A Conceptual Framework for Low-Cost Casing Design Using Inventory-Driven Optimization in Onshore Drilling

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Abstract- This paper presents a conceptual framework that integrates inventory management principles into the casing design process for onshore drilling operations. Traditional casing design often occurs independently of supply chain considerations, leading to inefficiencies, delayed procurement, and increased costs. The proposed model addresses these limitations by embedding real-time inventory constraints into the design optimization process. Grounded in established engineering principles, inventory theory, and cost modeling, the framework provides a structured approach to generating cost-effective and operationally feasible casing programs. Key components include a modular architecture that processes engineering inputs, inventory data, and logistical parameters to produce optimized design alternatives. The framework also outlines a practical implementation strategy involving cross-functional collaboration between drilling, procurement, and logistics teams. By incorporating reliability-based safeguards, the model ensures that cost savings do not come at the expense of well integrity. The paper concludes by discussing future directions such as automation, AI integration, and potential applications within digital drilling ecosystems.

Indexed Terms- Casing Design, Inventory Optimization, Onshore Drilling, Engineering Cost Efficiency, Supply Chain Integration, Reliability-Based Design

I. INTRODUCTION

1.1 Background and Motivation

Casing design is a critical component in the drilling of onshore wells, acting as both a structural backbone and a pressure containment system for the wellbore [1]. The selection, configuration, and deployment of casing strings directly influence well safety, operational efficiency, and, notably, project economics. [2] As drilling campaigns grow in complexity and frequency, particularly in maturing basins and marginal fields, the importance of optimizing casing design has become more pronounced [1]. Traditional design methodologies often focus on mechanical and geological considerations but do not fully account for logistical or cost-driven variables, particularly in environments with limited operational budgets [3].

The global emphasis on cost reduction in onshore oil and gas projects has intensified due to fluctuating commodity prices, regulatory pressures, and competitive bidding environments. Operators are increasingly expected to deliver technically sound wells while operating under stringent cost constraints [4]. This has catalyzed a shift from purely engineering-focused design approaches toward more integrated, cross-functional methods that account for financial and operational realities. One of the most promising yet underutilized opportunities in this regard is leveraging existing inventory data in the casing design process, thus aligning design with available resources [1].

Inventory management, often handled by procurement or supply chain departments, plays a pivotal role in the economics of well construction [5, 6]. Excess stock, delayed deliveries, or procurement mismatches can escalate costs significantly. However, these factors are rarely considered during the casing design phase [7, 8]. By embedding inventory considerations early in the design workflow, operators can not only reduce lead times and stockpiles but also align procurement strategies with field requirements. This integration has the potential to transform the casing design process from a cost center into a value-creating activity through improved alignment between design intent and available materials [9, 10].

1.2 Problem Statement

Despite the evident synergies between casing design and inventory management, the integration of these domains remains largely fragmented. Most casing designs are developed in isolation by drilling engineers using standardized criteria and safety factors, without insight into current inventory levels or procurement constraints. This disconnection often leads to the specification of casing grades or sizes that may not be readily available, resulting in project delays, expedited shipments, or costly last-minute purchases. Such inefficiencies become especially problematic in onshore projects where tight margins leave little room for logistical error or budget overruns [11].

A significant contributing factor to this fragmentation is the lack of communication and data sharing between engineering and supply chain teams. Drilling departments typically operate on technical criteria, while procurement functions are driven by cost and logistics. Without a framework to facilitate collaboration, decisions made by each group can inadvertently undermine the other's objectives [12]. For instance, engineers may prioritize technical robustness without realizing that a slightly modified design could utilize surplus inventory, leading to cost savings without compromising safety or performance [13].

Moreover, existing design software and workflows are not inherently equipped to incorporate inventory parameters as part of their optimization process. While digital tools are available to simulate mechanical performance, they do not consider stock availability, purchase history, or logistical timelines. This absence of integration results in suboptimal designs from both a financial and operational standpoint. Addressing this gap requires a reconceptualization of the casing design process—one that harmonizes engineering precision with inventory pragmatism to produce designs that are both technically viable and economically sound.

1.3 Objectives and Contributions

The primary objective of this paper is to present a conceptual framework that unifies casing design with inventory management through an optimization-driven approach. By treating inventory as an integral design variable rather than a downstream constraint, the framework aims to support design decisions that reflect both engineering needs and material availability. This paradigm shift encourages more adaptable and context-sensitive casing programs that align with real-world limitations and operational targets. The framework is not intended to replace existing design standards but rather to augment them by embedding logistical awareness into the design process.

A key contribution of this work is the introduction of inventory-driven design principles tailored to the casing selection process. These principles advocate for the use of available stock, historical usage data, and procurement forecasts as inputs into the design algorithm. By doing so, engineers can generate designs that are inherently optimized for cost and supply feasibility. The framework also promotes iterative communication between engineering and procurement teams, creating a feedback loop that ensures continuous alignment throughout the project lifecycle. This collaborative model can significantly enhance the efficiency of onshore drilling operations.

Lastly, this framework contributes to the ongoing effort within the oil and gas industry to adopt more sustainable and cost-effective practices. By minimizing waste, reducing excess inventory, and avoiding unnecessary purchases, the approach aligns with broader goals of operational efficiency and environmental responsibility. It also empowers drilling teams to make informed trade-offs between technical robustness and material availability, leading to decisions that are not only cost-conscious but also strategically sound. This paper sets the groundwork for a more integrated and resource-aware future in casing design.

II. THEORETICAL FOUNDATION

2.1 Casing Design Fundamentals

Casing design is governed by a series of engineering principles aimed at ensuring structural integrity throughout the life of the well. At its core, casing must withstand various mechanical loads, including burst (internal pressure exceeding external), collapse (external pressure exceeding internal), and tension (axial stress due to the weight of the casing) [14]. These loads are defined within the context of a "load envelope," which simulates the worst-case operational and environmental conditions a casing string may encounter [15, 16]. Engineers typically apply standardized safety factors and regulatory guidelines—such as those from the American Petroleum Institute—to ensure conservative yet functional designs. The resulting design envelopes form the basis for material selection and placement strategies in multi-string casing programs [17].

Material selection is a critical aspect of casing design and is influenced by both the anticipated loads and environmental conditions, such as temperature, pressure, and corrosivity. Engineers must choose between various grades of steel with different yield strengths, ductility, and corrosion resistance. Additional considerations include compatibility with cement, thermal expansion, and fatigue life under cyclical loading [18, 19]. While high-strength materials may offer improved performance, they often come at a higher cost and increased procurement complexity. Thus, the selection process must balance performance requirements with availability and economic feasibility. In practice, this decision-making process often excludes a real-time understanding of existing inventory, leading to designs that are technically robust but logistically burdensome [20].

Design constraints also extend to operational and logistical factors, including well trajectory, rig capacity, and hole geometry. Casing strings must be designed to fit within each other while maintaining sufficient clearance for cementing and tool passage [21, 22]. Additionally, the design must account for running forces, centralization, and mud pressures, which can affect the actual performance of the string during deployment. These constraints, while primarily technical, are further complicated when procurement timelines, transportation costs, and stock limitations are considered after the design phase. A more integrative design framework that anticipates these constraints holistically—including inventory realities—can help bridge the gap between optimal engineering and efficient execution [23].

2.2 Inventory Theory in Engineering Contexts

Inventory theory addresses the management of materials and goods to ensure timely availability while minimizing holding and ordering costs. In engineering contexts, particularly in drilling operations, inventory serves as both an operational resource and a financial asset [24]. Key concepts such as safety stock (to buffer against variability), reorder points (to trigger timely procurement), and lead time (the delay between ordering and receiving) are fundamental to understanding how inventory levels impact project execution. For casing design, inventory parameters influence not only cost but also feasibility, as unavailability of a specific grade or size can delay operations or force expensive substitutions [25].

Project-based industries like oil and gas often face unique inventory challenges due to non-repetitive demand, long procurement lead times, and variable field conditions. Unlike retail or manufacturing settings, where inventory usage is predictable, drilling operations require flexible and adaptive stock strategies [26]. Materials such as casing are often stored at central warehouses or rig yards, where they incur storage costs and risk of degradation. Moreover, decisions made in the design phase can render available stock obsolete, leading to waste or write-offs. This highlights the importance of aligning design activities with inventory data to prevent such inefficiencies and to facilitate just-in-time material usage [27].

Integrating inventory theory into engineering workflows can improve coordination between field operations and supply chain functions. By mapping engineering requirements against real-time stock data and procurement forecasts, engineers can identify opportunities for reuse, substitution, or bulk ordering [28, 29]. This integration fosters a demand-driven design approach, where design options are evaluated not only by technical merit but also by logistical feasibility and cost-efficiency. In the context of casing, this means prioritizing designs that utilize available stock or materials that can be sourced within required timeframes. This perspective transforms inventory from a passive constraint to an active design variable, aligning technical and operational goals [30, 31].

2.3 Optimization Principles in Engineering Design

Optimization in engineering design refers to the systematic selection of parameters that achieve the best possible outcome according to defined criteria [32, 33]. In casing design, this often means minimizing cost while satisfying mechanical performance requirements. This is achieved through the construction of objective functions—mathematical representations of goals such as cost, weight, or stress—alongside constraints that ensure technical feasibility [34, 35]. For example, a cost function may be subject to constraints on burst strength, collapse resistance, and tensile limits. Engineers use these formulations to explore trade-offs and identify solutions that best satisfy competing demands [36-38].

A central principle in optimization is the concept of trade-offs, particularly between cost and performance. Higher-grade materials may provide greater strength and reduce the need for multiple casing strings but come with increased procurement costs [39, 40]. Conversely, using lower-cost materials may necessitate more conservative design assumptions, leading to thicker walls or more intermediate strings, which increase operational complexity [41]. The challenge lies in quantifying these trade-offs and encoding them into the optimization process. This is particularly difficult when cost is not limited to material pricing but includes storage, transport, and delays due to availability, all of which are influenced by inventory status [42, 43].

Embedding inventory constraints within optimization algorithms offers a practical and scalable path to enhance engineering design. By incorporating inventory data—such as quantities on hand, expected delivery times, and storage locations—into the decision variables, engineers can generate designs that are not only technically sound but also executable with current or easily obtainable materials. This approach shifts the optimization problem from an isolated engineering task to a multi-objective decision model. It enables more realistic and cost-effective solutions that reflect the dynamic nature of drilling logistics. The resulting framework supports proactive planning, reduces inefficiencies, and enhances the responsiveness of drilling operations to both design and supply chain challenges [44].

III. FRAMEWORK DEVELOPMENT

3.1 Conceptual Model Architecture

The proposed conceptual framework is built on a modular architecture that integrates engineering design with inventory optimization. The model comprises four primary components: input parameters, decision variables, constraints, and outputs. Input parameters include well design specifications (depth, pressure profiles, expected formation loads), operational requirements (rig capacity, hole sizes), and inventory data (stock levels, material grades, delivery lead times). Decision variables refer to the casing design options, including string configurations, material grades, and wall thicknesses. These variables are adjusted during optimization to satisfy engineering and logistical requirements.

Constraints ensure that the casing design meets established technical and operational limits. These include mechanical constraints (burst, collapse, tension thresholds), geometrical constraints (clearance between casing and borehole), and logistical constraints (material availability and lead time). By applying both hard constraints (e.g., maximum allowable tension) and soft constraints (e.g., preferred use of available stock), the model remains flexible while preserving well integrity. Optimization algorithms—such as linear programming or genetic algorithms—can be used to navigate the solution space efficiently.

The model's output includes a set of optimized casing configurations that satisfy all defined criteria while minimizing total cost. These outputs are not limited to the mechanical design but also provide a bill of materials aligned with current inventory and procurement schedules. Though a visual diagram can enhance understanding, the model’s logic can be described as a closed-loop process: engineering requirements feed into a solver, which considers real-time inventory constraints and returns cost-effective, compliant designs. This architecture lays the groundwork for a scalable, automated system that supports decision-making across technical and supply chain functions.

3.2 Inventory-Driven Design Logic

At the heart of the framework lies an inventory-driven design logic that redefines how casing programs are developed. Traditional casing design typically begins with mechanical analysis, followed by procurement. In contrast, this model incorporates inventory data as a primary input in the early stages of design. Available materials—quantified by size, grade, length, and condition—are filtered into the algorithm to guide the selection process. This ensures that design candidates are not only technically viable but also readily constructible using existing stock or materials with short procurement lead times.

This design logic is reinforced through iterative feedback between procurement and engineering teams. As casing options are evaluated, procurement teams provide updates on availability, costs, and restocking timelines. These data points inform the selection of casing configurations, enabling the design team to adjust choices dynamically. If a preferred casing grade is low in stock or faces delivery delays, the algorithm evaluates alternative combinations within acceptable performance ranges. This feedback loop fosters collaboration, reduces rework, and supports agile decision-making in drilling operations.

Moreover, the integration of inventory into the design process promotes operational adaptability. Field conditions often evolve, and having a design that accommodates minor changes in material availability allows for quicker responses without sacrificing quality. This inventory-informed approach is particularly beneficial in remote or cost-sensitive onshore drilling campaigns where procurement flexibility is limited. By prioritizing materials already in stock or easily sourced, the framework mitigates supply chain risk and minimizes the need for emergency purchases. Ultimately, the inventory-driven logic establishes a more resilient and cost-aware foundation for casing design.

3.3 Cost Integration Approach

Cost is a central consideration in the proposed framework, and the model incorporates a comprehensive cost integration approach to guide decision-making. Traditional cost models in casing design primarily consider material unit prices [45, 46]. However, this framework expands the cost structure to include three additional factors: inventory availability, transportation costs, and storage overheads [47, 48]. For instance, using surplus casing from a nearby warehouse may reduce procurement and transport costs, even if the material has a slightly higher purchase price. Similarly, utilizing on-hand inventory reduces the cost of idle stock and frees up warehouse space, contributing to overall operational efficiency [49, 50].

The cost function embedded in the framework uses these parameters to evaluate the financial impact of different design choices. Each casing design option is assessed not only for mechanical compliance but also for its total cost across the supply chain [34, 51]. This includes direct costs (material acquisition), indirect costs (storage and handling), and temporal costs (delays due to out-of-stock components). These metrics are quantified and fed into the optimization engine, allowing the selection of designs that strike a balance between performance and affordability. The cost integration approach ensures that engineers can make informed decisions with visibility into both immediate and downstream financial implications [52].

To support trade-off evaluation, the framework includes a comparative analysis module. This component highlights the differences between "ideal" designs—based solely on technical criteria—and "available" designs—based on current inventory and logistical realities. Through this comparative lens, stakeholders can assess where compromises are acceptable or where performance must be prioritized [53, 54]. For example, a casing string that marginally exceeds minimum design thresholds but significantly reduces costs by utilizing existing inventory may be favored over a theoretically optimal design with long lead times. By capturing these trade-offs transparently, the framework facilitates balanced and pragmatic casing design decisions [55, 56].

IV. IMPLEMENTATION STRATEGY

4.1 Data Requirements and Sources

The effective application of the proposed framework depends on access to a minimum set of reliable and timely data. The core data requirements include well profiles (depth, trajectory, lithological data, and pressure regimes), casing design specifications (load cases, safety factors, material standards), and a comprehensive inventory database [57, 58]. This database should include up-to-date records on the quantity, specifications (OD, weight, grade), condition (new or used), and location of all available casing stock. Without this foundational data, the optimization logic cannot accurately evaluate feasible design alternatives or quantify trade-offs [59-61].

These data inputs are typically dispersed across multiple platforms within an organization. Well design parameters are generally maintained within drilling engineering software or project databases, while inventory data is captured by Enterprise Resource Planning (ERP) systems such as SAP or Oracle [62, 63]. Historical consumption trends, reorder patterns, and lead time statistics can be extracted from logistics dashboards and procurement reports. Field data, such as wear rates or reusability assessments, can further inform inventory classification and availability. Integrating these systems—either manually or through data pipelines—is crucial for enabling real-time inventory-aware design [64-66].

To streamline data gathering, the organization must establish standardized data interfaces and quality control protocols. Missing or inconsistent data can significantly impair model accuracy and utility. Therefore, implementing automated data validation routines, real-time syncing between ERP and design platforms, and clear ownership of data responsibilities is essential [67, 68]. A cross-functional data governance structure can ensure the continued integrity and completeness of the datasets. By setting these foundations early, the organization can support a scalable and robust implementation of the inventory-driven casing design framework [69-71].

4.2 Decision-Making Workflow

The implementation of this framework follows a structured decision-making workflow that spans planning, design, procurement, and execution phases. In the initial planning stage, project engineers define the operational parameters of the well, such as expected depths, formation pressures, and target completion architecture [72, 73]. These inputs are then used to generate preliminary casing design envelopes, which are passed to the optimization module. At this point, inventory data is overlaid onto the engineering model to identify feasible configurations that align with both technical needs and material availability [74-76].

During the design phase, drilling engineers iteratively evaluate alternative casing programs using the optimization outputs. The design software flags inventory-optimized solutions and highlights their associated cost, risk, and availability scores. Procurement teams are actively involved at this stage, providing updates on sourcing timelines, pricing trends, and contract limitations [77, 78]. Logistics personnel contribute by validating material transfer timelines and warehousing capabilities. This triad—engineering, procurement, and logistics—forms a collaborative loop that ensures alignment between technical feasibility and supply chain execution [79-81].

Once a casing design is selected, the framework outputs a detailed casing plan, procurement schedule, and transport sequence. These are integrated into the drilling execution plan and uploaded into project management systems [82, 83]. Continuous monitoring is encouraged throughout execution, allowing mid-course adjustments if material availability shifts or field conditions evolve [84]. By embedding inventory awareness into the design and planning cycle, this workflow minimizes reactive procurement, reduces risk of delay, and ensures that material decisions are made with full awareness of project objectives and constraints. This results in a more synchronized and efficient execution strategy across departments [85-87].

4.3 Risk and Reliability Considerations

While inventory-driven design offers clear cost and logistical benefits, it introduces potential risks that must be actively managed to preserve well integrity. Chief among these is the risk of selecting sub-optimal casing due to limited availability [61, 88]. If inventory constraints drive decisions too aggressively, the resulting design may approach minimum safety thresholds, reducing margins of reliability. This risk can be mitigated through the use of reliability-based design factors that assess how close a selected design is to failure limits under uncertain loads and operational conditions [89-91].

Reliability adjustments can be embedded into the optimization model using probabilistic safety factors or Monte Carlo simulations, even if no full-scale simulations are included in the paper itself. These methods allow the framework to account for variation in loads, material properties, and environmental conditions [92, 93]. By assigning confidence intervals to each design alternative, the model can flag solutions that, while cost-effective, may compromise long-term performance. Engineers can then choose designs that balance availability with risk tolerance, ensuring that operational safety remains uncompromised [94-96].

Additionally, a well-documented audit trail of decisions and rationale—particularly when deviating from ideal designs—enhances organizational learning and accountability. Lessons learned from previous projects can be used to refine inventory forecasting, improve procurement planning, and recalibrate risk thresholds [97, 98]. Establishing feedback loops from field performance back into the design model helps in continuously improving reliability assessments. Overall, the integration of reliability considerations ensures that the cost efficiencies of inventory-driven design do not come at the expense of operational robustness or well integrity [99-101].

CONCLUSION

5.1 Summary of Contributions

This paper has introduced a conceptual framework that integrates inventory management principles directly into the casing design process for onshore drilling. Unlike conventional approaches that treat engineering and procurement as distinct phases, this framework unifies them through a shared optimization model. The architecture links real-time inventory data with technical design requirements to produce casing programs that are not only structurally sound but also executable using materials that are already available or quickly obtainable. This integration represents a significant step toward synchronizing engineering logic with operational realities.

By embedding inventory constraints into the optimization process, the framework offers a new pathway for cost-efficiency in casing design. It expands the design criteria beyond mechanical performance to include stock availability, transportation costs, and warehousing factors. This approach minimizes excess procurement, reduces waste, and supports just-in-time logistics—ultimately lowering overall project costs. Crucially, it achieves this without compromising safety or compliance, as all design outputs are generated within established engineering constraints.

Operationally, the framework enhances practicality by providing a decision-making tool that reflects real-world constraints. It supports iterative, data-driven collaboration between drilling engineers, procurement teams, and logistics coordinators. Through this structure, the framework ensures that designs are not only theoretically robust but also feasible in the field, leading to fewer disruptions and improved resource utilization. It is this dual emphasis—on cost-efficiency and operational practicality—that underscores the novelty and relevance of the proposed model within the drilling industry.

5.2 Implications for Industry

For drilling contractors and operators, the adoption of this framework holds tangible benefits in terms of planning reliability, cost reduction, and execution efficiency. By aligning casing design with inventory conditions from the outset, operators can reduce emergency procurement, avoid material shortages, and make better use of existing stock. This not only leads to financial savings but also shortens planning cycles and improves responsiveness to dynamic field conditions. The ability to adapt designs in real-time based on actual inventory status enhances project flexibility and minimizes non-productive time (NPT).

Beyond project-level improvements, the framework fosters stronger cross-functional collaboration within organizations. Traditionally siloed teams—engineering, procurement, and logistics—are brought into a shared decision-making environment, reducing miscommunication and delays. The feedback mechanisms embedded in the framework promote transparency and enable more informed trade-offs across cost, time, and quality. As companies increasingly adopt integrated operations models, this framework supports cultural and structural shifts toward more collaborative and agile project delivery.

Moreover, the framework lays a foundation for more sustainable practices in the oil and gas sector. By leveraging surplus or reusable materials, it contributes to circular material usage and reduces the environmental footprint of drilling activities. This has strategic implications for companies aiming to meet environmental, social, and governance (ESG) benchmarks without sacrificing operational performance. As industry focus shifts toward digital transformation and efficiency, this framework can serve as a practical model for implementing intelligent, inventory-conscious engineering workflows that align with future-facing operational priorities.

5.3 Future Work Directions

While the current framework provides a solid conceptual foundation, several avenues for future development could enhance its capabilities. One promising direction is the integration of automation tools that enable real-time data exchange between ERP systems and engineering software. Automated data ingestion would eliminate manual errors and allow the model to respond dynamically to changing inventory levels or procurement delays. Coupling this automation with machine learning algorithms could further refine decision-making, enabling predictive analytics based on historical usage patterns and procurement behavior.

Another important extension is the incorporation of artificial intelligence to manage more complex decision spaces. AI-driven optimization can uncover design alternatives that balance conflicting objectives more efficiently than traditional rule-based methods. For example, reinforcement learning could be used to improve casing selection strategies based on project outcomes iteratively. These intelligent agents could also simulate supply chain disruptions and suggest contingency plans in near real time, offering significant resilience in volatile market conditions.

Finally, the framework holds potential for integration into broader digital drilling ecosystems. As the industry moves toward unified digital platforms—encompassing drilling planning, operations, and logistics—the framework can be embedded as a module within these environments. Such integration would allow casing design to interact seamlessly with digital twin models, rig scheduling software, and procurement portals. This convergence supports the vision of fully automated, data-informed drilling operations, where engineering and supply chain functions are no longer sequential, but inherently intertwined in a closed-loop digital workflow.

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