeholder involvement at the grassroots, thorough impact analysis, and adaptive approaches to align project objectives to community and political expectations. Transparent communication and shared benefits, such as job creation or community development initiatives, can help mitigate resistance and foster local support for the project (PMI, 2014).

2.6.2. Laws and Regulations Complexities

Laws and regulations introduce a great deal of complexity in pipeline projects due to the need for compliance across various jurisdictions, often spanning local, national, and international boundaries. Environmental regulations, safety standards, labor laws, and land acquisition policies are quite varied, making the legal requirements a maze that may cause delays in approvals and raise the cost of projects. For example, strict environmental impact assessments may require in-depth studies and mitigation plans, while land rights negotiations can be contentious, especially in regions with unclear ownership or indigenous rights (Bosch-Rekveldt et al., 2011).

Apart from this, regulatory changes within a project's lifecycle might have implications for redesign due to changes in emissions limits or alterations to energy policy. Pipelines crossing national borders pose greater legal difficulties, such as multiple jurisdictions, trade treaties, and geopolitical issues. Such complications are managed through collaboration with specialized lawyers, comprehensive compliance-tracking platforms, and relationship building with regulatory agencies for proactive insights into changing legal regimes (Denni-Fiberesima & Abdul Rani, 2011).

a) **Impact of Local Institutional and Legal Control**: The impact of local institutional and legal control is a critical complexity factor in pipeline projects, often shaping project timelines, costs, and operational strategies. Local institutions, such as municipal governments, environmental agencies, and community organizations, exert influence through permitting, zoning laws, and public consultations. These entities often impose unique requirements or restrictions tailored to regional priorities, such as protecting sensitive ecosystems or preserving local cultural heritage (Denni-Fiberesima & Abdul Rani, 2011).

   Besides, diverse legal environments concerning taxation, labor laws, and the acquisition of land may bring obstacles that require long negotiations and changes in the project design. Delays in approval or disputes with local authorities will result in rising costs, affecting timely completion of projects. Moreover, institutional rigidity or corruption in some regions increases the risks that need a proactive and collaborative approach in stakeholder engagement and legal compliance. Effective navigation of these complexities requires an in-depth understanding of the local legal and institutional environment, along with strategies for fostering constructive relationships with key local actors (PMI, 2014; Bosch-Rekveldt et al., 2011).

b) **Complex Interrelatedness/Interdependence of Contract Elements**: The interrelated and interdependent nature of contract elements involved in pipeline projects contributes to the overall management challenges of pipeline projects. These may include various aspects like procurement terms, construction schedules, resource allocation, and even adhering to local regulations. The interconnectedness of these elements means that changes in one area—such as delays in material delivery—can cascade into other parts of the project, affecting timelines, costs, and risk management strategies (PMI, 2014; Bosch-Rekveldt et al., 2011).

   This dynamic nature of interdependence requires strong mechanisms for planning and coordination. Ignoring these intricacies may result in misaligned expectations of stakeholders, disputes at the contract level, and lower efficiency in projects. Further, multiple contractors, subcontractors, and vendors add to the layers of interdependencies, thereby making such project executions even more difficult. Such interconnected elements of contracts need to be managed effectively in order to maintain stability in projects and to ensure successful outcomes.

c) **Complex contract form and types**: The complexity of pipeline projects has been driven far by the applied contract forms and types, which are complex in nature to meet legal, technical, and operation requirements. These would often have various elements including EPC phases of engineering, procurement, and construction adding complexity and customization based on project size and location.

   This may include lump-sum, cost-plus, or unit-rate contracts, which further introduce their own complexities because each one of these has different ways of apportioning risks and obligations. In addition, many contract provisions are interdependent; this means changes or delays in one area can spill into other areas and further complicate coordination and execution. This complexity is further heightened in large-scale pipeline projects involving multinational stakeholders, each operating under distinct legal and procedural frameworks, making consistent adherence to terms and conditions and daunting tasks (PMI, 2014; Bosch-Rekveldt et al., 2011).

d) **Impact of International Border Policy**: International border policies associated with pipeline projects introduce great complexity, especially in regard to legal, regulatory, and operational challenges. Pipelines often cross multiple jurisdictions with varying laws, policies, and administrative practices. The result is a fragmented legal landscape in which operators must navigate varied regulations on environmental protection, land acquisition, and taxation. Border crossings also imply the possibility of delays in the process of permitting, customs clearances, and inspections that can inflate project costs and timelines. Furthermore, differing national interests and geopolitics might increase risks in a dispute over resource distribution or even political instability. Management strategies should henceforth be supported by bilateral agreements, with clear legal frameworks and well-structured machinery to sort out cross-border conflicts for the smooth running of works (PMI ,2014; Ishtiaq & Jahanzaib ,2017).

e) **Permitting and regulatory requirements**: Permitting and regulatory requirements play a big role in the complexity of pipeline projects. Pipeline projects must navigate the tangled web of federal, state, and local regulations that govern everything from environmental impact and land use to safety. For example, using agencies such as the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) and state authorities impose strict demands on construction, maintenance, and operations (Ishtiaq & Jahanzaib, 2017).

   These rules and regulations protect the interests of public safety and environmental integrity, but their non-proficient management could result in unprecedented delays and cost overruns. Sometimes, interpretations that vary from one jurisdiction to another, or simply ever-evolving regulations, add further complication to an already daunting process of planning and execution. The complexity increases with the inclusion of adherence to permitting processes, such as securing Clean Water Act Section 401 certifications, in that projects must also ensure compliance with water quality and other environmental standards. Proper navigation through these requirements is critical to avoid legal disputes and ensure timely project delivery (PMI, 2014; Ishtiaq & Jahanzaib, 2017).

2.6.3. Project Resources Management Complexities

Complexities in the management of pipeline project resources are a vital challenge because the projects are usually large-scale and multidisciplinary in nature. Large-scale allocation of materials, manpower, equipment, and financial resources over extensive geographic locations has often been done with considerable logistic challenges. Variability in resource availability arising from disruptions within the supply chain, shortages of labor, or geopolitical factors results in delayed schedules and increased costs. Additionally, the coordination of diverse teams of different expertise, especially across borders, calls for strong communication and planning frameworks (Bosch-Rekveldt et al., 2011).

Financial resources are another major factor; pipeline projects often rely on multi-source funding, which introduces complexities in budgeting, accountability, and compliance with varied stakeholder requirements. The dynamic nature of these projects—such as sudden design changes or unexpected site conditions—further complicates resource forecasting and utilization. Effective project resource management is essential to minimize inefficiencies, mitigate risks, and ensure project timelines are adhered to (Denni-Fiberesima & Abdul Rani, 2011).

a) **Poor recourse allocation**: Poor resource allocation makes pipeline projects much more difficult to handle and usually causes inefficiencies, delays, and increases in costs. Inappropriate distribution of resources may be a consequence of miscalculated availability, failure to notice skill suitability, or simply failure to update according to changes in the project scope and requirement. For instance, poor planning or use of inappropriate tools usually results in miscommunication, double bookings, or lack of resources. The effect is a bottleneck that affects work flows and causes project delays. Furthermore, inadequately distributed resources can make teams work ineffectively, leading to low productivity and burnout. The absence of real-time resource visibility further aggravates these problems because it does not allow for proactive adjustments in response to the evolution of project demands. Overcoming these challenges requires a strong resource management strategy that aligns team skills, project needs, and organizational goals while considering flexibility to handle uncertainties effectively (PMI, 2014; Denni-Fiberesima & Abdul Rani, 2011).
b) **lack of past work experience**: In the case of pipeline projects, lack of past work experience causes huge hindrance among project personnel in the successful implementation of a project. It creates problems such as understanding complex systems, forecasting future challenges for the project, and coordinating efforts across teams with distinct functions. Inexperienced teams struggle to perform even basic activities such as risk management, cost estimation, or adherence to industry best practices, thus leading to inefficiencies and delays. In addition, little prior experience with large or geographically spread-out projects could hamper such flexibility regarding unexpected, unforeseen issues like regulatory changes and supply chain disruption. This gap can be remedied through appropriate training, mentorship

programs, and the addition of experienced personnel to guide teams on the intricacies of pipeline projects (Ebtisam Mirza & Nadeem Ehsan, 2017).

c) **Poor direct field labor management**: Poor direct field labor management is one of the key complexity factors in pipeline projects that usually lead to delays, cost overruns, and compromised quality. Inefficient allocation of tasks, lack of proper supervision, and inadequate communication can result in reduced productivity and increased rework. The challenges are further compounded by high turnover rates, skill gaps, and differing levels of experience among workers that disrupt the workflow. Additionally, failure to address site-specific conditions, such as weather or terrain challenges, may hinder the optimal use of labor resources. Effective field labor management is essential to ensure alignment with project schedules, minimize downtime, and maintain safety standards, emphasizing the need for robust planning and real-time coordination (PMI, 2014; Hare et al., 2016).

2.6.4. Market Complexities

Market complexities in pipeline projects emanate from fluctuating demands, volatile material prices, and the economic dynamics that might influence project planning and execution. The cost of essential materials like steel, valves, and specialized equipment is unpredictable, which could be influenced by global supply chain disruptions, trade tariffs, or changes in commodity markets (Ebtisam Mirza & Nadeem Ehsan,2017).

This volatility could further provide instances of budget overruns, delays in procurement, and difficulties in securing the needed resources. Besides, the market competition for the skilled labor force, contractors, and equipment fuels further scheduling conflicts and cost increases. Other factors that may alter the feasibility or scope of pipeline projects, and further complicate long-range planning, are regulatory changes, changes in energy demand, or geopolitical changes. To navigate these market complexities, pipeline projects require proactive risk management, flexible contract terms, and robust financial strategies to mitigate uncertainties and ensure the project remains economically viable and on track (Floricel et al., 2015).

a) **Demand Fluctuations**: Demand fluctuations create a serious factor in pipeline projects, since changes in volume and types of resources will immediately impact project planning, design, and operations. Shifting energy demand due to market trends, technological advancement, or geopolitical events may imply changes in pipeline capacity or routing that re-engineering or delays would resolve. For example, if demand for a certain type of crude oil or natural gas is reduced, then the design of a pipeline must be altered to accommodate carriage of different types of fluids and at perhaps lower flow rates. In addition, the uncertainty due to fluctuating demand ranges to financing and investment: project stakeholders may be unwilling to commit infrastructure where utilization is uncertain. Pipeline operators must be flexible with these market changes, using flexible design approaches and predictive modeling to ensure the long-term viability and efficiency of projects while minimizing the impact of demand changes on construction timelines and costs (Floricel et al., 2015).

b) **Market Competition**: Market competition is a significant complexity factor in pipeline projects, as it can influence both the pricing and availability of resources, contractors, and specialized equipment. In a competitive market, pipeline projects must contend with bidding wars for skilled labor, materials, and construction services, which can drive up costs and extend timelines. Tight competition also means that project owners may face pressure to reduce costs, potentially compromising quality or safety standards (Manesh Rad et al., 2022).

   Besides, fierce competition for major subcontractors or specific technologies could lead to delays in securing the much-needed expertise or equipment, and further complicate project execution. Other projects would also be competing for the same inputs, such as pipeline access, transport routes, or regulatory clearances, therefore creating conflicts or delays due to scheduling. These complexities can be managed within a pipeline project only with strategic planning and negotiation with suppliers and contractors, plus consideration of alternatives to provide timely, cost-effective solutions without compromising safety and quality standards (Floricel et al., 2015).

2.6.5. Risks and Uncertainties

Pipeline projects involve significant complications arising from risks and uncertainties in the project life cycle. Such risks can include unstable environmental conditions, changes in regulations, geopolitics, and markets that are not stable. For example, flooding or earthquakes may cause unpredictable delays or damage to a pipeline and require expensive repairs and/or redesigns. Regulatory uncertainty, changes in environmental policy, or changes in permit conditions may involve delays or raising compliance costs (Manesh Rad et al., 2022). Geopolitical hazards include political instability in different regions that pipelines cross may disrupt supply chains, change routes, or pose security risks.

Additionally, the potential for cost overruns due to fluctuating material prices or unexpected technical challenges adds another layer of unpredictability. To mitigate these risks, pipeline projects require comprehensive risk management strategies, including detailed contingency planning, regular monitoring, and the flexibility to adapt to changing circumstances, ensuring that the project remains on track despite uncertainties (Denni-Fiberesima & Abdul Rani, 2011).

a) **Ineffective future Forecasting**: Poor forecasting of the future increases the complexity of pipeline projects due to misaligned expectations, resource shortages, and unforeseen costs. Poor forecasting of future demand, market conditions, regulatory changes, or technological advances is always difficult. Inaccurate forecasts in this respect can lead to overbuilding or underbuilding pipelines. For instance, underestimation of transportation needs in the future leads to underutilized capacity; on the other hand, overestimation causes unnecessary capital expenditure on the infrastructure itself (Pitsis et al., 2018).

   Moreover, the forecast challenges also extend to environmental impacts, material costs, and labor availability, which could all fluctuate due to external factors such as global economic shifts or climate change. Inaccurate forecasts may lead to missed opportunities or financial strain because project schedules and budgets may have to be adjusted based on evolving conditions. For minimizing the impacts of ineffective forecasting, it is important that pipeline projects implement flexible planning, continuous monitoring of market trends, and regular reassessment of assumptions to ensure that there is adequate addressing of future uncertainties (Denni-Fiberesima & Abdul Rani, 2011).

b) **Ambiguity of project features and phases**: Ambiguity of project features and phases is one of the important factors contributing to the complexity of pipeline projects. Poorly defined or unclear project scopes can generate miscommunication, delays, and increased costs. Ambiguity usually arises at the beginning of the project when many key parameters such as exact pipeline routing, environmental impact assessments, or technical specifications are not ascertained or are subject to change. This can lead to ambiguity in changing design, construction methods, or project timelines, which may cause confusion among stakeholders and lead to challenges in coordinating tasks across multiple teams. Unclear phases of projects or activities that might run in tandem can give rise to inefficiencies; teams could progress without information or work out of step. Managing this complexity requires a good level of project management, clear communication, and detailed planning to ensure that phases in the project are well articulated, expectations are aligned, and ambiguities are dealt with well in advance to avoid significant disruptions (PMI 2014; Denni-Fiberesima & Abdul Rani 2011).

c) **Data limitation on TPD (Theft, Pilferage, and Damage)**: The scarce data on TPD-theft, pilferage, and damage-is one of the major complicating factors in pipeline projects since poor data or inadequate monitoring systems may limit the detection and prevention of these critical security risks. Theft and pilferage of pipeline materials or valuable equipment, along with damage caused by external factors such as vandalism, construction accidents, or natural disasters, can lead to costly delays, safety hazards, and environmental harm (Kraidi et al., 2021).

   Without accurate, real-time data on pipeline conditions or security threats, operators may be unable to quickly identify any breaches or issues, with the attendant risk of major operational disruption. Similarly, sparse data on historical incidents, or a lack of adequate tracking of pipeline integrity, can make it hard to predict and prevent future TPD occurrences. To address these complexities, pipeline projects must invest in robust surveillance technologies, advanced monitoring systems, and comprehensive data analysis to track the condition of both the pipeline and its surrounding environment, ensuring timely responses to threats and reducing the likelihood of damage or loss (Kraidi et al., 2021).

d) **Political and economic instability**: Political and economic instability are considered major factors of complexity in the case of pipeline projects because of the potential for their unanticipated risks to dislodge planning, construction, and long-term operation. Political instability, represented by changes in government, civil unrest, or conflicts, could abruptly change regulations, delay permitting, or even completely cancel projects. Pipelines may be exposed to the risk of expropriation, sabotage, or opposition from local communities or interest groups when located in regions prone to volatile political climates (Abafarin, 2018).

   However, economic instability, whether through inflation, currency fluctuations, or shifts in energy market prices, can make the material, labor, and equipment costs quite unpredictable and hence strain budgets, have financing challenges, and bring about delays. Besides that, economic downturns usually decrease demand for pipeline capacity, making it difficult to invest in or justify the viability of the project. Such uncertainties, therefore, need stringent risk management strategies that will involve flexible contracts, political risk insurance, and close watch on economic trends to change with the conditions (PMI, 2014; Abafarin, 2018).

e) **Security and vandalism**: Safety and vandalism are two major issues that add to the complexity of pipeline projects, often characterized by huge disruptions, unsafe conditions, and higher costs. Pipelines, particularly those passing through remote or politically unstable areas, can be subjected to acts of vandalism, sabotage, or theft that could result in damage to infrastructure, disrupted operations, and costly repairs. Security breaches may also present threats to the safety of workers, causing delays and a potentially hazardous working environment (Abafarin, 2018).

   Besides, vandalism can be directed against critical parts of the pipeline, like valves, pumps, or monitoring systems, thus undermining its functionality and increasing the likelihood of leaks or spills. Security at pipeline projects should be comprehensive to minimize such risks, including surveillance systems, access controls, and regular patrols. Collaboration with local law enforcement, the installation of remote monitoring technologies, and employing advanced threat detection systems can further reduce vulnerabilities and ensure pipeline integrity throughout its lifecycle (Abafarin, 2018).

f) **Probability of Cost overrun**: One of the key factors adding to the complexity is the likelihood of cost overrun, usually because of unforeseen challenges, market conditions, and scope changes. Pipelining projects are among the most susceptible projects to cost overruns due to reasons such as fluctuating prices of materials, shortage of labor, and delays for various environmental, technical, or regulatory reasons. Unpredictable issues like design changes, route modifications, or the discovery of unforeseen geotechnical challenges can require additional resources, time, and investment, pushing the project budget beyond initial estimates (Kraidi et al., 2021).

   Besides, external factors like inflation, fluctuation in currency exchange rates, or disruption in supply might also raise costs, which makes financial planning more complicated. Cost overrun probability can be managed by detailed cost estimation, proactive risk management, and the ability to adapt to changed circumstances without loss of project objectives. These cost uncertainties can be reduced by effective project monitoring, contingency budgets, and flexible contracts to keep the project on track (Kardes et al., 2013).

g) **Probability of Natural hazards**: Natural hazard probabilities remain an important complexity factor in any pipeline construction since environmental disturbances, such as earthquakes, floods, landslips, or extreme weather conditions, can severely affect the integrity of the pipeline and delay the scheduled timelines. Physical damage caused to the pipeline by natural hazards may also interrupt supply chains or create unanticipated challenges in the installation process (Kraidi et al., 2021).

Earthquakes can shift ground or damage a pipeline, floods can wash out sections of a pipeline or cut off access to an area needing work, and installation of pipelines in cold weather or heavy snowfall can cause problems for construction, testing, and maintenance. Risk assessment must be an extensive process during pipeline construction with the inclusion of environmental factors in the design, and advanced engineering techniques such as flexible joints, reinforced materials, or trenchless technologies should be stated in the design to give the pipeline resistance to environmental hazards. Contingency plans, real-time monitoring, and prompt increased response strategies all must together be utilized to mitigate these unpredictable effects (PMI, 2014; Kraidi et al., 2021).

2.6.6. Environmental conditions

Environmental conditions are a critical complexity factor in pipeline projects, as they directly influence design, construction, and operational strategies. Harsh or variable environmental factors such as extreme temperatures, heavy rainfall, flooding, or arid conditions can significantly impact the materials used, the construction timeline, and the overall feasibility of the project (Kraidi et al., 2021).

Pipelines in cold climates, for example, have to be designed to withstand freezing temperatures and any resultant problems, such as cracking or frost heave, while those in hot environments may be sited with special coatings or heat-resistant materials. Difficult terrain-such as wetlands, forests, or steep slopes-can complicate construction, necessitating specialized equipment and techniques that minimize land disturbance and ensure adherence to environmental regulations. In addition, it is often necessary to consider environmental impact studies and mitigation plans to preserve any ecosystems, water sources, or local wildlife, thereby increasing the project's overall complexity (Denni-Fiberesima & Abdul Rani, 2011). The management of environmental conditions includes detailed planning, using sophisticated technology, and close collaboration with environmental specialists to ensure that the work is carried out safely and sustainably according to set regulatory standards (PMI, 2014).

a) **Highly regulated environment**: High complexity in pipeline projects usually emanates from a highly regulated environment. A number of local, national, and international regulations add to the layers of intricacy in the planning, design, and construction phases. Most of the regulations cover wide areas like environmental protection, safety standards, land use, and community impact, and non-compliance can lead to very costly delays, fines, or shutdowns. It involves the headache of permitting at many levels, sometimes interlocking, acquiring permissions from different regulatory bodies, and keeping the pipeline in harmony with legal and environmental precepts-all needing careful coordination and substantial resources.

Additionally, regulatory changes during the project's lifecycle—such as updates to environmental laws or safety standards—can necessitate design modifications or adjustments to construction schedules. Managing these regulatory complexities demands thorough planning, continuous monitoring of evolving regulations, and effective communication with regulatory agencies and local stakeholders to ensure smooth project execution and avoid legal or financial setbacks (PMI, 2014; Denni-Fiberesima & Abdul Rani, 2011).

b) **Implementation of Sustainability Requirements (Reducing Emissions During Construction)**: The implementation of sustainability requirements, especially reduction of emissions during construction, is one of the key factors for complexity in pipeline projects, as it requires integrating environmentally sensitive practices while sustaining project efficiency and timelines. Pipeline construction can be highly emissive, including greenhouse gases from machinery, equipment, and transportation (Layth, 2020).

Clean technologies, such as electric or hybrid machinery, low-emission vehicles, and renewable energy sources, can be employed to meet the more stringent requirements of sustainability. This is at an increased upfront cost that may involve more difficult logistics. Construction methods may also have to be adjusted, with minimal disturbance to land, protection of local ecosystems, and reduced air or water pollution adding complexity to the project. Compliance with these sustainability requirements may also involve detailed environmental impact assessments, monitoring systems, and reporting mechanisms to track emissions and ensure that construction practices align with global climate goals. Balancing the need for sustainable practices with the technical and economic demands of pipeline construction requires careful planning, innovative solutions, and collaboration with environmental experts, all of which add layers of complexity to the project (Levenbach & Leong, 2023).

c) **Implementation of Health, safety, security, and environment(HSSE)**: The HSSE implementation is an important factor of complexity in pipeline projects, protecting workers, local communities, and environments at all times throughout when the pipeline is in existence. Compliance to HSSE is very strict whereby risk assessments are detailed and safety trainings are provided to workers, with emergency response plans in place for possible accidents to occur or for natural disasters (Ebtisam Mirza & Nadeem Ehsan, 2017).

   here are several types of common high-risk activities such as excavation, welding, and transportation of hazardous materials that pipeline projects usually have, and when considered, these will require high safety precautions to avoid that people get injured by accidents or spills. Pipeline security should further include areas where access is difficult or where there is political instability, in order to avoid theft, vandalism, or even sabotage. Keeping land disturbance to a minimum while tending to wildlife habitats and reducing emissions is further complication in HSSE standard implementation. There should be thorough planning to meet these requirements in coordination with continuous monitoring and strong safety culture, which add vastly to the time, costs, and complexity of pipeline projects. Balancing HSSE priorities with the project's budget and the timeline requires careful coordination and proactive approaches to risk management (Levenbach & Leong, 2023).

2.6.7. Technical and Engineering Challenges

Technical and engineering challenges are associated with pipeline projects due to the complexity of infrastructure design and actual construction over varied topographies and ecologies. Many of these challenges consist of geotechnical risks such as landslides, erosion, and unstable soils that could compromise pipeline integrity.

Designing for extreme weather conditions, such as freezing temperatures or high heat, adds further difficulty, as materials and construction methods must meet stringent safety and durability requirements (Ziadat et al., 2017). Navigating regulatory and environmental constraints, such as minimizing ecological disruption and ensuring compliance with local standards, can also pose engineering hurdles. Further, advanced technologies involving automation and monitoring systems call for skills that range from installation to maintenance. The various challenges necessitate thorough planning, creative solutions, and collaboration in multidisciplinary teams for pipeline safety, functionality, and long-term reliability (Shafiee et al., 2019).

a) **Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservoir properties)**: Challenges in the FEED and detailed design phases are considered critical factors of complexity in pipeline projects, especially in route optimization and fluid and reservoir properties. Route optimization has to balance environmental constraints, regulatory requirements, and land acquisition with minimal cost and environmental impact. This process is further complicated by the need to mitigate risks such as geo-hazards, water crossings, and urban development (Shafiee et al., 2019).

   Fluid and reservoir properties add to the complexity of understanding, since parameters such as pressure, temperature, viscosity, and composition have a direct influence on the selection of materials for the pipeline, sizing, and operational strategies. Poor or incorrect data/assumptions at this initial stage can result in design inefficiencies and operational failure (Ziadat et al., 2017). Successful navigation of these challenges requires comprehensive analysis, advanced modeling tools, and close collaboration among geotechnical, environmental, and engineering experts to create a robust and cost-effective pipeline design (Kraidi et al., 2021).

b) **Change in production processes (adapting to different types of crude oil and gases)**: The key factors include modification and changes in the process, mainly on crude oil grades and gas types. Pipelines need to be flexible and resilient in design and construction due to changes that could be found in crude oil properties such as viscosity, sulfur content, and density, and in gas composition such as impurities and moisture contents. These changes may necessitate modifications in material selection, pipeline diameter, or operational parameters such as pressure and temperature control (Bosch-Rekveldt et al., 2011). Furthermore, accommodating fluctuating production volumes or shifts between oil and gas transport can strain existing infrastructure, requiring additional equipment like separators, heaters, or blending facilities. Such adaptations often involve extensive re-engineering, compliance with evolving regulatory standards, and increased operational costs. Managing these complexities demands foresight in pipeline design, investment in advanced materials and technologies, and continuous collaboration with production teams to ensure efficiency and reliability across varying production scenarios (Khan & Hamid, 2020).

c) **Supply chain logistics (specialized equipment and cross-border logistics)**: Supply chain logistics, particularly involving specialized equipment and cross-border operations, is a significant complexity factor in pipeline projects. Procuring and transporting specialized materials, such as high-grade steel pipes, compressors, and coatings, requires meticulous planning and coordination to ensure timely delivery and compliance with project specifications (Nzeda et al., 2020).

Cross-border logistics further complicate the process due to delays, increased costs, and disruptions from the variance of customs regulations, trade restrictions, and political factors. The challenges with this industry are the low availability of equipment and long lead times, together with requirements for skilled labor for handling and assembling the components. Furthermore, safe and efficient transport of oversized and heavy equipment to remote and usually inaccessible areas calls for specially developed solutions, including vehicles and other protocols for handling. All such risks can be minimized through effective supply chain management, which comes into play with strong logistical planning, good vendor relations, and contingency plans so that projects are completed on schedule and within budget (Smith & Lee, 2020).

d) **Challenges posed by diverse terrains (Surface and subsea geography)**: In most cases, on land, pipelines pass through rugged mountains, dense forests, arid deserts, and wetlands-all requiring special construction techniques and equipment (Kraidi et al., 2021). Such terrain might expose the pipeline to specific hazards, such as landslides, erosion, and flooding, which may require special engineering solutions like reinforced foundations, flexible materials, or elevated sections (Ziadat et al., 2017).

In subsea environments, challenges are magnified by deep-water pressures, shifting seabed, and strong currents, which can complicate installation and maintenance. Additional risks, such as potential interactions with marine ecosystems and shipping routes, require stringent regulatory compliance and environmental mitigation strategies. Addressing these diverse terrain challenges necessitates the use of advanced survey technologies, geotechnical analysis, and innovative design approaches to ensure structural integrity, operational safety, and minimal environmental impact across varying geographic conditions (Ishtiaq & Jahanzaib,2017).

e) **Production shortfalls caused by blockages and damage of pipelines**: In pipeline projects, blockages and damage to the pipelines are critical factors that lead to shortfalls in production, causing stops in operation and financial losses. Blockages, whether by wax deposition, hydrate formation, or sedimentation, can reduce flow efficiency and make operations of cleaning and maintenance very expensive. On the other hand, physical damage due to external forces such as natural disasters, construction activities, or intentional sabotage may compromise pipeline integrity and result in leaks, spills, or total shutdowns (Kian Manesh Rad, 2016).

These issues are hard to detect and address in the case of many pipelines being in remote and often inaccessible locations. Advanced monitoring such as by pigging tools, sensors, and real-time flow diagnostics is indispensable, yet it adds to the venture's complexity and cost. This, therefore, calls for proactive maintenance strategies, strong pipeline design, and contingency planning to ensure operational continuity at minimal production loss (Bukkaraju et al., 2016).

f) **Vast scope or numerous interconnected tasks (Size or number of project activities)**: The vast scope and numerous interconnected tasks involved in pipeline projects are major complexity factors, driven by the sheer size and multitude of activities required for successful execution. From initial feasibility studies and route surveys to procurement, construction, and commissioning, each phase comprises numerous specialized tasks that must be meticulously coordinated (Ebtisam Mirza & Nadeem Ehsan, 2017). Activities like obtaining permits before construction or synchronizing material deliveries with installation schedules involve dependencies that increase the potential for delays and cost overruns (Bukkaraju et al., 2016). It also involves many different stakeholders, such as engineers, contractors, regulatory authorities, and the local community, which adds to the complexity. Such interlinked activities need detailed planning, an efficient project management system, and effective communication among teams to ensure coherence in all respects. A minor slip in one activity can snowball into the entire project, which indicates an integrated approach in scheduling, resource allocation, and risk management in such major projects (Ebtisam Mirza & Nadeem Ehsan, 2017).

g) **Schedule Complexity (challenges of maintaining critical paths)**: In particular, pipeline projects have complexity in scheduling, especially critical paths. Any delay in one phase would lead to the effect of a snowball into the whole timeline. Most times, the critical path-activities that define the project's completion sequence-is influenced by factors such as permitting delays, bad weather, or supply chain delays (Ebtisam Mirza & Nadeem Ehsan, 2017). These include dependencies of activities on land acquisition, followed by construction, or installation of equipment after laying the foundation, which puts additional pressure on meeting the schedule. Such challenges are accentuated by unexpected events like equipment failure or labor shortages, which demand quick responses to avoid long delays. The dynamic nature of pipeline projects, with their multiple stakeholders and diverse activities, necessitates robust scheduling tools, real-time progress tracking, and effective contingency planning to manage these complexities and ensure timely project delivery (Bukkaraju et al., 2016).

h) **Poor welding and joint integrity**: Poor welding and joint integrity are considered to be very critical factors of complexity in pipeline projects because the structural strength and safety of a pipeline directly depend on such factors. Weak joints resulting from improper alignment of the welds, poor penetration, or using substandard materials will result in increased risks for leakage, ruptures, and failure of the pipeline under operational stresses. Besides, the aforementioned issues are further compounded by difficulties in maintaining consistent quality in welding under different environmental conditions, such as extreme temperatures, high humidity, or even at remote locations (Taylor, 2019).

   Besides, joint integrity involves some serious inspection processes using advanced techniques such as radiography or ultrasonic testing, which is pretty time-consuming and expensive. If the welding and quality of joints are not addressed, this may lead to high maintenance costs, environmental hazards, and risks associated with safety. The pipeline projects should, therefore, be fully equipped with appropriate quality control measures, skilled labor, and advanced welding techniques to establish reliable and durable connections (Taylor, 2019).

i) **Crossing sensitive areas**: Crossing sensitive areas is a significant complexity factor in pipeline projects, as it involves navigating regions that are environmentally, culturally, or socially vulnerable. These areas may include wetlands, protected wildlife habitats, water bodies, or regions of cultural heritage, where construction activities must adhere to strict regulatory guidelines to minimize disruption (Taylor, 2019).

   Other environmental issues such as soil erosion, water contamination, and disruption of ecosystems require specialized techniques in construction, like HDD or trenchless technology, in order to avoid direct contact with the land. This type of sensitive area also faces increased public scrutiny, greater local opposition, and frequently, delays due to possible court battles or additional mitigating measures. Managing these complexities demands careful planning, comprehensive environmental impact assessments, and close collaboration with regulatory bodies, environmental experts, and local communities to ensure compliance and minimize the long-term impact of the pipeline (Taylor, 2019).

j) **Real-Time Data Analysis Challenges**: Real-time data analysis challenges are a significant complexity factor in pipeline projects, as they involve processing vast amounts of data generated by sensors, monitoring systems, and operational activities to ensure safety, efficiency, and performance. Collecting and analyzing real-time data from pipeline pressure, temperature, flow rates, and structural integrity requires robust infrastructure, specialized software, and skilled personnel to interpret the information effectively (Hartmann, 2023).

This means that the challenge will be not only in volumes but also in the accuracy of this information, considering the failures or interference of sensors with environmental influences. Moreover, quick action based on real-time data insights is crucial in the avoidance of blockages, leakage, and mechanical failures that could lead to very costly delays and safety hazards (Denni-Fiberesima & Abdul Rani, 2011).

The integration of real-time data with other project management systems to optimize operations, maintenance, and emergency responses adds another layer of complexity, requiring seamless communication and a proactive approach to risk management (Hartmann, 2023).

k) **The Availability and reliability of geospatial data in remote terrains**: Complexity factors for pipeline projects revolve around the availability and reliability of geospatial data, given that effective mapping and terrain analysis are important elements of planning and design. Ensuring the reliability of geospatial information can be difficult in very remote or inaccessible regions such as mountainous regions, forests, and offshore due to access difficulties, harsh environmental conditions, and a lack of sufficient surveying infrastructure (Kian Manesh Rad et al., 2016).

Inaccurate or outdated geospatial data result in miscalculations at route selection, which may cause unforeseen obstacles or safety risks in construction. Moreover, reliable data on environmental assessments, land acquisition, and regulatory compliance are crucial for acquiring permits and reducing environmental impacts (Geo-awesome Team, 2024).

Overcoming these challenges requires the use of advanced technologies such as satellite imagery, drones, and Geographic Information System (GIS) tools to collect high-quality geospatial data and ensure the accuracy of route planning, while also addressing the logistical difficulties of data collection in remote, often inaccessible, terrains (Manesh Rad, 2022).

l) **Design changes and overlapping of process**: Design changes and the overlapping of processes are significant complexity factors in pipeline projects, as they can lead to project delays, increased costs, and coordination challenges. Pipeline projects often require adjustments to the original design due to unforeseen site conditions, regulatory changes, or new technological requirements, which can impact both the engineering and construction phases (Taghi Zadeh et al., 2015).

These design changes, if made late in the process, might necessitate rework, additional approvals, or material and equipment changes that disrupt the flow of work. Additionally, the overlap of processes, such as detailed engineering while construction is going on or procurement of materials while permitting is still in process, can create inefficiencies and risks, since different teams may be working with incomplete or updated information. Effective management of these complexities requires careful planning, transparent communication, and a flexible project management approach that can accommodate changes without compromising project timelines or quality (Mossolly, 2013).

2.7. Using Delphi and AHP to Address Complexity in Pipeline Projects

Large-scale operations, multidisciplinary teams, and a mix of technical, environmental, and socio-economic challenges make pipeline projects inherently complex. Precise identification and assessment of such complexities are linked with the effective management of the project. This research employs the Delphi method and AHP, since the two techniques provide systematic and reliable tools to deal with such challenges.

The Delphi method is a systematic and effective way to collect and refine expert opinions on complicated issues. It builds consensus on the most important factors of complexity through successive rounds of structured feedback. Anonymity of the process reduces the potential bias of dominant voices, hence fairly representing diverse perspectives. This is especially useful in pipeline projects, where expertise is drawn from several disciplines and a holistic view is important.

AHP supplements the Delphi method with a structure that assigns priority to the factors identified. Organizing the decision in a hierarchical manner, through pairwise comparisons, AHP converts subjective judgments into quantified weights. Its embedded consistency checks add to making the outcome reliable and meaningful, which is essential for a pipeline project where prioritizing helps the project balance technical, regulatory, and environmental demands.

The Delphi method combined with AHP forms a powerful combination wherein Delphi ensures comprehensive, unbiased identification of the complexity factors and AHP provides a structured way of ranking them by importance. Integrated, the approach enhances decision-making, resource allocation, and risk mitigation as a necessary strategy to deal with the complexity of pipeline projects.

In this chapter, we plunged into the concept of complexity and its implications for project management, in detail studying the definitions and characteristics that distinguish complex projects and their impact on project success. Considerable attention was given to the oil and gas industry, focusing on pipeline projects as typical examples of highly complex projects. We analyzed various sources of complexity that may arise and impact project performance from a technical, organizational, and environmental perspective.

In addition, through a thorough literature review, we developed a comprehensive list of complexity factors for pipeline projects. Synthesizing insights from prior research and industry reports, these factors provided a broad basis for understanding the challenges unique to this domain.

The sum of these factors adds up to the complexity, hence forming a critical component of the research and will be further utilized in the next chapter as a basis for methodological analysis. Further steps will involve evaluation and prioritizing of the factors in a systematic way to develop actionable strategies for managing complexity in pipeline projects. This framework will bridge the gap between theoretical knowledge and practical application and contribute to better management practices in the oil and gas industry.

Chapter Three: Research Methodology

3.1 Academic Literature Review and Criteria Identification

Managing complexity has emerged as the key success factor in pipeline mega-projects, especially in high-stakes industries like oil and gas. Pipeline mega-projects are beset with special mixes of challenges such as technical difficulties, environmental constraints, organizational Obstacles, regulatory demands, and risks inherent in the projects. Each of these factors greatly influences project performance in terms of timelines, budgets, and overall results. Consequently, stakeholders have made identifying and managing such complexities their priority to achieve success in projects.

The literature review in the previous section presented a critical review of the literature, which identified that project complexity is a multi-dimensional factor with wide ramifications. Based on various studies, the review identified the key determinants of Pipeline Project Complexity (PPC). The review mapped not only the complex relationships of these factors with project outcomes but also identified the key dimensions that form the framework for this study.

With this theoretical basis, the research will now turn to a systematic study of PPC. The following diagram depicts the methodology of research that follows in logical sequence from theoretical inputs to practical analysis. This provides a structured framework within which the inherent complexities of pipeline projects will be comprehensively and rigorously explored for a clear route to understanding and prioritizing challenges particular to the oil and gas industry.

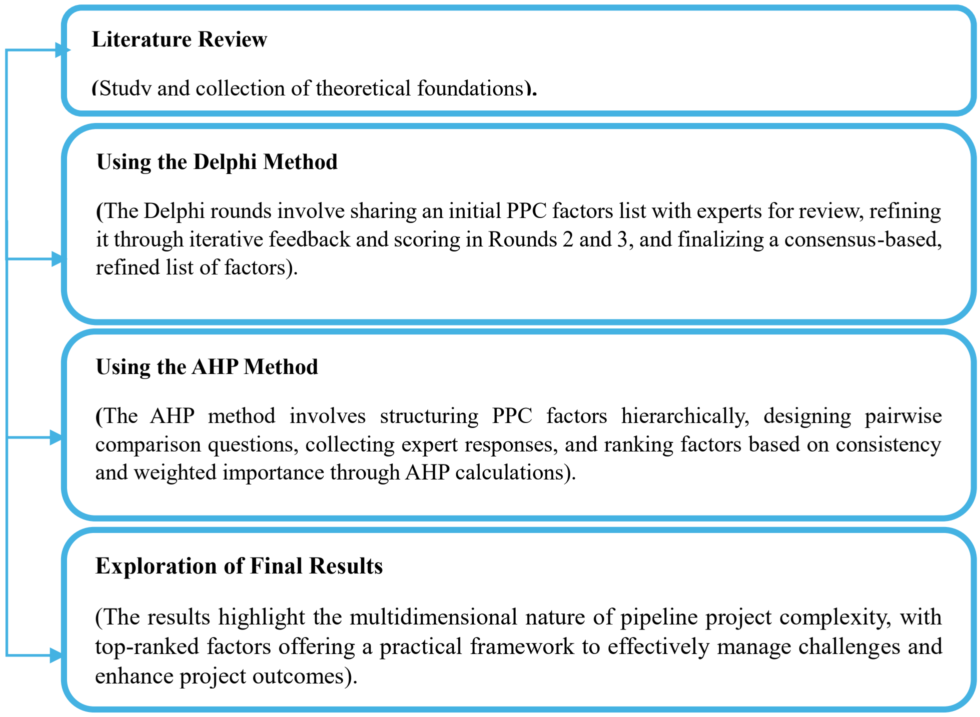

Figure 1: Steps of methodology by author.

3.2. Overview on Delphi Method

The Delphi method is considered both a qualitative and quantitative method that assists a panel of experts in reaching a structured consensus regarding complex problems. This iterative survey technique requires several rounds in which experts individually assess a set of predefined issues. Responses after every round are anonymized upon collection, and then presented to the group as feedback. This allows participants to review their judgments and converge towards an agreement.

The Delphi method is useful when the problem is complex or multi-dimensional, empirical data are scarce, and consensus is imperative. The structured nature helps in systematically breaking down and addressing intricate issues. Expert insights compensate for the lack of concrete data. The iterative process and feedback mechanism facilitate collective agreement through structured group input. It finds broad applications in strategic planning, policy development, and technology forecasting, among other areas, using expert knowledge to obtain trustworthy and informative results (Hsu & Sandford, 2007)

3.2.1. Steps of the Delphi Method

- **Step 1: Define the Problem and Objectives**

It involves, first, the identification of the research problem and formulation of goals consistent with the purpose of the study. Researchers identify why consensus is needed and how the Delphi method will address the issue's complexity (Dalkey & Helmer ,1963).

- **Step 2: Select the Expert Panel**

The experts are chosen with care, considering their knowledge, experience, and qualification. It could be professional expertise, academic backgrounds, or relevant research experience. A diverse panel ensures a variety of perspectives while maintaining credibility (Okoli & Pawlowski, 2004).

- **Step 3: Round 1 – Idea Generation (Qualitative Phase)**

Open-ended questions are used to which experts respond with a wide range of ideas, factors, or solutions. The responses are analyzed and consolidated into a refined list for the next phase (Hasson et al., 2000).

- **Step 4: Round 2 – Refinement and Prioritization (Quantitative Phase)**

Using tools like a Likert scale, experts rate or rank the consolidated list based on criteria like importance or impact. Statistical analysis (mean, median, standard deviation) highlights areas of agreement or divergence. Summarized feedback is shared with the panel to encourage further reflection and refinement (Hsu & Sandford, 2007).

- **Step 5: Build Consensus**

In successive rounds, experts reconsider feedback and change judgments. Iterations continue until a consensus threshold-e.g., 70-80% agreement-recommended in literature-is reached. The last ranking of the factors is thus drawn from collective expert judgment (Keeney et al., 2006).

- **Step 6: Analyze and Validate Results**

The results are then analyzed using statistical tools to identify priority levels and strength of agreement. Experts consider the final results to ensure that they are accurate and confirm consensus (Paré et al., 2013). This systematic process has made the Delphi method very effective in handling complex issues while ensuring that informed and reliable decisions are arrived at.

3.2.2. Advantages of the Delphi Method

The Delphi method should work as a very effective means of gauging various priorities of complexities for pipeline projects, considering its advantages such as anonymity in the submissions of expert opinion and reduction of risks regarding group thinking or domination of discussion by more vocal participants; the iterative process with feedback that allows multiple rounds of reflection, refinement, and movement toward a commonly held perception.

- **Structured Consensus**: The structured response and analysis provide a no ambiguous process of reaching a consensus.
- **Flexible**: The technique is very versatile-it can be used for the brainstorming of qualitative ideas or for ranking those ideas in quantitative terms.
- **Suitable for Complex Problems**: Delphi is particularly suited to ill-defined problems when hard data is lacking but a decision needs to be made based on the vision of experts.

This is the combination that would make Delphi methods very powerful choices for navigation within complex decision-making situations.

3.3 Analytical Hierarchy Process Method and Criteria Weighting

The Analytical Hierarchy Process was introduced in the 1970s by Thomas L. Saaty, and as such, it is designed to analyze complex problems organized in a hierarchy of goals, criteria, and sub-criteria (Saaty, 2004). This structure gives ample opportunity for the decision-makers to prioritize and evaluate each factor systematically by merging their qualitative judgments with quantitative data (Danesh et al., 2017). AHP is particularly useful in scenarios like project management, where conflicting criteria—technical, financial, and environmental—must be controlled (Podvezko, 2011).

The method works through pairwise comparisons, where criteria are rated on a scale of 1 (equal importance) to 9 (extreme importance), creating a matrix that reflects the decision-maker's preferences (Ossadnik & Lange, 1999). These comparisons generate priority weights for each criterion, making the method effective for decisions in complex industries like oil and gas (Saaty, 2004; Vidal et al., 2011).

AHP has become a popular tool for selecting and prioritizing options in large-scale projects, particularly when multiple alternatives need to be evaluated against competing objectives (Poggio, 2021). Its intuitive framework is accessible even to non-technical managers, making it highly practical for real-world applications (Vidal et al., 2015). The method’s strengths include:

- Balancing multiple objectives
- Managing complex systems effectively
- Exploring interdependencies between factors
- Creating clear hierarchical structures
- Assessing both measurable and abstract aspects
- Consistency of judgment
- Integration of diverse inputs into actionable priorities

These flexibilities and rigors make AHP a major approach for tackling decision-making challenges in various fields.

3.3.1. AHP application in Project Management

AHP is one of the most widely used multi-criteria decision-making techniques in project management, adopted in solving complex decisions (Al-Harbi, 2001). This ability to decompose complex problems into a hierarchy of smaller, more manageable elements has made it particularly applicable to industries such as oil and gas, where projects are typically very complex in nature (Darko et al., 2018). Oil and gas projects are typically large-scale, technologically demanding, capital-intensive, and governed by strict safety and environmental regulations (Vidal et al., 2011). In this context, AHP is applied to tasks such as selecting contractors, prioritizing projects, assessing risks, and allocating resources (Lifson & Shaifer, 1982; Al-Harbi, 2001).

What really makes AHP effective, particularly in the oil and gas industry, is the flexibility in handling qualitative and quantitative factors. It gives a structured framework that helps decision-makers face multifaceted challenges of managing complex projects for better outcomes and improved efficiency (He et al., 2023; Podvezko, 2011). AHP supports the execution of such critical activities as evaluating contractors and resource allocation with great success in projects within this demanding sector by simplifying complex decisions (Goepel, 2013).

3.3.2.AHP Practical Application

AHP is a structured decision-making technique that consists of two major steps: design and evaluation (Ossadnik & Lange, 1999). During this step, a hierarchy is developed to organize the problem into well-defined levels and elements. The entire process begins with a clear understanding of the problem issue and incorporates the opinions and preferences of the decision makers. Since the preferences are subjective, the hierarchies established can be very different (Vasina, 2014).

The design phase has been further divided into three interdependent activities:

- **Identifying Levels and Elements**: Establishing the structure of the hierarchy with the goal at the top and criteria, sub-criteria, and alternatives at subsequent levels.
- **Defining Concepts**: Scope and meaning of each element must be clearly outlined to maintain consistency and clarity.

- **Formulating Questions**: Construction of the pairwise comparisons that will be used to drive the evaluation phase (Vargas et al., 1990).

This approach ensures that every aspect of the problem at hand is analyzed before actual evaluation is done.

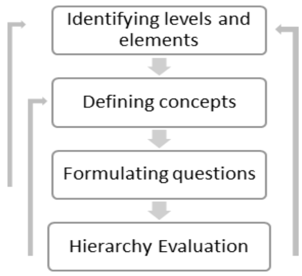

Figure 2: Correlation of AHP method's steps (Vargas et al., 1990).

During the design, the levels of the structure are described, and the elements of each level are specified. The hierarchy may be revised if any difficulty arises with the decision-makers or participants during the formulation of questions or evaluation (Vasina, 2014). During the design phase, it is dynamic because the questions in the evaluation phase give shape and define the levels and elements of the hierarchy (Podvezko, 2011).

After designing, the evaluation phase follows. Here, pairwise comparisons are used to analyze the hierarchy. Decision-makers assess each criterion by comparing elements to determine which has a greater influence on the level above (Podvezko, 2011). This process is repeated throughout the hierarchy, creating a comparison matrix. To fine-tune the analysis, the eigenvalue method calculates the relative weights of the elements. These weights are then combined to rank and prioritize the available alternatives (Zahedi, 1986).

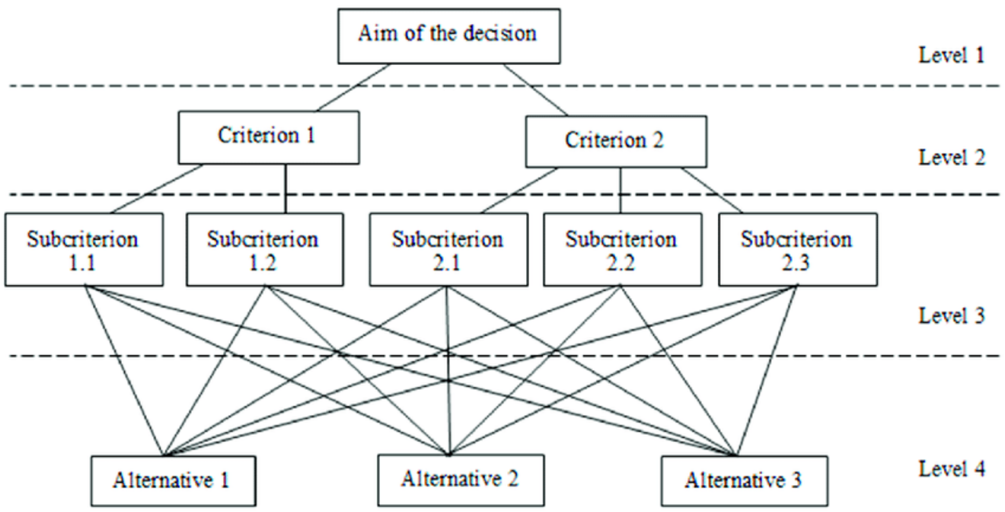

Figure 3: AHP method's Hierarchy Framework (Watrobski et al., 2016).

The AHP method is highly regarded for its ability to simplify complex systems and balance diverse objectives. It excels in analyzing both the tangible and intangible factors of a decision and assessing interdependencies between elements (Saaty, 2004). AHP ensures consistency in judgments while synthesizing all criteria into a comprehensive framework (Danesh et al., 2017). By deconstructing problems into smaller components, leveraging pairwise comparisons, and integrating qualitative and quantitative factors, AHP empowers decision-makers to effectively manage project complexities (Podvezko, 2011). After completing the pairwise comparisons, decision-makers use a standard scale of absolute numbers to quantify their judgments (Saaty, 2004; Podvezko, 2011). Based on the collected data, a reciprocal comparison matrix (A) is constructed. This matrix facilitates the computation of relative weights and priorities, which are derived using the eigenvalue method (Saaty, 2004; Poggio, 2021).

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment moderately favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extremely importance	The evidence favoring one activity over another is the highest possible order of affirmative
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of above number assigned to when compared with activity j, then j has reciprocal value when compared with i.	
Rational	Ratios arising from the scale. If consistency were to be forced by obtaining n numerical value to spin the matrix.	

Table 1: The Fundamental Scale in AHP (Dawotola et al., 2010).

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} = \begin{pmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{pmatrix}$$

Figure 4: AHP Matrix (Saaty, 2004).

To determine the weight vector w=(w1,...,wn)w = (w_1, ..., w_n)w=(w1,...,wn), the equation Aw=nwAw = nwAw=nw is solved, where n is the principal eigenvalue of the matrix, and w represents the eigenvector. This process calculates the weights corresponding to each element in the hierarchy, highlighting their relative importance (Saaty, 2004; Poggio, 2021).

Given that the pairwise comparison matrix A relies on subjective judgments, there is a risk of inconsistencies. To mitigate this, a consistency ratio (CR) is calculated to assess the matrix's reliability. A (CR) value below 0.1 is generally acceptable, ensuring credible results and strengthening the suitability of AHP for handling complex, subjective issues (K H Chua et al., 1999).

The final step involves deriving the overall weights for each hierarchy element. For hierarchies with multiple levels, the overall weight of a factor is calculated by multiplying the weights from each level. This approach ensures that the priorities accurately reflect each factor's contribution to the overarching goal at the hierarchy's top (Poggio, 2021; K H Chua et al., 1999).

The AHP method's strength lies in its combination of robustness and simplicity. Its success is rooted in several key axioms (Vargas et al., 1990):

- **Reciprocal Comparison**: If factor X is preferred over Y by a certain degree, then Y is less preferred by the reciprocal of that value.
- **Homogeneity**: Judgments are made on a bounded scale, ensuring consistency.
- **Independence**: Preferences are expressed under the assumption that criteria are independent of the alternative elements.
- **Expectations**: The hierarchy is assumed to be complete, enabling effective decision-making and comparisons.

This structured yet flexible process allows decision-makers to systematically analyze complex decisions while ensuring consistency and accuracy throughout.

The Analytical Hierarchy Process (AHP) is a structured technique used for organizing and analyzing complex decisions (Goepel, 2013). It uses mathematics and psychology to determine the importance (weights) of each criterion in decision-making and assesses the consistency of expert responses in pairwise comparisons (Poggio, 2021). Below is a detailed explanation of how the AHP method calculates, with all necessary formulas included.

- **Step 1: Construct the Pairwise Comparison Matrix**

The pairwise comparison matrix P is a square matrix P=[p_{ij}], where p_{ij} represents the relative importance of criterion i compared to criterion j.

- p_{ii}=1 (since any criterion compared to itself is of equal importance).
- $p_{ij}=\frac{1}{p_{ji}}$ (since if criterion i is more important than criterion j, then j must be less important than i)(Dawotola et al., 2010).

For example, for a decision problem with 3 criteria, the pairwise comparison matrix P will look like:

$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{12}\cdots & p_{1m} \\ p_{21} & p_{22}\cdots & p_{2m} \\ \vdots & & \vdots \\ p_{m1} & p_{m2}\cdots & p_{mm} \end{pmatrix}$$

- **Step 2: Compute the Eigenvector for Weighting Criteria**

The next step involves finding the eigenvector corresponding to the largest eigenvalue λ_{max} of the pairwise comparison matrix P. The eigenvector provides the relative weights ω_i of the criteria (Dawotola et al., 2010).

3.3.3. Weight Calculation and Consistency Check in AHP

Product of Elements in Each Row: For each row i of matrix P, compute the product of all the elements in the row:

$$\prod_{j=1}^{m} pij$$

where m is the number of criteria.

Take the m-th Root: Compute the m-th root of the product obtained for each row:

$$\omega_i = \left(\prod_{j=1}^{m} pij\right)^{1/m}$$

Normalize the Weights: Normalize the weights by dividing each ω_i by the sum of all ω_i:

$$\omega_i = \frac{w_i}{\sum_{i=1}^{m} w_i}$$

These ω_i values represent the relative importance (weights) of the criteria (Poggio, 2021).

- **Step 1: Calculate the Maximum Eigenvalue λ_{max}**

To ensure consistency, we estimate λ_{max}, the largest eigenvalue of the matrix. This is done by multiplying the pairwise comparison matrix P by the weight vector ω:

$$P \cdot \omega = \lambda_{max} \cdot \omega$$

For each row i, compute:

$$\lambda_{max}^{i} = \frac{(P \cdot \omega)_i}{\omega_i}$$

The maximum eigenvalue λ_{max} is the average of the λ_{max}^{i}'s (Poggio, 2021):

$$\lambda_{max} = \frac{\sum_{i=1}^{m} \lambda_{max}^{i}}{m}$$

- **Step 2: Consistency Index and Consistency Ratio**

To measure how consistent, the pairwise comparisons are, we compute the Consistency Index (CI) and Consistency Ratio (CR) (Franek & Kresta, 2014).

Consistency Index (CI):

The Consistency Index is calculated as:

$$CI = \frac{\lambda_{max} - m}{m - 1}$$

Where m is the number of criteria (the order of the matrix) (Franek & Kresta, 2014).

Consistency Ratio (CR):

The Consistency Ratio (CR) compares the (CI) with the Random Index (RI), which is the consistency index for a randomly filled matrix. The (RI) depends on the number of criteria mmm and can be obtained from predefined tables (Goepel, 2013).

$$CR=\frac{CI}{RI}$$

If CR<0.1, the consistency of the judgments is considered acceptable. If CR≥0., it indicates that the judgments are too inconsistent, and the pairwise comparisons need to be revised (Poggio, 2021).

The AHP method provides a systematic approach to making complex decisions by breaking them down into smaller, more manageable comparisons. The use of eigenvalues and consistency checks ensures that the criteria are weighted appropriately, and the results are consistent. The method is especially useful when dealing with subjective criteria that are hard to quantify directly (Dawotola et al., 2010).

Composite Global Importance (CGI)

The Composite Global Importance (CGI) is calculated to assess the overall importance of each criterion within the global hierarchy. The formula for CGI is as follows:

$$CGI = \frac{2\sum_{i<j} \ln a_{ij} - \ln \frac{p_i}{p_j}}{(N-1)(N-2)}$$

Where:

- aij are the pairwise comparison values,
- pi and pj are the priority weights for criteria Ci and Cj,
- N is the number of criteria.

This formula incorporates both the logarithmic differences between pairwise comparisons and the relative weights of criteria, giving a comprehensive view of the global importance of each criterion.

3.3.4. Software Tools for AHP Calculations: Features and Detailed Processes

Analytic Hierarchy Process analysis can be supported by different software tools that may enable calculations involved in matrix building, determination of eigenvalues, checks for consistency, among others. These tools will make complex decision-making processes easier; thus, a set of features will be helpful to the user in different steps of AHP, including hierarchy definition, pairwise comparison, and consistency checks (Goepel, 2018).

- **Microsoft Excel**

Those who still want manual control may use Microsoft Excel as a strong tool for performing calculations for AHP. Functions in Excel like =MMULT () for the multiplication of matrices and =GEOMEAN () to calculate the weights make manipulations with AHP matrices easy to operate. It provides a fully customizable environment for all users where one can easily perform weight determination, normalization, calculation of eigenvalue, consistency index, and computation of the consistency ratio, all according to the AHP practical application. It is excellent for small-scale analyses and flexible, yet the main principles of AHP calculations can be followed. (Siraj et al., 2015).

- **Super Decisions**

Super Decisions is a specialist software for AHP. It includes various advanced functions, such as the graphical representation of decision hierarchies and eigenvalue computations automatically. This tool addresses all the steps involved in AHP, from taking pairwise comparison inputs to their consistency checking. Its central features can be listed as: Automatic Pairwise Matrix Generation: Enables the comparison of inputs taken directly through GUI (Saaty, 2001). Calculation of Eigenvalue: Automates the process to find λ_max and performs a check on CR for inconsistency. Decision Hierarchies: Hierarchies can be built visually; hence, decisions are transparent and user-friendly (Mu & Pereyra-Rojas, 2016).

- **Expert Choice**

Expert Choice is another popular software for AHP, often used in corporate environments. It simplifies the entire process through an intuitive interface, automatically generating matrices and performing consistency checks (Buede, 1992). Each software has its own advantages depending on user needs and familiarity. AHP-OS excels in flexibility and advanced eigenvalue calculations, while Excel offers a more hands-on approach for smaller, customizable AHP models. Super Decisions and Expert Choice are ideal for those analysts who prefer automated processes and sophisticated graphical interfaces (Buede, 1992).

3.4. Transitioning from Theory to Practical Framework

3.4.1. Preparation of the pipeline project complexity (PPC) Factors

The qualitative part of this stage is, therefore, a systematic identification and categorization of the key variables that relate to PPC. The key variables were compiled in a long list through a painstaking process, which was detailed in Table 2 and highlighted various dimensions and factors contributing to complexity in pipeline projects. The review process emphasizes not only the identification of these factors but also their interrelations and potential impacts on project outcomes. This long list of variables forms the basis for further refinement and prioritization in subsequent phases of the research. This phase also looks at the bigger picture of project complexity, its application in pipeline projects, and how it shapes management practices.

This includes a general review of PPC practices, both theoretical and applied, in order to understand the objectives and challenges unique to pipeline projects. The review also combines findings from case studies and empirical results in the oil and gas industry for better lessons learned on practical implications arising out of managing complexity.

The literature review pinpoints gaps in research that exist, thus availing an opportunity to answer unresolved questions and further enhance PPC understanding. For instance, while there are numerous reviews about general project complexity, only a few studies have been conducted so far that investigate its application in large pipeline projects. This deficiency underlines the need for focused analysis capturing the sector-specific challenges. Based on this critical review process, this study develops an overall framework that identifies not only the factors of complexity but also categorizes them into meaningful dimensions. The provided dimensions give further insight into the multidimensional nature of PPC in reference to both practitioners and researchers. This step will guarantee that the study keeps the views on complexity within the particular challenges of pipeline projects while aligning with the real-world needs and contributes to the bigger discourse about project management in the oil and gas industry.

ID	Dimensions	Factors of PPC	Factors Definitions	References
A	Project & Stakeholder Management Complexities	Stakeholder diversity	The variety of stakeholders with differing roles, interests, and perspectives influencing project decisions.	Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90. Abifarin, O. (2018). An Evaluation of Success Factors for Upstream Oil & Gas Megaprojects in the Middle-East, School of Management the University of Liverpool master thesis. PMI. (2014). Navigating Complexity: A Practice Guide. Newtown Square, USA: Project Management Institute.
		Conflicts between the key project parties	Disputes or disagreements among project teams, stakeholders, or contractors impacting progress.	Cleveland, S. (2017). On Developing Project Complexity Framework. *Twenty-third Americas Journal on Information Systems*, 1, 57-80.
		Lack of team cooperation	Insufficient collaboration, coordination, or alignment among team members, departments, or contractors involved in the pipeline project.	Kian Manesh Rad, E., Sun, M., Bosche, F. (2017). Complexity for Megaprojects in the Energy Sector. *Journal of Management in Engineering*, 42, 102-125.
		Dynamic and evolving team structure	Changes in team composition, roles, or hierarchy during the project's lifecycle.	
		Cultural differences	Variations in cultural norms and practices among teams or stakeholders, affecting collaboration, negotiation, and decision-making.	Kardes, I., Ozturk, A., Cavusgil, T., Cavusgil, E. (2014). Managing global megaprojects: Complexity and risk management in oil and gas projects. *International Business Review*, 8, 604-630.
		Separate organization strategy	Different strategies or priorities among project stakeholders, contractors, or organizations, causing misalignment in project execution.	Floricel,s. Michela, J. Piperca, S.(2015). Complexity, uncertainty-reduction strategies, and project performance. *International Journal of Project Management*, 35, 24-42.
		Inadequate Use of Project Management Practices	Insufficient or improper application of essential project management principles, tools, and processes in managing pipeline projects.	Paknahad, M., Tavakkoli-Moghaddam, R., Salimi-Rad, M., Abbasi, S. (2023). Identifying required project managers' core competencies in complex product systems using project complexity assessment: A case study in Iran's oil and gas R&D projects. *Journal of Engineering*, 203, 85-101. Layth, K. (2020). Development of an integrated risk management framework for oil and gas pipeline projects. PhD thesis, Liverpool university.
		Different languages and nationalities	Communication barriers and challenges in collaboration due to multilingual and multicultural teams.	Ebtisam Mirza, M., Nadeem Ehsan, R. (2017) Quantification of Project Execution Complexity and its Effect on Performance of Infrastructure Development Projects. *Engineering Management Journal*, 29, 108-123. Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., &Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (technical, organizational and environmental) framework. *International Journal of Project Management*, 29(6), 728–739.
		Project impact of local social and political groups (stakeholders)	Influence of local communities and political entities on the project's approval, land acquisition, and construction progress.	Hare, E., Anderson, S., Shane, J., Kermanshachi, S., Dao, B. (2016). Exploring and Assessing Project Complexity. *Journal of Construction Engineering and Management*, 7, 402-415.

ID	Dimensions	Factors of PPC	Factors Definitions	References
B	Laws and Regulations Complexities	Impact of Local Institutional and Legal Control	The influence of local government institutions, regulations, and legal frameworks on the planning, execution, and operation of pipeline projects.	Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90.
		Complex Interrelatedness/Interdependence of Contract Elements	Complex dependencies between contracts (e.g., suppliers, transporters, and contractors) increasing project management challenges.	Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., &Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (technical, organizational and environmental) framework. *International Journal of Project Management*, 29(6), 728–739.
		Complex contract form and types	The variety and complexity of contracts used in pipeline projects, such as Engineering, Procurement, and Construction (EPC), Design-Build (DB), Lump Sum Turnkey (LSTK), and Operation and Maintenance (O&M) contracts	
		Impact of International Border Policy	The influence of regulations, trade agreements, and geopolitical factors on pipeline projects that cross international borders.	Ishtiaq, F., Jahanzaib, M. (2017). Impact of Project Complexity and Environmental Factors on Project Success: A Case of Oil and Gas Sector of Pakistan. *Journal of Basic & Applied Sciences*, 6, 62-79.
		Permitting and regulatory requirements	Compliance with licenses, approvals, and regulatory standards essential for project execution.	Dao, B., Kermanshachi, S., Shane, J., Anderson, S., Hare, E. (2016). Identifying and measuring project complexity. *International Journal on Sustainable Design, Engineering and Construction*, 145, 476 – 482.
C	Project Resources Management Complexities	Poor recourse allocation	Inefficient distribution or mismanagement of essential resources, including manpower, equipment, budget, and time, across the project lifecycle.	Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90.
		lack of past work experience	Limited expertise or experience in managing similar pipeline projects, increasing risks of errors or inefficiencies.	Ebtisam Mirza, M., Nadeem Ehsan, R. (2017) Quantification of Project Execution Complexity and its Effect on Performance of Infrastructure Development Projects. *Engineering Management Journal*, 29, 108-123. .
		Poor direct field labor management	Ineffective oversight and coordination of on-site labor, resulting in reduced productivity, inefficiencies, and project delays.	Hare, E., Anderson, S., Shane, J., Kermanshachi, S., Dao, B. (2016). Exploring and Assessing Project Complexity. *Journal of Construction Engineering and Management*, 7, 402-415.
D	Market Complexities	Demand Fluctuations	Variations in oil and gas demand influencing project timelines, investment, and operational scalability.	International Energy Agency. (2023). Oil Market Report: March 2024. Retrieved from https://www.iea.org/reports/oil-market-report-march-2024.
		Market Competition	Rivalry among oil and gas companies influencing project costs, timelines, and access to resources or markets.	Manesh Rad, E., Sun, M., Bosch, F. (2022). Complexity for Megaprojects in the Energy Sector, *Engineering management*, 6, 75-99.

ID	Dimensions	Factors of PPC	Factors Definitions	References
E	Risks and Uncertainties Complexities	Ineffective future Forecasting	The inability to accurately predict and plan for future market trends, risks, operational challenges, and resource needs during pipeline project planning and execution.	Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90.
				Pitsis, A., Clegg, S., Freeder, D., Sankaran, S., Burdon, S. (2018) Megaprojects redefined- complexity versus cost- and social imperatives in oil and gas projects. *Journal of Energy*, 29, 323-360.
		Ambiguity of project features and phases	Unclear project specifications or uncertain timelines leading to inefficiencies and potential rework.	PMI. (2014). Navigating Complexity: A Practice Guide. Newtown Square, USA: Project Management Institute.
		Data limitation on TPD (Theft, Pilferage, and Damage)	Lack of accurate tracking mechanisms for losses, impacting financial estimates and operational integrity.	Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2021). Analysing Delay Impact from Potential Risk Factors on Project De livery of Oil and Gas Pipeline: A Case Study in IRAQ. *Journal of Engineering and Technology*, 4, 123-156.
		Political and economic instability	Uncertainty in political or economic conditions disrupting project continuity.	Abifarin, O. (2018). An Evaluation of Success Factors for Upstream Oil & Gas Megaprojects in the Middle-East, School of Management the University of Liverpool master thesis.
		Security and vandalism	Threats to pipeline infrastructure from theft, sabotage, or vandalism requiring enhanced security measures.	
		Probability of Cost overrun	Likelihood of exceeding the budget due to unforeseen circumstances such as material price hikes, labor shortages, or delays.	Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2021). Analysing Delay Impact from Potential Risk Factors on Project De livery of Oil and Gas Pipeline: A Case Study in IRAQ. *Journal of Engineering and Technology*, 4, 123-156.
				Kardes, I., Ozturk, A., Cavusgil, T., Cavusgil, E. (2014). Managing global megaprojects: Complexity and risk management in oil and gas projects. *International Business Review*, 8, 604-630.
		Probability of Natural hazards	Risk of pipeline damage or delays caused by natural disasters like earthquakes, floods, or severe weather.	Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2021). Analysing Delay Impact from Potential Risk Factors on Project De livery of Oil and Gas Pipeline: A Case Study in IRAQ. *Journal of Engineering and Technology*, 4, 123-156.
F	Environmenta l Complexities	Highly regulated environment	Strict adherence to local, national, and international regulations governing pipeline construction, operation, and environmental impact.	Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90.
				PMI. (2014). Navigating Complexity: A Practice Guide. Newtown Square, USA: Project Management Institute.
		Implementation of Sustainability Requirements (Reducing Emissions During Construction)	Integrating eco-friendly practices and technologies during pipeline construction to minimize greenhouse gas (GHG) emissions and environmental impact.	Layth, K. (2020). Development of an integrated risk management framework for oil and gas pipeline projects. PhD thesis, Liverpool university.
				Levenbach, S., & Leong, W. (2023). Building a national network of composite pipes to reduce greenhouse gas emissions. *Federation of American Scientists*, 3, 855-870.
		Implementation of Health, safety, security, and environment(HS SE)	Ensuring the safety and well-being of workers, protecting infrastructure from threats, and minimizing environmental risks throughout the project lifecycle.	Ebtisam Mirza, M., Nadeem Ehsan, R. (2017) Quantification of Project Execution Complexity and its Effect on Performance of Infrastructure Development Projects. *Engineering Management Journal*, 29, 108-123.

ID	Dimensions	Factors of PPC	Factors Definitions	References
G	Technical and Engineering Complexities	Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservior properties)	Insufficient planning and optimization during the front-end engineering design (FEED) phase, particularly in selecting and designing the pipeline route and designing pipelines to accommodate specific properties of transported oil and gas, such as viscosity, temperature, and pressure.	Ziadat, W., Kirkham, R., Gardiner, P. (2017). On the Edge of Chaos: Complexity Offering Value Expectations on O&G Projects. *Society of Petroleum Engineers*, 13, 72-83.
				Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2021). Analysing Delay Impact from Potential Risk Factors on Project De livery of Oil and Gas Pipeline: A Case Study in IRAQ. *Journal of Engineering and Technology*, 4, 123-156.
				Ziadat, W., Kirkham, R., Gardiner, P. (2017). On the Edge of Chaos: Complexity Offering Value Expectations on O&G Projects. *Society of Petroleum Engineers*, 13, 72-83.
				Shafiee, M., Hakim, A., & Dahlan, K. Z. (2019). Route optimization in pipeline network design: A multi-objective approach. *Journal of Pipeline Engineering*, 18(2), 123–135.
		Change in production processes(adapting to different types of crude oil and gases)	Adapting pipelines to handle varying types and grades of crude oil and natural gases during operations.	Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., &Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (technical, organizational and environmental) framework. *International Journal of Project Management*, 29(6), 728–739.
				Khan, M. A., & Hamid, M. (2020). Adaptation strategies for pipelines transporting varying crude oil and gas types. *Journal of Pipeline Engineering and Technology*, 32(3), 145–160.
		Supply chain logistics(specialized equipment and cross-border logistics)	Managing the transportation of specialized equipment and coordinating across international borders for timely delivery.	Nzeda, B., Schamp, J., Schmitt, T. (2020). Development of Well Complexity Index to Improve Risk and Cost Assessments of Oil and Gas Wells. *Drilling Journal*, 5, 20-36.
				Smith, J., & Lee, A. (2020). Cross-border logistics and equipment challenges in infrastructure projects. *Journal of Logistics and Supply Chain Management*, 12(3), 145–160.
		Challenges posed by diverse terrains (Surface and subsea geography)	"Rugged terrain, such as mountains, steep slopes, or uneven ground, complicates pipeline construction and increases the risk of instability or landslides.	Kraidi, L., Shah, R., Matipa, W., Borthwick, F. (2021). Analysing Delay Impact from Potential Risk Factors on Project De livery of Oil and Gas Pipeline: A Case Study in IRAQ. *Journal of Engineering and Technology*, 4, 123-156.
				Ziadat, W., Kirkham, R., Gardiner, P. (2017). On the Edge of Chaos: Complexity Offering Value Expectations on O&G Projects. *Society of Petroleum Engineers*, 13, 72-83.
				Ishtiaq, F., Jahanzaib, M. (2017). Impact of Project Complexity and Environmental Factors on Project Success: A Case of Oil and Gas Sector of Pakistan. *Journal of Basic & Applied Sciences*, 6, 62-79.
		Production shortfalls caused by blockages and damage of pipelines	Managing and mitigating losses caused by pipeline blockages, leaks, or damage.	Kian Manesh Rad, E., Sun, M., Bosche, F. (2017). Complexity for Megaprojects in the Energy Sector. *Journal of Management in Engineering*, 42, 102-125.
				Bukkaraju, S. K., Osorio, N. F., Annadorai, K. M., Garduño, J. L., & Golden, N. K. (2016). Practical guidelines for the diagnosis and remediation of pipeline blockages. *Proceedings of the Offshore Technology*, 8, 51-73.
		Vast scope or numerous interconnected tasks(Size or number of project activities)	Handling the complexity and scale of tasks in large pipeline projects, including construction, testing, and commissioning.	Ebtisam Mirza, M., Nadeem Ehsan, R. (2017) Quantification of Project Execution Complexity and its Effect on Performance of Infrastructure Development Projects. *Engineering Management Journal*, 29, 108-123.
		Schedule Complexity (challenges of maintaining critical paths)	Ensuring project milestones are met despite delays, dependencies, or resource constraints.	

ID	Dimensions	Factors of PPC	Factors Definitions	References
G	Technical and Engineering Complexities	Poor welding and joint integrity	Inadequate welding practices or substandard joint quality, compromising the structural and operational reliability of the pipeline.	Taylor, B. (2019). Pipeline Geo-Hazard Management: Identification, Assessment, and Mitigation of Risks. *Terracon Journal*, 6, 32-60.
		Crossing sensitive areas	Navigating construction through environmentally or socially sensitive zones while minimizing disruption.	
		Real-Time Data Analysis Challenges	Difficulties in implementing, managing, and utilizing real-time data analytics systems for monitoring and decision-making during pipeline project execution and operations.	Hartmann, D. (2023). Real-time digital twins for online prediction and optimization of dynamic industrial assets. Retrieved from https://arxiv.org/abs/2311.14691.
				Denni-Fiberesima, D., Abdul Rani, N. (2011). An evaluation of critical success factors in oil and gas project portfolio in Nigeria. *Journals of Project management*, 15, 67-90.
				PMI. (2014). Navigating Complexity: A Practice Guide. Newtown Square, USA: Project Management Institute.
		The Availability and reliability of geospatial data in remote terrains	Accessing accurate mapping and location data in remote areas for proper pipeline placement and monitoring.	Kian Manesh Rad, E., Sun, M., Bosche, F. (2017). Complexity for Megaprojects in the Energy Sector. *Journal of Management in Engineering*, 42, 102-125.
				Geo-awesome Team. (n.d.). The critical role of ground-based data in regression model accuracy for remote sensing applications. Geo-awesome. Retrieved from https://geoawesome.com/eo-hub/the-critical-role-of-ground-based-data-in-regression-model-accuracy-for-remote-sensing-applications
		Design changes and overlapping of process	Managing unexpected design revisions and overlapping construction activities to avoid delays and cost overruns.	Taghi Zadeh, M., Dehghan, R., Ruwanpura, J., Jergeas, G. (2015) Factors Influencing Design Changes in Oil and Gas Projects. *International Journal of Construction Engineering and Management*, 1, 306-340.
				Mossolly, M. (2013). Managing Technological Complexities in Oil & Gas EPC Projects. *SPE international Journal*, 7, 13-22.

Table 2: Long list of pipe line projects' complexity factors by author.

3.4.2. Apply Delphi in practice

- **Expert Panel Formation**

Selection to the expert panel was done with a lot of care for diversity, expertise, and credibility. Besides their professional experience, the academic background of each panelist was put into consideration to ensure that they are competent in providing meaningful and reliable insights. The balance between a wide-angle view and specialized knowledge finds reflection in the composition of this panel, which is pledged to high standards of evaluation and analysis. The credentials and roles of the expert panel that have been selected are shown in the following table:

Panel	Role	Year of professional Experience (>10)	Advanced degrees in engineering fields	familiar with advanced project management techniques
Expert 1	Project Director	25	Yes	Yes
Expert 2	Operation manager	20	Yes	Yes
Expert 3	Site manager	25	Yes	Yes
Expert 4	Planing and control manager	27	Yes	Yes
Expert 4	Chairman	40	Yes	Yes
Expert 6	Project Manager	10	Yes	Yes
Expert 7	Operation manager	22	Yes	Yes

Table 3: The credentials and roles of the expert panel.

Each member of the panel had over 10 years of experience in pipeline projects and was familiar with the Delphi method, project management techniques, and the specific complexities of oil and gas infrastructure. All experts also had advanced degrees in engineering fields, further enhancing the panel's technical and managerial competence.

- **Round 1: Identification of New Factors**

During the first round of the Delphi process, experts were interviewed to provide their insights into the critical factors that contribute to pipeline oil and gas project complexities. In this qualitative phase, experts reviewed the initial long list of factors derived from the literature and suggested additional factors based on their experience and expertise. These interviews led to the addition of a number of new factors, including the following:

- Challenges in the availability of local resources for the construction phase
- Lack of an incentives program to enhance productivity
- Challenges in the interface of pipeline and the compressor stations
- Inspection of welding and QA/QC problems

These factors were incorporated into the refined long list to make it even more complete and representative for further evaluation.

- **Round 2: Scoring and Evaluation of Factors**

In Round 2, the list of factors was refined from the literature and new ones identified in Round 1, and an Excel file was prepared and sent to the expert panel for quantitative evaluation.

Scoring System: The experts were required to rank each factor based on a 1 to 5 Likert scale, in which:

Scale	Complexity Level
1	Very Low Complexity
2	Low Complexity
3	Moderate Complexity
4	High Complexity
5	Very High Complexity (Optional)

Table 4: Ranking Scale and Complexity level.

Scores from all selected experts were collected and the following key statistical measures of interest were calculated:

- Mean Score: It expresses the overall importance of each factor.
- Standard Deviation: To measure the variability in expert responses.

This step gave the preliminary ranking of the factors and showed the inconsistencies or scattering in the scoring by the experts.

- **Consistency Check and Refinement**

A third round was therefore conducted to further strengthen the consistency and reliability of the results. This round aims to refine the expert responses with summarized feedback from Round 2. Aggregated results of Round 2 were prepared for presenting to the experts of this round, including:

The average score for each factor and Statistical measures such as standard deviation, indicating the level of agreement. This feed back allowed experts to compare their initial responses with those of the group consensus.

- **Final Screening Criteria**: The following quantitative filters were used to shortlist the factors:
- **Average Score**: Factors scoring more than 3 on an average were retained since those were moderate to high on importance.
- **Coefficient of Variation**: The CV, measured by the ratio between the standard deviation and the mean, was used as the indicator of consistency. Consistency was considered strong in items with a CV score of less than 0.3.
- **Combined Filtering**: Only factors that meet both criteria-mean above 3, CV less than 0.3-have been retained for the final shortlist to ensure rigor.

- **Outcome of Round 3**

The Delphi process yielded a refined, prioritized shortlist of factors that drive pipeline project complexity. In the table below, critical factors in influencing pipeline project performance have been established by expert consensus.

No.	Criteria List	Average Score	Accepted Avrage>3	Standard Deviation	Coefficient of Variation(CV)	Accepted Coefficient of Variation(CV)<0,3	Combine Both Criteria (Average Score > 3 and CV < 0.3)
1	Stakeholder diversity	3,67	Accepted	0,745	0,203	Accepted	Accepted Factor
2	Impact of Local Institutional and Legal Control	3,33	Accepted	0,471	0,141	Accepted	Accepted Factor
3	Security and vandalism	3,50	Accepted	0,957	0,274	Accepted	Accepted Factor
4	Permitting and regulatory requirements	3,50	Accepted	0,957	0,274	Accepted	Accepted Factor
5	Poor recourse allocation	3,17	Accepted	0,373	0,118	Accepted	Accepted Factor
6	Real-Time Data Analysis Challenges	3,33	Accepted	0,471	0,141	Accepted	Accepted Factor
7	Ambiguity of project features and phases	3,33	Accepted	0,471	0,141	Accepted	Accepted Factor
8	Probability of Cost overrun	3,50	Accepted	0,500	0,143	Accepted	Accepted Factor
9	Highly regulated environment	3,17	Accepted	0,898	0,283	Accepted	Accepted Factor
10	Implementation of Health, safety, security, and environment(HSSE)	3,17	Accepted	0,687	0,217	Accepted	Accepted Factor
11	Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservior properties)	3,67	Accepted	0,745	0,203	Accepted	Accepted Factor
12	Supply chain logistics(specialized equipment and cross-border logistics)	3,33	Accepted	0,745	0,224	Accepted	Accepted Factor
13	Production shortfalls caused by blockages and damage of pipelines	3,17	Accepted	0,373	0,118	Accepted	Accepted Factor
14	Implementation of Sustainability Requirements (Reducing Emissions During Construction)	3,17	Accepted	0,373	0,118	Accepted	Accepted Factor
15	lack of past work experience	3,33	Accepted	0,471	0,141	Accepted	Accepted Factor
16	Conflicts between the key project parties	3,50	Accepted	0,764	0,218	Accepted	Accepted Factor
17	Inadequate Use of Project Management Practices	3,83	Accepted	0,373	0,097	Accepted	Accepted Factor
18	Complex contract form and types	3,00	Accepted	1,000	0,333	Accepted	Accepted Factor
19	Poor welding and joint integrity	4,00	Accepted	0,000	0,000	Accepted	Accepted Factor
20	Crossing sensitive areas	3,83	Accepted	0,373	0,097	Accepted	Accepted Factor
21	Challenges in the interface of pipeline and the compressor stations	3,83	Accepted	0,373	0,097	Accepted	Accepted Factor
22	Variants of the path and length of right of way	3,83	Accepted	0,373	0,097	Accepted	Accepted Factor
23	Challenges in land acquisition	4,17	Accepted	0,687	0,165	Accepted	Accepted Factor

Table 5: critical factors in influencing pipeline project performance by expert consensus

3.4.3. Preparation of the AHP Questionnaire and Expert Evaluation

As part of the hierarchical process, the evaluation began with the development of a clear structure for prioritizing the complexity dimensions. This structured approach was conducted first to ensure an organized and methodical decision-making process. To gather input for this evaluation, a questionnaire was developed using a ranking scale of 1, 3, and 5, where:

1 indicated Less Complexity,

3 indicated Medium Complexity, and

5 indicated High Complexity.

The questionnaire was distributed to a panel of subject-matter experts with significant experience in pipeline project management. The experts systematically evaluated the relative importance of each dimension through pairwise comparisons, and their responses were consolidated to form the values in the pairwise comparison matrix. Once the hierarchy was established, we proceeded with the pairwise comparison matrix for the dimensions. The final shortlist of dimensions, identified through the Delphi process, served as the input for this matrix. Pairwise comparisons were performed to evaluate the relative importance of each dimension against the others in a systematic manner. This step was critical in determining the priority vectors (weights) for each dimension.

By normalizing the pairwise comparison matrix and calculating row averages, we derived the relative importance of each dimension. This structured approach ensures that the broader complexity dimensions are prioritized first, creating a solid foundation for analyzing the specific factors within each dimension in subsequent steps. The AHP (Analytic Hierarchy Process) table below presents the results, including pairwise comparisons, normalized values, priority vectors, rankings, and consistency validation metrics. This method ensures the reliability of the results while establishing a clear and consistent hierarchy of dimensions influencing pipeline project complexity.

ID	Dimensions	Factors of PPC	Factors Definitions	Refrence
A	Project & Stakeholder Management Complexities	Stakeholder diversity	The variety of stakeholders with differing roles, interests, and perspectives influencing project decisions.	Literature Review
		Conflicts between the key project parties	Disputes or disagreements among project teams, stakeholders, or contractors impacting progress.	Literature Review
		Inadequate Use of Project Management Practices	Insufficient or improper application of essential project management principles, tools, and processes in managing pipeline projects.	Literature Review
B	Laws and Regulations Complexities	Impact of Local Institutional and Legal Control	The influence of local government institutions, regulations, and legal frameworks on the planning, execution, and operation of pipeline projects.	Literature Review
		Permitting and regulatory requirements	Compliance with licenses, approvals, and regulatory standards essential for project execution.	Literature Review
		Complex contract form and types	The variety and complexity of contracts used in pipeline projects, such as Engineering, Procurement, and Construction (EPC), Design-Build (DB), Lump Sum Turnkey (LSTK), and Operation and Maintenance (O&M) contracts	Literature Review
C	Risks and Uncertainties Complexities	Security and vandalism	Threats to pipeline infrastructure from theft, sabotage, or vandalism requiring enhanced security measures.	Literature Review
		Ambiguity of project features and phases	Unclear project specifications or uncertain timelines leading to inefficiencies and potential rework.	Literature Review
		Probability of Cost overrun	Probability of Cost overrun	Literature Review
D	Technical and Engineering Complexities	Real-Time Data Analysis Challenges	Difficulties in implementing, managing, and utilizing real-time data analytics systems for monitoring and decision-making during pipeline project execution and operations.	Literature Review
		Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservior properties)	Insufficient planning and optimization during the front-end engineering design (FEED) phase, particularly in selecting and designing the pipeline route and designing pipelines to accommodate specific properties of transported oil and gas, such as viscosity, temperature, and pressure.	Literature Review
		Supply chain logistics(specialized equipment and cross-border logistics)	Managing the transportation of specialized equipment and coordinating across international borders for timely delivery.	Literature Review
		Production shortfalls caused by blockages and damage of pipelines	Managing and mitigating losses caused by pipeline blockages, leaks, or damage.	Literature Review
		Poor welding and joint integrity	Inadequate welding practices or substandard joint quality, compromising the structural and operational reliability of the pipeline.	Literature Review
		Crossing sensitive areas	Navigating construction through environmentally or socially sensitive zones while minimizing disruption.	Literature Review
		Challenges in the interface of pipeline and the compressor stations	Challenges in the connection point where compressors maintain pressure and flow.The pipeline-compressor interface faces challenges like pressure management, design compatibility, and safety risks.	Expert suggestion
		Variants of the path and length of right of way	Variations in the pipeline route and length of the right of way (ROW) are influenced by environmental, technical, regulatory, and social factors that determine the feasibility and efficiency of the pipeline project.	Expert suggestion
		Challenges in land acquisition	The process of obtaining legal rights to use land for pipeline construction often involves negotiations with landowners, governments, and communities, presenting a variety of challenges.	Expert suggestion
E	Environmental Complexities	Implementation of Health, safety, security, and environment(HSSE)	Ensuring the safety and well-being of workers, protecting infrastructure from threats, and minimizing environmental risks throughout the project lifecycle.	Literature Review
		Implementation of Sustainability Requirements (Reducing Emissions During Construction)	Integrating eco-friendly practices and technologies during pipeline construction to minimize greenhouse gas (GHG) emissions and environmental impact.	Literature Review
		Highly regulated environment	Strict adherence to local, national, and international regulations governing pipeline construction, operation, and environmental impact.	Literature Review
F	Project ResourcesManagement Complexities	lack of past work experience	Limited expertise or experience in managing similar pipeline projects, increasing risks of errors or inefficiencies.	Literature Review
		Poor recourse allocation	Inefficient distribution or mismanagement of essential resources, including manpower, equipment, budget, and time, across the project lifecycle.	Literature Review

Table 6: AHP table, final short list of complexity factors.

ID	Dimentions	Technical and Engineering Complexities	Risks and Uncertainties Complexities	Project & Stakeholder Management Complexities	Environmental Complexities	Project ResourcesManagement Complexities	Laws and Regulations Complexities	priority vector (row averages of the normalized matrix)		Weighted Su m	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR<0,1	CR <10%
1	Technical and Engineering Complexities	0,273	0,345	0,213	0,190	0,382	0,332	W1	0,289	3,40	11,76	6,62	6,00	0,12	1,24	0,0993	9,93%
2	Risks and Uncertainties Complexities	0,116	0,146	0,231	0,162	0,120	0,151	W2	0,154	0,96	6,20						
3	Project & Stakeholder Management Complexities	0,186	0,091	0,144	0,162	0,140	0,129	W3	0,142	0,78	5,47						
4	Environmental Complexities	0,233	0,146	0,144	0,162	0,120	0,129	W4	0,156	0,91	5,85						
5	Project ResourcesManagement Complexities	0,086	0,146	0,123	0,162	0,120	0,129	W5	0,128	0,66	5,17						
6	Laws and Regulations Complexities	0,107	0,125	0,144	0,162	0,120	0,129	W6	0,131	0,69	5,24						

Table 7: Dimensions for complexity factors.

- **Key Components of the Table**

Six critical dimensions were evaluated:

  - Technical and Engineering Complexities
  - Risks and Uncertainties Complexities
  - Project & Stakeholder Management Complexities
  - Environmental Complexities
  - Project Resources Management Complexities
  - Laws and Regulations Complexities

- **Pairwise Comparison:**

Each dimension was compared against the others, and the values in the matrix reflect their relative importance.

- **Priority Vector:**

The priority vector represents the row averages of the normalized matrix, which quantifies the relative weight (importance) of each dimension.

- **Ranking:**

Based on the priority vector, the dimensions were ranked from the most to the least significant.

- **Weighted Sum and Eigenvalue (λ max):**

The weighted sum for each dimension and the largest eigenvalue (λ max) were calculated to validate the consistency of the pairwise comparisons.

- **Consistency Index (CI) and Ratio (CR):**

The Consistency Index and the Consistency Ratio ensure the judgments are reliable.

A CR value of 0.0993, 9.93%, will indicate that comparisons are consistent, since this is below the threshold of 10%.

3.4.4. Preparation of Questionnaire and Pairwise Comparison Matrix for Factors

In this regard, in order to evaluate factors in each dimension, a ranking scale of 1, 3, and 5 was used in a self-designed questionnaire similar to that for dimensions. Then the same questionnaires were forwarded to the same experts who were participated in the evaluation of dimension. Experts provided pairwise comparisons between factors under each particular dimension based on their experiences and judgment. We then employed data gathered in order to obtain the pairwise comparison matrix of factors. As with the dimension assessment, we have normalized the matrix; after calculating priority vectors - weights and performing consistency judgement consistency, by using Consistency Index, CI, and Consistency Ratio, CR, we employed CGI for the integration at a factor level with previous calculations made at a dimension level regarding the weights. The global weight for each factor is obtained by multiplying its local weight obtained from the factor-level AHP by the weight of the parent dimension as derived from the dimension-level AHP results.

PPC ID	Factors	Implementation of Health, safety, security, and environment(HSSE)	Implementation of Sustainability Requirements (Reducing Emissions During Construction)	Highly regulated environment	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR	CR < 10%	CGI
1	Implementation of Health, safety, security, and environment(HSSE)	0,4	0,4	0,4	W1	0,383	1,37	3,57							0,0597
2	Implementation of Sustainability Requirements (Reducing Emissions During Construction)	0,4	0,4	0,3	W2	0,350	1,12	3,20	3,08	3,00	0,04	0,58	0,07	7%	0,0546
3	Highly regulated environment	0,2	0,3	0,3	W3	0,267	0,66	2,47							0,0416

Table 8: Environmental complexity Factors.

PPC ID	Factors	Impact of Local Institutional and Legal Control	Permitting and regulatory requirements	Complex contract form and types	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR	CR < 10%	CGI
1	Impact of Local Institutional and Legal Control	0,4	0,4	0,4	W1	0,353	1,13	3,20	3,02	3,00	0,01	0,58	0,02	2%	0,0463
2	Permitting and regulatory requirements	0,4	0,4	0,4	W2	0,353	1,13	3,20							0,0463
3	Complex contract form and types	0,3	0,3	0,3	W3	0,294	0,78	2,67							0,0385

Table 9: Laws and Regulations Complexity Factors.

PPC ID	Factors	Stakeholder diversity	Conflicts between the key project parties	Inadequate Use of Project Management Practices	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage max λ	n	CI	RI	CR	CR < 10%	CGI
1	Stakeholder diversity	0,3	0,4	0,3	W1	0,332	1,00	3,00							0,0471
2	Conflicts between the key project parties	0,3	0,4	0,4	W2	0,375	1,29	3,44	3,05	3,00	0,02	0,58	0,04	3,90%	0,0532
3	Inadequate Use of Project Management Practices	0,3	0,3	0,3	W3	0,294	0,79	2,69							0,0417

Table 10: Project & Stakeholder Management Complexity Factors.

ID	Factors	lack of past work experience	Poor recourse allocation	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR	CR < 10%	CGI
	lack of past work experience	0,6	0,6	W1	0,591	1,44	2,44	2,07	2,00	0,07	0,00	NO NEED	NO NEED	0,0754
	Poor recourse allocation	0,4	0,4	W2	0,409	0,69	1,69							0,0523

Table 11: Project Resources Management Complexity Factors.

PPC ID	Factors	Security and vandalism	Probability of Cost overrun	Ambiguity of project features and phases	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR	CR < 10%	CGI
1	Security and vandalism	0,3	0,4	0,3	W1	0,331	0,99	3,00	3,07	3,00	0,03	0,58	0,06	5,95%	0,0511
2	Probability of Cost overrun	0,3	0,4	0,4	W2	0,384	1,37	3,57							0,0593
3	Ambiguity of project features and phases	0,3	0,2	0,3	W3	0,285	0,75	2,64							0,0440

Table 12: Risks and Uncertainties Complexity Factors.

PPC ID	Factors	Real-Time Data Analysis Challenges	Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and	Supply chain logistics(specialized equipment and cross-border logistics)	Production shortfalls caused by blockages and damage of pipelines	Poor welding and joint integrity	Crossing sensitive areas	Challenges in the interface of pipeline and the compressor stations	Variants of the path and length of right of way	Challenges in land acquisition	priority vector (row averages of the normalized matrix)		Weighted Sum	Calculate the Largest Eigenvalue (λmax)	Avrage (λmax)	n	CI	RI	CR	CR < 10%	CGI
1	Real-Time Data Analysis Challenges	0,11	0,13	0,11	0,10	0,08	0,11	0,10	0,08	0,10	W1	0,104	0,97	9,31	10,07	9,00	0,13	1,45	0,09	9,23%	0,0302
2	Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservior properties)	0,11	0,13	0,25	0,10	0,12	0,13	0,10	0,08	0,13	W2	0,129	1,47	11,44							0,0372
3	Supply chain logistics(specialized equipment and cross-border logistics)	0,11	0,06	0,11	0,31	0,16	0,11	0,10	0,08	0,10	W3	0,127	1,52	11,97							0,0366
4	Production shortfalls caused by blockages and damage of pipelines	0,09	0,11	0,03	0,09	0,14	0,11	0,10	0,08	0,10	W4	0,096	0,84	8,78							0,0277
5	Poor welding and joint integrity	0,11	0,09	0,06	0,05	0,25	0,22	0,12	0,12	0,10	W5	0,126	1,46	11,62							0,0364
6	Crossing sensitive areas	0,11	0,11	0,11	0,09	0,04	0,11	0,25	0,18	0,10	W6	0,122	1,35	11,02							0,0353
7	Challenges in the interface of pipeline and the compressor stations	0,11	0,13	0,11	0,09	0,07	0,04	0,10	0,21	0,13	W7	0,110	1,11	10,04							0,0318
8	Variants of the path and length of right of way	0,11	0,13	0,11	0,09	0,06	0,05	0,04	0,08	0,13	W8	0,089	0,70	7,86							0,0257
9	Challenges in land acquisition	0,11	0,11	0,11	0,09	0,08	0,11	0,08	0,07	0,10	W9	0,097	0,83	8,59							0,0279

Table 13: Technical and Engineering Complexity Factors.

Chapter Four: Discussion

These two charts represent the results of using the Delphi method in combination with the Analytic Hierarchy Process to evaluate and prioritize complexities in oil and gas pipeline projects.

The first chart represents in detail the relative weights assigned to six major dimensions of project complexity. These are the broad categories influencing project management and performance, in order of their impact.

The second chart gives further elaboration with the breakdown of each contributing factor in every dimension, therefore giving specific elements adding complexity to a particular area of challenge.

These two charts provide results that are both hierarchical and prioritized; they can help decision-makers locate the most critical challenges. The structured approach given is bound to provide insight useful in underpinning effective management strategies for tackling such complexities in oil and gas pipeline projects.

4.1. Analysis of Dimensions and Weights

The dimension's table ranks six primary complexity dimensions and their cumulative weights, which highlight their contribution to overall pipeline project complexity. Below is a breakdown and detailed analysis:

Dimentions	Weights	Cumulative	Rank
Technical and Engineering Complexities	28,89%	28,89%	1
Environmental Complexities	15,58%	44,47%	2
Risks and Uncertainties Complexities	15,44%	59,91%	3
Project & Stakeholder Management Complexities	14,21%	74,12%	4
Laws and Regulations Complexities	13,11%	87,23%	5
Project ResourcesManagement Complexities	12,77%	100,00%	6

Table 14. Dimensions Weights.

4.1.1. Detailed Insights

- The highest values are contributed by Technical and Engineering Complexities at 28.89%, accounting for almost one-third of the total weight, thus indicating the high importance of technical feasibility, engineering accuracy, and specialized expertise.
- The second and third places go to Environmental Complexities 15.58% and Risks and Uncertainties 15.44%, showing the importance of managing impacts on the environment and properly addressing project risks.
- Stakeholder Management (14.21%) and Laws and Regulations (13.11%) underscore managerial and regulatory challenges as important, though less dominant, factors.

- Project Resource Management has the lowest weight of 12.77%; it therefore still reflects key challenges in the management of workforce, equipment, and materials.

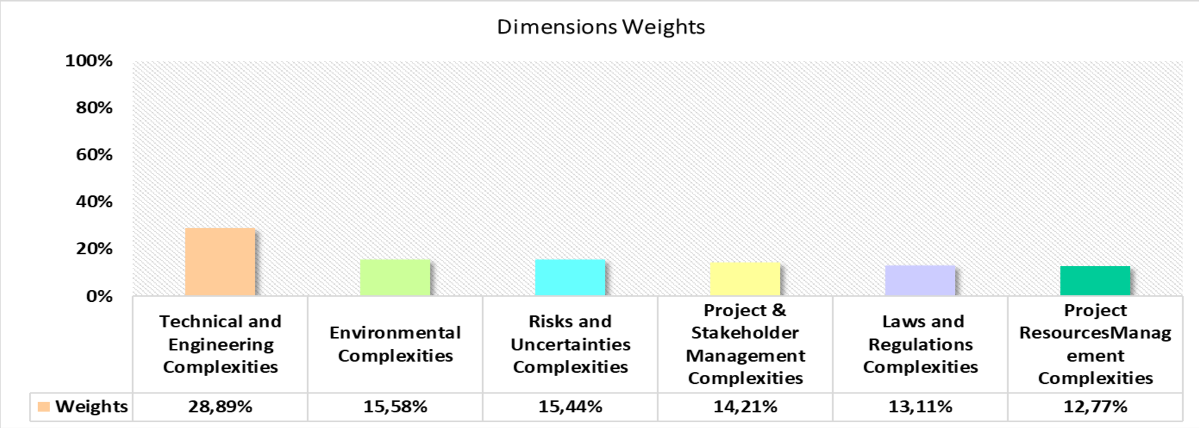

Chart 2. Dimensions Weights.

4.2. Analysis of Factors Weights

4.2.1. Technical and Engineering Complexities (28.89%)

These two graphs summarize the integrated findings from the Delphi method and AHP for analyzing priorities of complexities in oil and gas pipeline projects.

The first chart illustrates the relative importance of the six major dimensions of project complexity in order of their influence on project outcomes.

The second chart breaks down the factors that contribute to each dimension, further specifying what particular elements drive the complexity.

Together, these results form a hierarchical and prioritized framework to support decision-makers in identifying and addressing the most critical challenges with respect to effective pipeline project management.

Dimensions	Factors	Weights	Avrage	Cumulative	Rank
Project ResourcesManagement Complexities	lack of past work experience	7,54%	4,35%	7,54%	1
Environmental Complexities	Implementation of Health, safety, security, and environment(HSSE)	5,97%	4,35%	13,51%	2
Risks and Uncertainties Complexities	Probability of Cost overrun	5,93%	4,35%	19,44%	3
Environmental Complexities	Implementation of Sustainability Requirements (Reducing Emissions During Construction)	5,46%	4,35%	24,90%	4
Project & Stakeholder Management Complexities	Conflicts between the key project parties	5,32%	4,35%	30,22%	5
Project ResourcesManagement Complexities	Poor recourse allocation	5,23%	4,35%	35,45%	6
Risks and Uncertainties Complexities	Security and vandalism	5,11%	4,35%	40,55%	7
Project & Stakeholder Management Complexities	Stakeholder diversity	4,71%	4,35%	45,27%	8
Laws and Regulations Complexities	Impact of Local Institutional and Legal Control	4,63%	4,35%	49,90%	9
Laws and Regulations Complexities	Permitting and regulatory requirements	4,63%	4,35%	54,52%	10
Risks and Uncertainties Complexities	Ambiguity of project features and phases	4,40%	4,35%	58,92%	11
Project & Stakeholder Management Complexities	Inadequate Use of Project Management Practices	4,17%	4,35%	63,10%	12
Environmental Complexities	Highly regulated environment	4,16%	4,35%	67,26%	13
Laws and Regulations Complexities	Complex contract form and types	3,85%	4,35%	71,11%	14
Technical and Engineering Complexities	Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and reservior properties)	3,72%	4,35%	74,83%	15
Technical and Engineering Complexities	Supply chain logistics(specialized equipment and cross-border logistics)	3,66%	4,35%	78,50%	16
Technical and Engineering Complexities	Poor welding and joint integrity	3,64%	4,35%	82,13%	17
Technical and Engineering Complexities	Crossing sensitive areas	3,53%	4,35%	85,66%	18
Technical and Engineering Complexities	Challenges in the interface of pipeline and the compressor stations	3,18%	4,35%	88,84%	19
Technical and Engineering Complexities	Real-Time Data Analysis Challenges	3,02%	4,35%	91,86%	20
Technical and Engineering Complexities	Challenges in land acquisition	2,79%	4,35%	94,66%	21
Technical and Engineering Complexities	Production shortfalls caused by blockages and damage of pipelines	2,77%	4,35%	97,43%	22
Technical and Engineering Complexities	Variants of the path and length of right of way	2,57%	4,35%	100%	23

Table 15. Factors Weights.

The primary technical challenges related to pipeline project complexity include the following:

- **Challenges in Project FEED and Detailed Design (Route Optimization, Fluid and Reservoir Properties) – 3.72%**

Description: FEED plays a major role in the establishment of any project on the technological and engineering foundation. It establishes that the design specifications will meet the engineering standards necessary for a project, thus confirming its technical viability. Bad FEED means super-expensive consequences down the line of rework, delays, and inefficiency of operations.

Relationship: FEED directly influences Technical and Engineering Complexities. Inability or failure at this stage, like poor design or material mismatch, further enhances the challenges in execution and overall project complexity.

Example: The inappropriate selection of diameter or unsuitable pipeline material may lead to operation failures, such as not being able to bear pressure conditions, thereby resulting in costly repairs with possible disruptions to the project.

- **Supply Chain Logistics (Specialized Equipment and Cross-Border Logistics) – 3.66%**

Description: Pipeline construction requires special valves, pipes, and coatings that are normally imported from international locations. This further involves various logistical challenges in customs clearance, transportation delays, and complicated documentation.

Relationship: These, in turn, create Technical and Engineering Complexities. Delays in equipment delivery disrupt the construction schedule, lowering productivity and raising project risks.

Example: Delays in the delivery of critical compressors from foreign manufacturers can bring pipeline welding and assembly to a standstill, leaving labor standing and ballooning overall project costs.

- **Poor Welding and Joint Integrity – 3.64%**

Description: Welding is one of the critical links in pipeline construction; low-quality welds or joint defects may lead to structural failure, leakage, or operational shutdowns that may critically affect the safety and reliability of the pipeline.

Relationship: Compromising the structural integrity of the pipeline, directly influences Technical and Engineering Complexities. Poor weld quality generally results in extended repairs and increased downtimes, further increasing project complexity.

Example: Poor welds may further cause gas leakage, leading to an emergency shutdown to allow for checks, repairs, and revalidation that the pipeline is safe and functional.

- **Crossing Sensitive Areas – 3.53%**

Description: Pipelines often cross areas sensitive to environmental impacts or social protection, such as wetlands, forests, and urban zones. Engineering is complicated because many special construction techniques must be applied to minimize ecological and social disturbance.

Relationship: It complicates Technical and Engineering Dimensions because of the technical adaptations required in rerouting or alternative drilling methods that are needed for sensitive areas.

Example: Building a pipeline across a wetland might require Horizontal Directional Drilling, which would avoid disturbing the ecosystem but raise the cost and construction time.

- **Challenges in the Interface of Pipeline and the Compressor Stations – 3.18%**

Description: Compressor stations are used to preserve the flow and pressure in fluids across long pipelines. Inadequate integration or misalignment between pipelines and compressor stations causes inefficiency in operation and results in pressure loss.

Relationship: Affects Technical and Engineering Complexities, since interface mismatches increase technical risks, reduce operational efficiency, and need expensive modifications.

Example: A compressor station that is not in accordance with the pressure specifications of the pipeline may fail in sustaining proper flow rates; this can lead to project delays with losses in production.

- **Real-Time Data Analysis Challenges – 3.02%**

Description: This involves real-time monitoring that enables tracking of pipeline performance, detection of anomalies-be it a leak or pressure drop-necessary for operational safety. The absence or underutilization of these systems results in delayed fault detection and increased risks.

Relationship: This adds to Technical and Engineering Complexities because there is reduced optimization of operations, failure predictions, and smooth functioning.

Example: Undetected leak in a pipeline, as IoT-based pressure sensors aren't installed, and so an environmental disaster along with heavy repair costs can easily be caused.

- **Challenges in Land Acquisition – 2.79%**

Description: Land acquisition for pipeline right-of-way is often developed by negotiation with landowners and the resolution of legal controversies, with approval, particularly across populated or disputed areas.

Relationship: Contributes to technical and engineering complexities by delaying the start of construction activities and enhancing the need for alternative engineering solutions.

Example: The delay in land acquisition could therefore mean routing the pipeline through difficult terrain, raising technical workload and costs.

- **Production Shortfalls Caused by Blockages and Damage of Pipelines – 2.77%**

Description: Pipeline blockages caused by debris, internal corrosion, or third-party damage minimize flow rates, thus hindering production and therefore need to be repaired or changed.

Relationship: Impacts directly upon Technical and Engineering Complexities as blockages create operational inefficiencies and require complex repair activities.

Example: Corrosion of a blockage in a pipeline reduces the flow of oil, hence the production rate, and requires immediate replacement of the pipeline.

- **Variants of the Path and Length of Right of Way – 2.57%**

Description: The pipeline routes will have to pass through diversified terrains, environmental constraints, and urban development. Variation in the path or increased lengths in pipeline creates an engineering challenge; hence, route optimization with necessary technical modification.

Relationship: Increases Technical and Engineering Complexities since route adjustments prolong the construction time, cost, and technical risks.

Example: Changing the route of this pipeline to avoid a dense urban area adds several kilometres of pipeline that need more resources and material.

4.2.2. Environmental Complexities (15.58%)

This dimension focuses on challenges related to health and safety compliance, environmental sustainability, and strict regulatory frameworks that pipeline projects must adhere to, especially when operating in sensitive ecosystems. Identified complexity factors related to environment includes:

- **Implementation of Health, Safety, Security, and Environment (HSSE) – 5.97%**

Description: Health, Safety, Security, and Environmental standards are important to reduce risks to personnel, property, and the environment when constructing or operating a pipeline. Poor practices in HSSE lead to accidents, damage to the environment, and penalties.

Relationship: Directly impacts Environmental Complexities, as meeting HSSE standards requires additional time, investment, and operational changes to achieve legal and safety standards.

Example: Advanced leak detection systems and fire safety installations in oil and gas pipelines increase the initial cost, yet are a must for compliance.

- **Implementation of Sustainability Requirements (Reducing Emissions During Construction) – 5.46%**

Description: Sustainability measures include minimizing environmental impact through emission control, eco-friendly practices, and resource optimization. These requirements are increasingly mandated in modern construction projects.

Relationship: Adds to Environmental Complexities because meeting the sustainability goals requires adopting some innovative technologies that could add to project cost and time.

Example: While using low-emission equipment and biodegradable pipeline coatings during construction increases sustainability, it also requires additional investment.

- **Highly Regulated Environment – 4.16%**

Description: Environmental laws are very strict, and regulatory bodies ensure that ecological damage is minimal. Approvals, permits, and monitoring are required to adhere to these regulations.

Relationship: Contributing to environmental complexities by introducing bureaucratic delays, increased compliance costs, and technical modifications.

Example: Pipelines through protected areas like forests or wetlands would require EIAs and various clearances before actual laying can commence.

4.2.3. Risks and Uncertainties Complexities (15.44%)

This dimension highlights uncertainties and external challenges, including financial risks, security threats, and poorly defined project scopes that introduce unpredictability into pipeline projects. The factors on this section can be mentioned as:

- **Probability of Cost Overrun – 5.93%**

Description: Cost overruns are increased expenses beyond the initial budget caused by scope changes, risks that were not put into consideration, or poor cost estimation.

Relationship: Directly impacts Risks and Uncertainties Complexities, since financial unpredictability causes disruption in project execution and raises stakeholder concerns.

Example: Sudden increases in the prices of pipeline steel drastically raise the material procurement cost excessively beyond the initial estimate.

- **Security and Vandalism – 5.11%**

Description: Pipelines, particularly those in remote or politically unstable regions, run the risk of vandalism, theft, or sabotage that compromise safety and operations.

Relationship: Adds to Risks and Uncertainties Complexities are added because unplanned disruptions by external threats necessitate further repairs and other security measures.

Example: Unauthorized tapping of oil pipelines in remote areas causes leaks, environmental damage, and loss of production.

- **Ambiguity of Project Features and Phases – 4.40%**

Description: Poorly defined project scope, indistinct requirements, or incomplete designs make for confusing and inefficient executions.

Relationship: Directly impacts Risks and Uncertainties Complexities - Ambiguity increases the risk of rework, delays, and misalignment between project teams.

Example: Ambiguous pipeline specifications regarding pressure or material grade may require costly redesigns during construction.

4.2.4. Project & Stakeholder Management Complexities (14.21%)

This dimension highlights the challenges of coordinating diverse stakeholders, resolving conflicts, and ensuring smooth communication and collaboration throughout the project lifecycle. The factors that can be mentioned under this section are:

- **Conflicts Between Key Project Parties – 5.32%**

Description: Conflicting or misaligned goals from primary project stakeholders-contractors, subcontractors, owners-leads to delay, disputes, and inefficiency within the project.

Relationship: Adds to project and stakeholder management complexities as disputes disrupt the flow of work and decision-making.

Example: Disagreement over project schedules or payment milestones between contractors and owners leads to stalled construction activities.

- **Stakeholder Diversity – 4.71%**

Description: The presence of numerous stakeholders with diverse interests-regulatory bodies, local communities, and investors-embeds decision-making in several layers of complexity.

Relationship: Contributes to Project & Stakeholder Management Complexities because accommodating diverse expectations requires extensive communication and alignment.

Example: Resistance from local communities, concerned about environmental impacts, delays project approvals.

- **Inadequate Use of Project Management Practices – 4.17%**

Description: Absence or ineffective use of project management tools and methodologies result in miscommunication, coordination failure, and inefficiencies.

Relationship: The impacts are directly on Project & Stakeholder Management Complexities by reducing team alignment and slowing down execution.

Example: Ineffective adoption of modern project management software results in delays in material delivery tracking and resources allocation.

4.2.5. Laws and Regulations Complexities (13.11%)

This dimension focuses on legal challenges, regulatory hurdles, and institutional control that delay progress and introduce operational uncertainties. Contributing factors are:

- **Impact of Local Institutional and Legal Control – 4.63%**

Description: Delays have been caused by the imposition of some legal and administrative requirements by local regulations and institutional processes.

Relationship: Adds to Laws and Regulations Complexities as navigating local laws requires extensive engagement with regulators.

Example: Many pipeline projects in some countries need to cross through indigenous lands for which local tribal authorities' approvals are required. The negotiations for compensation might take several months and years for cultural impact studies to get legal permissions.

- **Permitting and Regulatory Requirements – 4.63%**

Description: Securing permits and complying with regulations is often time-consuming and bureaucratic, delaying project execution.

Relationship: Directly impacts Laws and Regulations Complexities by creating administrative hurdles that slow progress.

Example: Pipelines running through ecological areas can have their approval delays hold up construction for many months.

- **Complex Contract Form and Types – 3.85%**

Description: Unclear or excessively complicated agreements cause legal disagreements, operation delays, and misinterpretations between different parties to a project.

Relationship: Impacts Complexity of Laws and Regulations Due to unclear obligations that bring confusion and disagreement.

Example: Ambiguous clauses within an EPC - Engineering, Procurement, and Construction contract lead to conflict in understanding deliverables and timelines.

4.2.6. Project Resource Management Complexities (12.77%)

This dimension reflects challenges in workforce expertise and efficient allocation of critical resources such as labor, equipment, and materials. Main factors in this part are:

- **Lack of Past Work Experience – 7.54%**

Description: Lack of experience related to handling large and complex pipeline projects increases the probabilities of errors and inefficiencies.

Relationship: Adds to Project Resource Management Complexities decreasing the quality and speed of project execution.

Example: Poorly skilled welders not meeting pipeline quality standards lead to repairs and rework repeatedly.

- **Poor Resource Allocation – 5.23%**

Description: Poor labor, equipment, and material allocation delay, idle resources, and cost overruns.

Relationship: Directly affects the complexities of Project Resource Management, since poor planning leads to underutilization or overutilization of resources.

Example: Delays in mobilizing construction equipment result in idle labor and increased project costs.

4.3. Final Discussion

4.3.1. Evaluation of Factors Based on Average Value

Given the chart presented and taking as a baseline the average value of all factors, which equals 4.35%, an interesting conclusion can be drawn about the distribution of complexities across dimensions. Although the factors of Technical and Engineering Complexities have lower individual weights compared to other dimensions, their large number of contributing factors makes this category critically important in oil and gas pipeline projects.

This dimension, the Technical and Engineering Complexities, has a total of 9 factors out of the total 21. Their individual weights are below the average value of 4.35%, but the cumulative contribution of these factors becomes high with such a large number of factors. That indicates that technical and engineering complexities are made up of several small challenges which, when aggregated, turn it into the most important area that needs attention in pipeline projects. While each factor may have lesser importance individually, together they bear directly on design, construction, and operations, making this dimension a foundation of project success.

Comparing Technical Complexities with other dimensions, it is seen that certain factors of the Project Resource Management, Risks and Uncertainties, Environmental, and Stakeholder Management Complexities exceed its average value significantly. The presence of high-weighted factors in those dimensions points out their individual significance even though the number may be smaller.

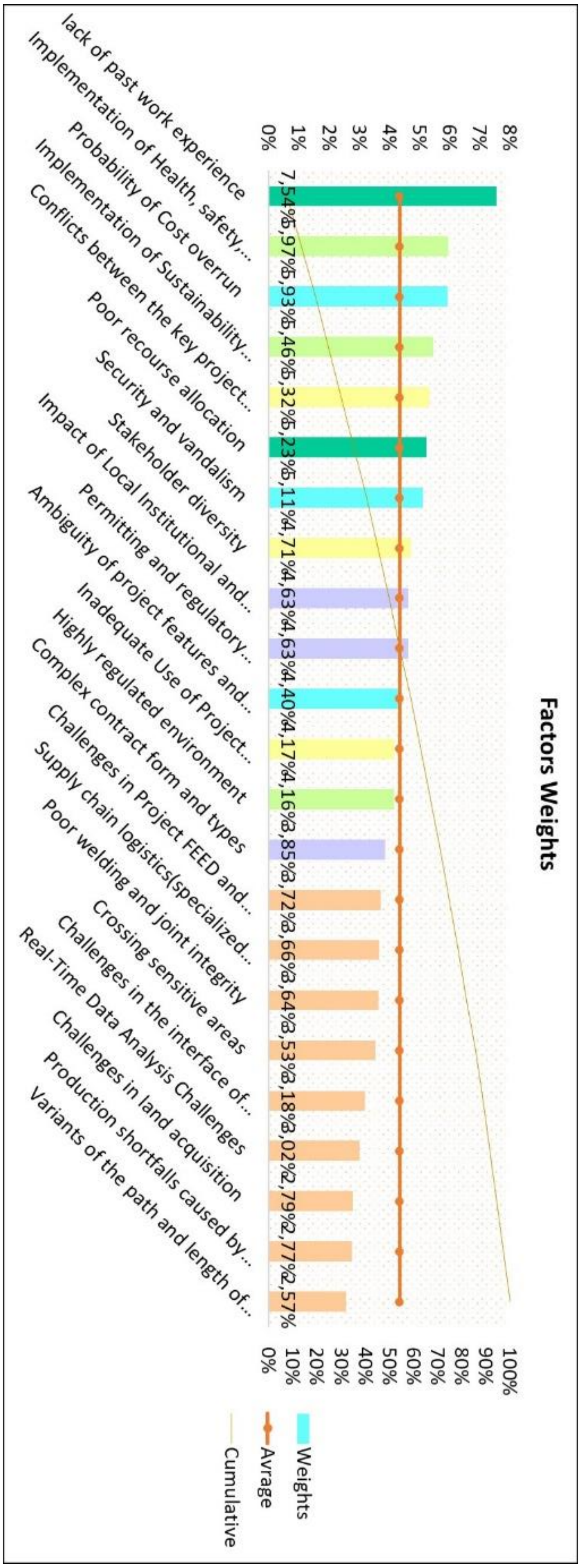

Chart 3. Factors Weights

Chapter Five: Conclusion

5.1. Highlights of Study

It lets the study underline the multi-dimensional and interrelated complexity regarding the oil and gas pipeline projects. It combines the Delphi method and the Analytic Hierarchy Process in order to identify, prioritize, and structurally evaluate the identified critical factors leading toward complexity in oil and gas pipeline projects. A structured frame of reference is developed through this integrated approach that helps in understanding the interdependencies of technical, managerial, environmental, and risk-related challenges, thus providing a solid basis for the decision-making process.

These results have underlined the need for addressing the complexities holistically and in a balanced manner. While the Technical and Engineering Complexities turn out to be most dominant due to its cumulative impact and wide range of factors, other dimensions such as Resource Management, Environmental Compliance, Risks and Uncertainties, and Stakeholder Management, too, stand at the center. These dimensions have highly weighted individual factors that need focused interventions reflecting their immense influence on project outcomes.

Technical and Engineering Complexities contribute 28.89% to the overall project complexity. While some particular factors that build up this aspect, such as "Challenges in FEED" or "Welding and Joint Integrity," may look separately quite low in weight, their number discloses a far more serious problem. Each factor addresses essential elements of pipeline design, construction, and operation to form the basis of a successful project. These technical factors are related in such a way that a problem in one sector may cascade into others, resulting in costly reworks, delayed operations, and poor performance. Delays in procuring specialized equipment could affect welding activities, while poor design at the FEED stage may result in inefficient operations throughout the life of the pipeline. Addressing these challenges collectively is, therefore, crucial to ensuring pipeline integrity, safety, and reliability.

While the Technical and Engineering Complexities dominate due to their cumulative nature, other dimensions carry factors that have much higher individual weights, indicating their critical importance. Project Resource Management: Factors such as "Lack of Past Work Experience" with a percentage of 7.54% indicate the disproportional influence of the expertise of the workforce on the project outcomes. A shortage of skilled personnel can lead directly to lower quality work, productivity, and adherence to project schedules. Environmental Compliance: Factors such as HSSE Implementation (5.97%) and Sustainability Requirements (5.46%) reflect increasing pressure to balance construction activities with environmental stewardship and safety standards. Risks and Uncertainties: Factors related to Cost Overruns (5.93%) and Security and Vandalism (5.11%) underscore the need for effective risk mitigation and contingency planning to prevent unforeseen disruptions. Stakeholder Management and Regulatory Compliance: Conflicts among key stakeholders, delays in regulation, and ambiguous legal frameworks are factors that might bring things to a standstill and will require clear communication, alignment, and proactive legal management. Their presence due to these highly weighted individual factors therefore means that though fewer in number, they are big risks which may immediately substantially affect project execution and performance.

5.2. The Need for a Balanced and Integrated Approach

The findings of this study emphasize that complexities in pipeline projects cannot be addressed in isolation. Instead, they require a balanced and integrated approach that considers both:

The cumulative nature of the Technical and Engineering challenges is systemic in project design, resource planning, and methodologies for construction. It can help target high-weighted individual factors: workforce inefficiency, cost overruns, environmental compliance, and stakeholder conflict. Any silo approach to managing the projects' complexities-where just one category or a set of challenges is highlighted-will fall short on interdependency resolution between dimensions. For instance, engineering optimizations can be necessary that, if not considered for environmental compliance, will lead to regulatory penalties, delays in projects, or community opposition. Analogously, better management of resources without mitigating fiscal and security risks would endanger the budgets and safety of the operations. Hence, this calls for an integrated strategy on managing complexity, a strategy that aligns technical precision and workforce competencies with risk mitigation, considering regulations and stakeholder involvements within one framework to project execution.

5.3. Suggestions and Recommendations for Risk Analysis and Management in Oil and Gas Pipeline Projects

Effective risk analysis and management practices are essential to realize oil and gas pipeline projects that include various technical, environmental, and financial challenges. To further strengthen risk mitigation strategies, below are the most important recommendations:

- **Proactive Risk Mitigation through Iterative Review**

Regularly conducted project evaluations are important tools to bring out the risks fairly early to allow for interventions. Implementing a structured and systematic milestone review process, the teams will be able to analyze the emerging risks, fine-tune the mitigation plans, and enable continuous improving. The iterative reviews will also feed further lessons learnt from previous phases for better decision making and less costly disruption (Saberi et al., 2019).

- **The AI Enabled Risk Management Platform**

A highly integrated comprehensive risk assessment and management platform that could model all technical and managerial interdependencies will show significant improvements in identifying and managing risks. Sophisticated tools that rely on AI and machine learning for real-time dynamic risk exposure assessment shall modify mitigation strategies based on changing project conditions. For that matter, AI-powered predictive analytics can offer future insights into costs overruns, delays in the schedule, and safety hazards so that preventive strategies can be in place for project managers (Aven, 2021).

- **Virtual Pipeline Simulations for Design Optimization**

Digital simulations in the pipeline projects enhance in risk assessments in the engineering and designing phase. Virtual models have made it possible to enable engineers to test out different pipeline designs or configurations, determine interactions between the environment and pipelines, and expose potential threats before construction starts. Such an approach and methodologies not only reduce technical uncertainties but also add to the regulatory compliance through the stress tests, corrosion resistance, and operational efficiency under different conditions (Khakzad et al., 2018).

- **Block chain for Transparent Supply Chain Management**

A block chain system entrusts the transaction completion process on the smart instruments by which all supplier agreements, deliveries of the materials, and certifications of the quality get recorded in a ledger without the possibility of that being altered, and as such adding transparency, security and traceability of critical materials in procurement and supply chain management. It makes improper activities impossible, thereby reducing the length of delays in procurement and ensuring the compliance of all standards within the industry (Saberi et al., 2019).

- **Drones and Robots for Automated Inspections**

Using autonomous drones and robotic systems for monitoring and inspection makes risk assessment faster and more accurate. Drones with high-resolution cameras and thermal imaging can determine pipeline anomalies such as leaks, corrosion, or structural weaknesses in real time. Ground robots can be used instead for detailed inspections in hazardous areas that cannot be reached to reduce human exposure and enhance safety in the entire project (Rezaii et al., 2021).

All these modern risk management techniques can actually give oil and gas pipeline projects a much higher safety level, efficiency, and cost-effectiveness. A holistic approach to risk mitigation would involve project reviews on a regular basis, AI-enabled risk assessment tools, virtual simulation, block chain for supply chain integrity, and autonomous inspection technologies. This future research should nurture technology advancement and analyze their effects together on risk management for large energy infrastructure projects.

5.4. Practical Contributions of the Research

This framework would act as a strategic tool for project managers, engineers, policymakers, and stakeholders involved in the oil and gas sector. The practical contributions of the study will involve the following:

- **Improved Decision-Making**: The study will be able to help decision-makers address the most critical challenges first, hence optimizing resource allocation and strategic planning through a prioritized hierarchy of dimensions and factors.
- **Risk-Resilient Project Delivery**: Effective identification and mitigation of some of the high-impacting factors, such as cost overruns, technical inefficiencies, and stakeholder conflicts, minimize the occurrence of project failures.
- **Sustainability and Compliance**: Highlighting environmental and safety compliance will ensure that projects meet regulatory standards with minimal ecological and social impacts.
- **Multi-criteria Approach Holistic management framework**: Indeed, holistic analysis of related complexities or ways the interlinking complexities might best be targeted to cut project planning and implementation fragmentation.

5.5. Laying the Foundation for Future Research and Implementation

The present research not only covers the current challenges in oil and gas pipeline projects but also lays a foundation for future research and practical implementation:

- **Methodological novelties**: the result obtained by integrating Delphi and AHP methods underlines an effective multi-criteria decision-making approach with good potential to be applied in other infrastructure projects.
- **Further Research**: This proposed framework can be applied in various project environments, such as renewable energy infrastructure, urban development, and cross-border projects, and could be tested in future studies.
- **Technology Integration**: Advanced technologies like AI-based monitoring systems, digital twins, and real-time predictive analytics call for further research in finding the most efficient ways of solving the technical challenges.

5.6. Final Remarks

The study, therefore, established interconnected and multi-dimensional complexities relative to the oil and gas pipeline project. Though Technical and Engineering Complexities represent the backbone of the challenges because of their cumulative importance, high-weighted individual factors across other dimensions, such as Resource Management, Environmental Compliance, and Risk Mitigation, cannot be ignored.

With an integrated and balanced approach to dealing with complexity, the project managers could contribute to:

Increased efficiency and better performance, Reduced risks and disruption.

This research gives clear, practical directions to help overcome the challenges of modern oil and gas infrastructure projects. Large-scale, high-stakes projects will be executed more resiliently, precisely, and successfully.

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