

# Towards an Integrated Blockchain and Artificial Intelligence Framework for Ghanaian Oil Marketing Companies' Supply Chain Management System

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## ABSTRACT

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Fundamental to optimal supply chain management systems is the need to operate efficiently and effectively. Supply chain in the Ghanaian Oil Marketing sector is managed by both local and foreign oil marketing companies that coordinate complex logistics and inventory transfers across the country. Despite its economic importance, this supply chain demonstrates structural complexity, involving several stakeholders, geographically dispersed assets, and urgent coordination requirements. Previous research highlights difficulties associated with rigid forecasting models, insufficient data integration across departments, and limited analytical complexity. In view of the inherent benefits of blockchain and artificial intelligence, this study examines the application of blockchain and artificial intelligence technologies in supply chain management for oil marketing in Ghana. The study used an integrated inductive and deductive methodologies to establish a framework that merges blockchain and artificial intelligence throughout all phases of Ghanaian Oil Marketing operations in the downstream. This presents the opportunity to enhance policy and practice to improve supply management within the sector.

**Keywords:** Oil Marketing Companies, Supply Chain, Blockchain, Artificial Intelligence, Ghana.

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## 1. BACKGROUND TO THE STUDY

The oil marketing supply chain consists of a set of successive phases that convert crude oil into refined goods and distribute them to end consumers. The stages generally encompass refining, wherein crude oil is converted into usable petroleum products; storage and bulk distribution at depots; secondary distribution through tankers and pipelines; and retail delivery via service stations and off-take points (Birol, 2024).

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In Ghana, these steps are overseen by local and multinational oil marketing firms that orchestrate intricate logistical and inventory transfers nationwide. Notwithstanding its economic significance, this supply chain exhibits structural complexity, encompassing various stakeholders, geographically scattered assets, and time-critical coordination demands. Global oil marketing supply chains exhibit analogous structural and operational difficulties that compromise efficiency, transparency, and resilience. A major difficulty is demand volatility, resulting from variable consumption patterns driven by seasonal changes, macroeconomic influences, and policy alterations. Precise demand forecasting is essential for aligning service station inventory with consumer requirements; nevertheless, conventional forecasting techniques frequently neglect to account for nonlinear patterns induced by swift market fluctuations (Aghaei et al., 2025). A second difficulty is inventory mismanagement; inadequate synchronisation of inventory levels among depots and retail outlets can result in stockouts or overstock, leading to missed sales or excessive carrying costs. Third, the frequency of product adulteration, whether by deliberate or accidental contamination of petroleum products, presents concerns to quality and safety, particularly in environments with inadequate monitoring and enforcement procedures.

Further issues encompass several types of fraud and a lack of transparency in transactions and logistics, exacerbated by undocumented trades and insufficient real-time monitoring. Disparate data systems among supply chain partners generate data silos, impede collaboration, prolong decision-making, and diminish transparency (Park, 2021; Saberi, Kouhizadeh, & Sarkis, 2019). Prominent energy corporations worldwide, like Shell plc and ExxonMobil, are using digital technologies to augment traceability, diminish inefficiencies, and bolster operational resilience. Shell has publicly outlined strategic objectives to utilise blockchain to achieve cost reductions, enhance process efficiency, and standardise operations throughout its worldwide supply chains (Shell, 2025). Industry reports indicate that digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain can diminish greenhouse gas emissions and waste by improving transparency and operational precision in energy supply chain processes (Offshore Technology, 2022). The growing implementation of these technologies signifies a wider transition to digitised and data-centric supply chain management in the energy sector, where conventional systems reliant on enterprise resource planning (ERP) and manual supervision are inadequate for managing intricate, real-time logistics and analytical requirements.

Blockchain technology is a decentralised digital ledger that guarantees the immutability, transparency, and security of transactional records among authorised parties. Blockchain in supply chains enhances data visibility, auditability, and stakeholder trust by facilitating real-time products monitoring, immutable event recording, and automated contract execution using smart contracts (Park, 2021; Karaduman, 2025). A thorough examination of blockchain-based supply chain solutions indicates that these systems can improve traceability, diminish information asymmetry among stakeholders, and facilitate the verification of product origin (Karaduman, 2025). Artificial Intelligence (AI) is “the capability of computer systems to perform tasks that typically require human intelligence, such as learning, reasoning, problem-solving, perception, and decision-making” (Russel et al., 2021). Simultaneously, AI facilitates operational excellence by providing predictive analytics, pattern identification, logistics schedule optimisation, and improved decision-making using machine learning models (Aghaei et al., 2025; Tsolakis et al., 2022). The predictive capacities of AI, particularly in demand forecasting and inventory optimisation, enhance the transparency and trust offered by blockchain, fostering prospects for collaborative digital innovation in supply chain management (Hossain et al., 2025).

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Nonetheless, despite the theoretical advantages of blockchain and AI, empirical studies on their combined implementation in oil marketing supply chains, especially in emerging economies like Ghana, are few. Many studies concentrate on certain sectors (e.g., agriculture, food distribution, fisheries) or on global supply chain models, neglecting localised examinations of context-specific restrictions and potential (Tsolakis et al., 2022). Research indicates that although blockchain and AI individually enhance supply chains, their combined application could yield greater resilience, sustainability, and efficiency, contingent upon overcoming challenges related to expertise, infrastructure, and governance (Hossain et al., 2025; Agya, 2025). Utilising these insights in Ghana's oil marketing sector establishes a foundation for systematic investigation into how emerging technology can resolve persistent operational issues

### **1.1 Statement of Problem**

Conventional supply chain management systems in most Ghanaian oil marketing companies predominantly depend on outdated tools, rudimentary ERP modules, and manual procedures for planning, execution, and oversight. These technologies, although beneficial for fundamental record-keeping and coordination, are insufficient for managing real-time analytics, comprehensive transparency, and swift decision-making necessary in intricate energy supply chains. ERP systems mostly function inside organisational confines, frequently lacking full integration with partner systems or real-time synchronisation across scattered entities. Consequently, data fragmentation endures, resulting in data silos that obstruct visibility into inventory levels, demand variations, and transaction integrity.

The 2022 Annual Report and Financial Statements of the Ghanaian National Petroleum Authority indicated downstream petroleum losses, diversions, and transparency deficiencies (NPA, 2022). This substantiates the problem statement by illustrating that insufficient traceability and disjointed monitoring generate financial, regulatory, and reputational concerns within Ghana's oil marketing business. Additionally, inefficiencies in the supply chain and coordination issues within Ghana's petroleum sector were documented in the 2021 Annual Report of the Ghanaian Bulk Oil Storage and Transportation Company Limited (BOST, 2021). All these results corroborate Boateng et al. (2016) about the difficulties of forecasting and inventory planning in Ghanaian OMCs. The aforementioned research and studies underscore the structural constraints of ERP installations in Ghana, including inflexible forecasting models, inadequate data linkage among departments, and restricted analytical sophistication. These findings substantiate the assertion that traditional ERP-based systems dependent on historical averages may encounter difficulties in variable demand contexts, such as petroleum markets influenced by price variability and seasonal consumption changes.

ERP-based systems generally lack effective means for secure and tamper-proof data sharing among numerous stakeholders without centralised oversight, resulting in trust and transparency challenges in oil marketing activities. Inadequate traceability complicates the auditing of product transfers from depots to retail outlets, heightening the danger of fraud, adulteration, and unauthorised diversions, which carry financial and reputational repercussions. Furthermore, conventional forecasting instruments integrated into ERP systems frequently rely on historical averages and rigid models, rendering them inadequate for managing fluctuating demand patterns, resulting in inventory inconsistencies and inefficient replenishment plans. In oil marketing supply chains, which comprise several independent businesses such as importers, refiners, transporters, depot operators, and retailers, trust and synchronisation among these participants are essential.

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The constraints of traditional supply chain management technology consequently generate operational inefficiencies that diminish competitiveness, escalate costs, and undermine consumer confidence. There is an urgent requirement for novel frameworks that augment transparency, bolster confidence, optimise inventory management, and facilitate proactive decision-making via predictive analytics and decentralised data governance.

### 1.2 Research Objective

This study seeks to investigate the utilisation of blockchain and artificial intelligence technologies in the realm of supply chain management for oil marketing in Ghana. Defined objectives encompass:

- 1) To examine the function of blockchain technology in improving transparency and trust in oil marketing supply chain activities.
- 2) To assess the capabilities of AI-driven predictive analytics for demand forecasting, inventory optimisation, and distribution efficiency.
- 3) To develop a cohesive AI-blockchain architecture customised for the operational and structural requirements of Ghanaian oil marketing supply chains.
- 4) To evaluate the obstacles and incentives for the adoption of these technologies among supply chain participants in the Ghanaian energy sector.

### 1.3 Research Questions

To guide the inquiry, the following research questions are posed:

- 1) How can blockchain technology improve traceability, transparency, and trust among actors in the Ghanaian oil marketing supply chain?
- 2) To what extent can AI optimize inventory levels, demand forecasting, and distribution pathways within the supply chain?
- 3) What are the synergistic impacts of combining blockchain and AI frameworks on overall supply chain performance and resilience?
- 4) What organizational, technological, and regulatory factors influence the adoption of blockchain and AI in Ghana's oil marketing sector?

## 2. LITERATURE REVIEW

### 2.1 Overview of Digital Technologies in Supply Chain Management

Digital transformation has swiftly altered modern supply chain management (SCM), propelled by the increasing demand for resilience, visibility, and efficiency across intricate global networks. Emerging technologies, including blockchain and artificial intelligence (AI), are increasingly acknowledged as possible facilitators of these goals, providing solutions to persisting issues such as information asymmetry, data silos, and operational inefficiencies (Aba-Talib & Zouine, 2025). Traditional supply chain management solutions typically rely on isolated enterprise resource planning modules and manual reconciliation processes; however, blockchain and artificial intelligence can significantly improve data integrity, decision-making, and automation within multi-party value chains. Blockchain technology offers a decentralised, unchangeable distributed ledger that securely records transactions among all participating entities. This intrinsic transparency facilitates traceability and auditability, hence diminishing potential for fraud and data manipulation (Karaduman, 2025).

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Conversely, AI includes sophisticated computational methods like machine learning and predictive analytics that allow supply chains to foresee demand fluctuations, optimise inventory levels, and detect anomalies in real time (Teixeira, 2025). When combined, these technologies can establish hybrid systems where blockchain guarantees trustworthy data provenance and AI facilitates informed supply chain decisions based on that reliable data (Aba-Talib & Zouine, 2025).

The integration of blockchain with AI has garnered significant academic attention as a means to enhance supply chain transparency, operational velocity, and collaborative efficacy. A recent comprehensive evaluation of research determined that the amalgamation of AI with blockchain significantly improves transparency, security, and collaborative decision-making among supply chain participants (Aba-Talib & Zouine, 2025). Furthermore, studies across several sectors demonstrate that the integration of blockchain and AI can alleviate data silos, enhance real-time collaboration, and diminish fraud threats (Oyeyemi et al., 2024). This literature review consolidates studies on the traceability functions of blockchain, the predictive capabilities of AI, and their combined potential in supply chain contexts, particularly concerning Ghanaian oil marketing supply chains.

## **2.2 Blockchain Technology in Supply Chain Management**

The benefit of blockchain in supply chain management mostly stems from its ability to establish an auditable, tamper-resistant record of events shared among decentralised supply chain participants. The fundamental characteristics of immutability, decentralisation, and distributed consensus empower stakeholders to authenticate transactions independently of a central authority, hence minimising coordination expenses and augmenting confidence (Aba-Talib & Zouine, 2025; Karaduman, 2025). In the context of supply chain management, blockchain can monitor products, financial transactions, and contractual stipulations throughout a multi-tier network, providing a unified version of the truth for all stakeholders.

A substantial corpus of literature underscores blockchain's capacity to enhance traceability and visibility. Enhanced traceability enables stakeholders to track assets from their source to ultimate delivery, hence facilitating the early detection of abnormalities such as adulteration or diversion ((Oyeyemi et al., 2024); Deloitte, 2024). Traceability frameworks established for textile or food supply chains demonstrate how decentralised ledgers may document product status at each transition, offering transparency that bolsters consumer trust and mitigates information asymmetries (Agrawal, 2021). In the oil and gas industry, blockchain has been suggested as a tool to monitor custody transfers from refining to distribution phases, enhancing visibility into product movement and minimising chances for illicit diversions (Kishnani et al., 2023).

Research on blockchain usage frequently indicates favourable effects on inventory levels and lead times, highlighting its ability to optimise logistics and enhance resource planning (Vu, 2025). Notwithstanding these advantages, experts warn that blockchain implementation encounters many problems, such as scalability constraints, interoperability with existing systems, substantial initial expenditures, and governance issues in multi-party environments (Karaduman, 2025; Oyeyemi et al., 2024), 2025). In industries like oil marketing, where various independent entities engage from import terminals to depots and retail outlets, it is imperative to tackle these socio-technical difficulties through harmonised data standards, governance policies, and a unified commitment among stakeholders.

### 2.3. The Role of Artificial Intelligence in Supply Chain Management

The function of AI in supply chain management focuses on its capacity to automate decision-making, derive insights from extensive information, and facilitate intricate forecasting activities. Methods including machine learning, neural networks, and predictive analytics enhance supply chain systems' capacities to anticipate and react to fluctuating situations (Teixeira, 2025). AI integration has been linked to enhanced operational planning, increased responsiveness to demand fluctuations, and more efficient logistical resource utilisation. Systematic reviews indicate that AI applications in supply chain management improve predictive accuracy for demand forecasting and inventory optimisation, allowing enterprises to sustain optimal stock levels and react to fluctuating patterns with diminished human involvement (Teixeira, 2025; Jubair, 2025). These models generally depend on historical data, external indications (e.g., seasonal trends), and sophisticated learning algorithms to enhance predicting accuracy compared to conventional statistical methods. AI facilitates anomaly detection by spotting atypical patterns or variations that may indicate fraud or operational anomalies, such as gasoline adulteration or unauthorised transfers.

Research indicates that AI can enhance supply chain resilience through proactive risk management. Systematic assessments of AI in supply chain risk assessment demonstrate machine learning's capacity to identify risk patterns and enhance contingency planning, especially in situations involving supply disruptions or demand shocks (Jahin et al., 2023). Nonetheless, these researchers emphasise that successful implementation relies on data quality, suitable infrastructure, and proficient individuals to analyse model outputs elements that may be limited in emerging nations without solid digital ecosystems.

### 2.4. Interactions Between Blockchain and Artificial Intelligence

The marriage of blockchain and AI can yield synergistic advantages that surpass their individual contributions to supply chain enhancements. An expanding body of scholarship highlights that blockchain's reliable, decentralised ledger can provide a secure framework for AI algorithms, guaranteeing that analytics rely on dependable, traceable input data ((Oyeyemi et al., 2024); Kumar et al., 2025). Conversely, AI can augment blockchain by automating the decision-making criteria within smart contracts and facilitating dynamic modifications based on predictive analytics. A recent empirical analysis elucidates various methods by which blockchain and AI converge: instantaneous data interchange, improved collaboration, fraud detection, and synchronised decision-making among supply chain actors. This connection enhances transparency and responsiveness, enabling enterprises to more precisely identify unlawful activities and coordinate logistics operations ((Oyeyemi et al., 2024); Kumar et al., 2025). Furthermore, AI integration mitigates scalability obstacles of blockchain by facilitating intelligent prioritisation and compression of transactional data, hence diminishing latency and enhancing system throughput.

Notwithstanding the increasing scholarly endorsement for this integration, empirical data from extensive implementations is still scarce, particularly in industries such as oil marketing. Numerous studies indicate that pilot applications or conceptual frameworks necessitate significant technology preparedness, governance structures, and inter-organizational alignment for effective operationalisation. In emerging nations devoid of such infrastructure, research underscores the necessity for incremental adoption and capacity development to leverage the synergistic benefits of blockchain and AI.

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## 2.5. Theoretical Frameworks for Technology Adoption

Researchers often utilise established theoretical frameworks to elucidate the acceptance and diffusion of blockchain and AI within supply chain environments.

### Technology-Organization-Environment (TOE) Framework

The TOE framework asserts that the adoption of technology by organisations is affected by technological factors (e.g., perceived relative advantage, compatibility), organisational readiness (e.g., IT infrastructure, internal expertise), and environmental conditions (e.g., competitive pressure, regulation). Research on blockchain applications in supply chain management has employed the Technology-Organization-Environment framework to identify barriers and facilitators, revealing that technology maturity and inter-organizational governance substantially influence adoption pathways (Preprints.org, 2024).

### Theory of Diffusion of Innovations (DOI)

Rogers' Diffusion of Innovations theory highlights traits such relative advantage, compatibility, complexity, trialability, and observability as key factors influencing the diffusion process. The DOI framework has been utilised in research investigating the dissemination of blockchain and AI across industries, emphasising that demonstrable success in pilot applications and alignment with current systems facilitate acceptance among supply chain collaborators. The Unified Theory of Acceptance and Use of Technology (UTAUT) and Task-Technology Fit (TTF) models concentrate on individual and task-specific acceptance of technology, respectively. These methodologies have been modified to elucidate how end-users—such as logistics managers or depot operators—assess the utility and user-friendliness of blockchain and AI tools, influencing overall implementation success when users deem the systems beneficial for their operational responsibilities (Preprints.org, 2024).

### Resource-Based View (RBV)

The Resource-Based View posits that organisations derive competitive advantage from distinctive resources and competencies. In the realm of blockchain and AI, companies possessing superior data assets, digital competencies, and technological infrastructure are more likely to reap the benefits of adoption, whilst lagging organisations may encounter performance disparities. These frameworks collectively offer a multi-tiered perspective on the differential adoption rates of blockchain and AI among supply chain participants, as well as the internal or external variables that either support or impede integration.

## 2.6. Research Gaps and Directions

A notable deficiency in the literature is the scarcity of actual evidence about the comprehensive implementation of integrated blockchain and AI systems inside intricate supply chains, such as oil marketing, particularly in developing nations. Although literature offers strong conceptual frameworks and preliminary findings, there is a necessity for context-specific research that investigates actual operational performance, governance issues, and regulatory effects. A further gap exists in the integration of socio-technical elements (e.g., partner relationships, trust norms) with technical assessments, as adoption within multi-party oil marketing networks relies on collaboration and common standards. Research must investigate the ramifications of nascent AI subfields (e.g., explainable AI, massive language models) in orchestrating supply chain management choices utilising blockchain-validated data streams.

Finally, research concentrated on policy are essential to tackle regulatory challenges, data privacy difficulties, and cross-border data sharing protocols that affect adoption preparedness in countries such as Ghana.

### 3. METHODOLOGY

This study employs a conceptual framework technique, suitable for interdisciplinary fields to facilitate model/framework building. The research methodology integrated both inductive and deductive approaches to formulate the proposed framework; the deductive aspect involved a review of literature and documents from various companies, while the inductive aspect was grounded in empirical data gathered from data collection. In this research, 82 of the 170 OMCs were utilised. A total of 104 personnel were interviewed and observed, including chief executive officers, operations managers, marketing managers, information technology officers, forecourt attendants, station supervisors, liaison officers, and truck drivers. Primary qualitative data is gathered and integrated with existing literature on blockchain, artificial intelligence (AI), and supply chain management (SCM), along with contextual insights from Ghana's downstream petroleum sector, to formulate a structured, technology-enabled supply chain framework. The conceptual framework technique has four systematic stages: Problem Structuring, Theoretical Integration, Architecture Modelling, and Validation via Logical Consistency and Feasibility Analysis.

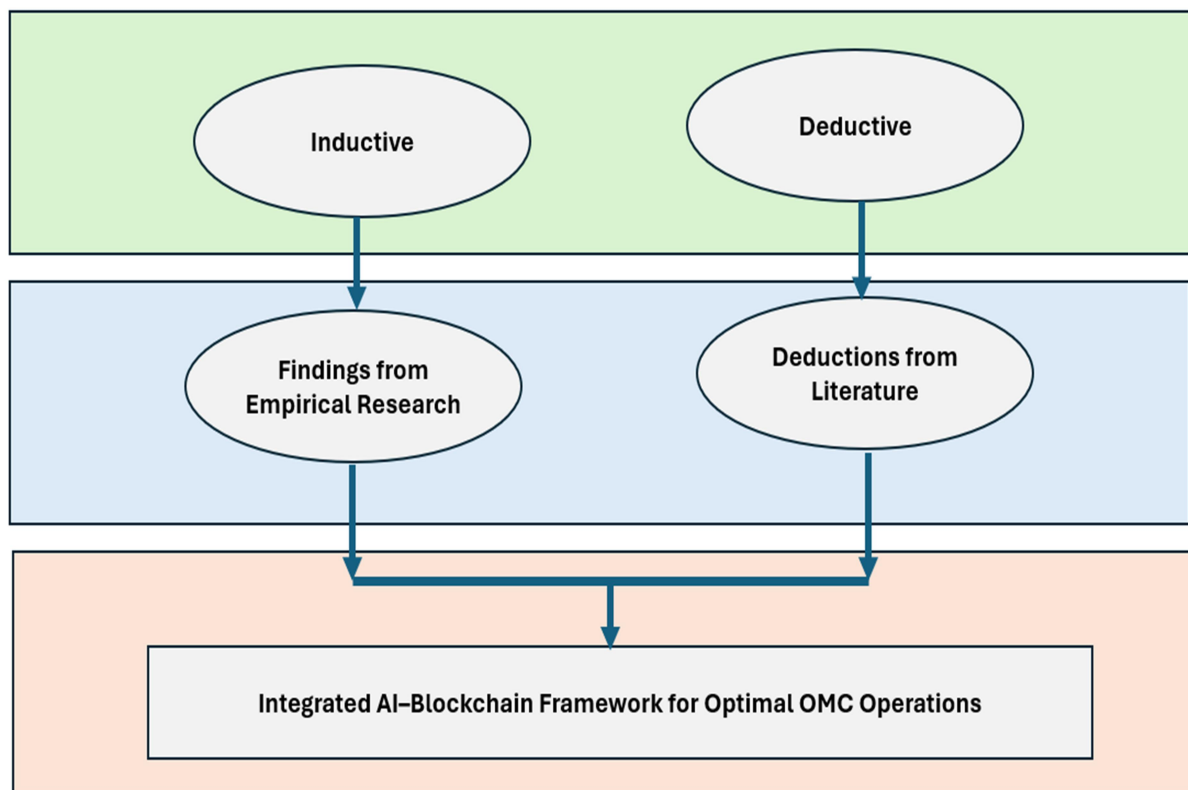


Figure 1: Research Approach

Source: Author(s)

6. DATA PRESENTATION

The Ghanaian Context

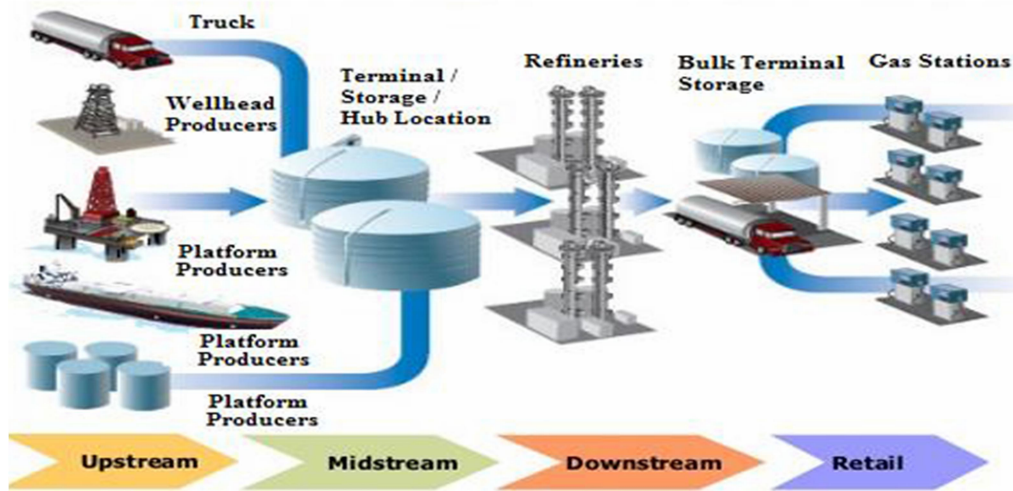


Figure 2: Ghana Petroleum Industry Value Chain  
 Source: Amponsah and Opei, (2014)

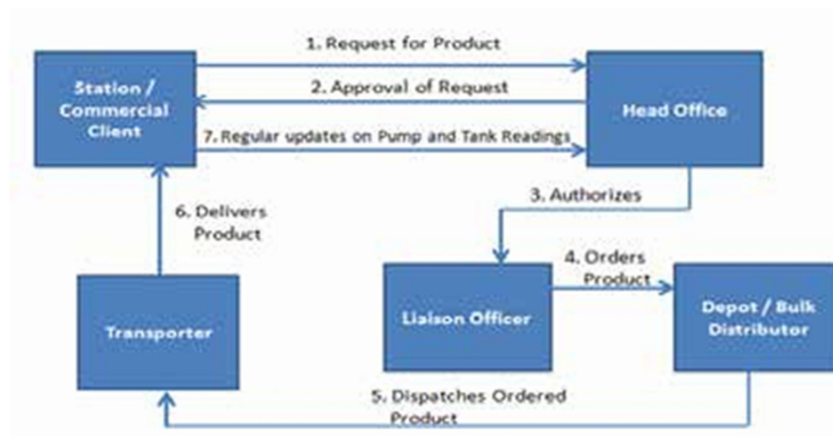


Figure 3: Typical Ghana OMC Supply Chain Process  
 Source: Danquah (2017)

The two diagrams depict the structural and operational dynamics of the petroleum supply chain and ordering process, pertinent to the Ghanaian oil marketing context and the broader discourse on the implementation of blockchain and artificial intelligence (AI) in supply chain management systems. Figure 2 illustrates the macro-level framework of the petroleum value chain, categorised into four principal segments: upstream, midstream, downstream, and retail. In the Ghanaian context, the upstream sector encompasses crude oil exploration and production activities, notably offshore production fields including Jubilee, TEN, and Sankofa.

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Despite Ghana's production of crude oil, a significant portion of the refined petroleum products utilised domestically is either imported or processed abroad prior to entering the local downstream market. The upstream stage pertains to crude extraction activities, but the downstream stage in Ghana is predominantly characterised by practical supply chain operations, as the majority of Oil Marketing Companies (OMCs) largely function within the downstream and retail sectors. The midstream phase in the diagram terminal storage and hub locations aligns in Ghana with bulk storage facilities overseen by entities such as the Bulk Oil Storage and Transportation Company (BOST) and privately owned depots. These facilities obtain refined petroleum products either from imports via Tema Oil Refinery (TOR) or from foreign sources at the ports of Tema and Takoradi. Amponsah & Opei (2014) assert that inefficiencies at this step, including as storage limitations, infrastructure bottlenecks, and transportation delays, have historically compromised the reliability and cost efficiency of Ghana's downstream petroleum sector.

The downstream section encompasses bulk terminal storage, transit via tanker trucks, and distribution to retail locations. In Ghana, petroleum products are mostly conveyed by road tankers from depots to service stations nationwide. This dependence on road transport creates vulnerabilities, including delays, diversion hazards, fuel contamination, and restricted real-time visibility of product transit. The retail phase comprises service stations and business clients where products are ultimately sold to consumers. Amponsah and Opei (2014) identify significant difficulties in Ghana's downstream petroleum supply chain, such as inadequate coordination among stakeholders, information asymmetry, infrastructural deficiencies, and ineffective monitoring systems. These structural deficiencies engender chances for fraud, lack of transparency, and inefficiency. The figure visually underscores the fragmented and multi-actor characteristics of the supply chain, highlighting the numerous custody changes that transpire between production, storage, transportation, and retail stages.

The second picture offers a detailed operational perspective of the ordering and replenishment process in Ghanaian Oil Marketing Companies. The process delineates a standard sequence commencing with a station or commercial client submitting a product request to the central office. The request undergoes assessment and approval, subsequently granting authorisation to a liaison officer who places an order with the depot or bulk distributor. The depot sends the product, a transporter conveys it to the station, and updates concerning pump and tank readings are relayed to the head office. This workflow illustrates the hierarchical and centralised decision-making framework common across numerous Ghanaian OMCs. Danquah (2017) notes that numerous OMCs depend on semi-manual procedures and outdated IT systems to oversee these interactions, resulting in delays, erroneous inventory reporting, and restricted real-time data exchange. Pump readings and tank measurements are frequently reported intermittently, leading to information delays that hinder demand forecasts and replenishment planning.

From a supply chain management standpoint, figure 3 reveals multiple deficiencies. Initially, it illustrates several layers of permission, which could impede response time. Secondly, communication is predominantly linear instead of integrated, heightening the likelihood of data silos among stations, depots, transporters, and the head office. The non fully of automated, tamper-proof transaction recording systems may facilitate gasoline diversion or adulteration during transportation. These challenges align with the concerns articulated by Amponsah and Opei (2014), who cited inadequate coordination and restricted information visibility as significant impediments in Ghana's downstream petroleum sector.

The two figures jointly demonstrate the crucial points for the introduction of technical interventions concerning blockchain and AI applications. Blockchain technology has the potential to improve the macro-level supply chain (figure 2) by documenting each custody transfer from depot to transporter to retail station on a decentralised ledger. This would enhance traceability and diminish potential for fraud or unauthorised diversions. Smart contracts may automate the authorisation steps illustrated in figure 3, thereby minimising bureaucratic delays and assuring adherence to established operational regulations. Conversely, artificial intelligence could improve demand forecasting and inventory management at both retail and depot levels. Through the analysis of historical sales data, seasonal consumption trends, and real-time tank measurements, AI systems could forecast replenishment requirements with greater precision than the predominantly reactive methodology presently illustrated. This would mitigate stockouts and surplus inventories while enhancing distribution scheduling.

In the Ghanaian context, the downstream petroleum sector exhibits fragmentation and coordination issues; thus, the integration of blockchain and AI could rectify the structural and operational inefficiencies highlighted in the literature. Danquah (2017) underscores that the shift to an IT-based supply chain management system is essential for enhancing performance in Ghanaian OMCs. The illustrations illustrate the present operational status and emphasise opportunities for digital transformation. The figure 2 depicts the structural flow of petroleum products via the upstream, midstream, downstream, and retail segments in Ghana, whilst figure 3 delineates the internal transactional and authorisation processes among parties in oil marketing operations. Both illustrations highlight systemic issues including inadequate visibility, coordination deficiencies, and dependence on manual reporting systems. These realities bolster the argument for utilising blockchain to enhance transparency and traceability, and AI to refine forecasting and operational decision-making within Ghana’s oil marketing supply chain.

**4. RESULTS FROM INTERVIEWS**

Table 1 presents a summary of the interviewees. Below are the details.

Table 1: Summary of Interviewees

No	Actor Rank	Quantity Interviewed
1	Chief Executive Officers	7
2	Operations Managers	12
3	Marketing Managers	15
4	IT Officers	20
5	Forecourt Attendants	20
6	Station Supervisors	12
7	Liaison Officers	8
8	Drivers	10
<b>Total</b>		<b>104</b>

### Operationalized Supply Chain Management System

All Oil Marketing Companies (OMCs) in Ghana are required to utilise the Enterprise Relational Database Management System (ERDMS), also known as the Electronic Reporting and Data Management (ERDM) system, to oversee, monitor, and administer the operations of OMCs and other downstream petroleum service providers. Noncompliance with requirements, including inadequate reporting via various channels, may result in penalties or the termination of licenses. Recent developments indicate that Automatic Tank Gauge (ATG) systems have been implemented at Oil Marketing Company (OMC) filling stations in Ghana as part of a project by the National Petroleum Authority (NPA). The implementation of ATGs is essential for monitoring fuel stock levels, identifying leaks, and managing inventories, hence addressing industry concerns such as potential under-delivery of fuel to customers.

Furthermore, the OMCs are required to implement and activate forecourt controllers. A forecourt controller is a hardware or software system that serves as the central hub for managing petrol station devices, including fuel dispensers, tank gauges, price poles, and car washes, by linking them to the Point-of-Sale (POS) and back-office systems. The technology is integral to a comprehensive, continuous digital transformation designed to mitigate unlawful gasoline distribution and enhance efficiency in the petroleum downstream sector. 70% of the interviewed companies had deployed the mandatory required systems ATGs and Forecourt Controllers, challenges of downtime were common amongst all of the OMCs with operationalized ATGs due to unreliable power supply.

### Responses Related to Process

The output of their feedback depicts the following as the supply chain cycle product request, approval, notification or authorization, product ordering, dispatch, receipt acknowledgement, forecourt updates, and end-to-end integration represent the core transactional workflow of Oil Marketing Companies (OMCs).

The details are namely:

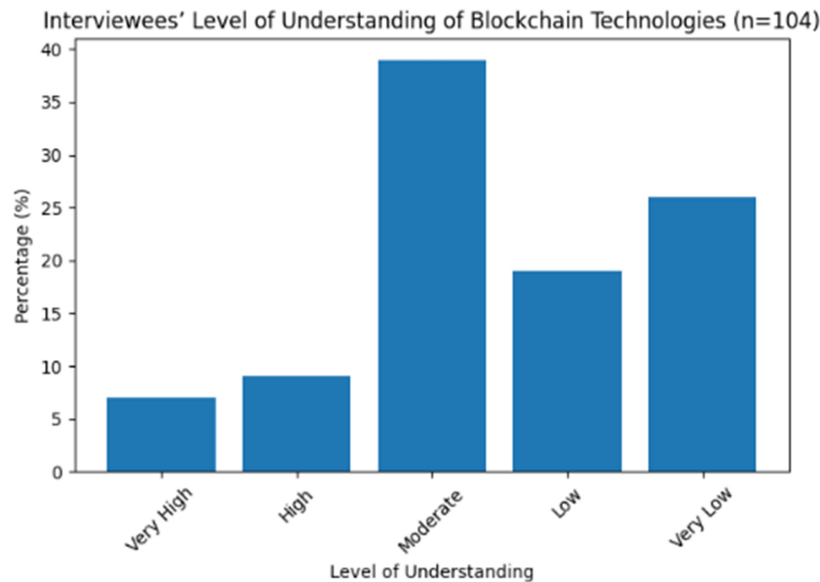
- a) **Product Request:** The product request stage begins at the retail service station or commercial client level. In Ghana, station managers typically monitor underground tank levels and submit replenishment requests to head office when stock approaches a minimum threshold. Traditionally, this process is manual or semi-digital, relying on periodic tank readings and historical sales patterns.
- b) **Approval:** Once a product request is generated, it moves to the approval stage. In Ghanaian OMCs, approval is often conducted at head office, where management verifies credit limits, regulatory compliance, and depot stock availability.
- c) **Notification or Authorization:** After approval, the system must notify relevant stakeholders. Traditionally, this involves emails, phone calls, or ERP entries communicated between departments.
- d) **Product Ordering:** The product ordering stage formalizes the volume and type of fuel to be dispatched. In conventional systems, this stage may rely on manual quantity determination or static reorder levels.
- e) **Dispatch:** Dispatch is one of the most critical and risk-sensitive stages in Ghana's oil marketing supply chain. Fuel diversion, route deviations, and adulteration risks often occur during transportation. At dispatch, depot loading details (volume, batch ID, tanker ID, timestamp), IoT-enabled meters confirm loaded quantities and GPS tracking monitors tanker movement in real time.

- f) **Receipt Acknowledgement:** Upon delivery to the retail station, receipt acknowledgement confirms successful custody transfer. Traditionally, this may involve manual signatures or paper documentation.
- g) **Forecourt Updates:** The forecourt is where fuel is dispensed to consumers. Continuous updates from pumps and tanks are essential for monitoring performance and detecting irregularities.

Retail stations continuously update their systems with pump sales volumes, remaining tank levels and throughput rates.

**Responses Related to Research Questions:**

It is essential to indicate that a relatively large percentage of the respondents did not understand and appreciate blockchain as a technology in particular, AI was relatively more appreciated by the respondents. The general responses to the research questions detailed below are a summary of responses by interviewees on the various research questions.



**Figure 4: Interviewees' Level Understanding of Blockchain Technologies**

The data reveals that most respondents had a moderate understanding of blockchain technologies (39%), followed by a significant percentage with very poor understanding (26%) and low understanding (19%). A mere fraction exhibits elevated (9%) or exceptionally elevated (7%) expertise.

Concerning the research objective, these findings indicate that although there is a basic awareness of blockchain in the sector, advanced technical understanding is still restricted. The prevalence of moderate-level comprehension indicates a receptiveness to digital innovation while underscoring the necessity for organised capacity-building programs, technical training, and executive awareness prior to comprehensive framework execution.

The significant percentage of individuals with poor and very low comprehension (45% combined) may provide obstacles to adoption, such as reluctance to change, misreading of technical advantages, and hazards associated with implementation. Consequently, the effective integration of blockchain with AI in Ghanaian oil marketing supply chains necessitates intentional knowledge transfer initiatives, stakeholder involvement, and pilot demonstrations to address competency deficiencies and improve organisational preparedness. The respondents' distribution of blockchain knowledge is likely to affect the study's conclusions in several ways. The prevalence of moderate comprehension (39%) indicates that the majority of participants can effectively participate in conceptual conversations regarding blockchain–AI integration. This enhances the dependability of insights concerning perceived advantages, implementation obstacles, and strategic coherence among Ghanaian Oil Marketing Companies (OMCs).

The significant percentage of individuals with low or very low comprehension (45%) may impact the depth and technical accuracy of responses. Participants with insufficient knowledge may offer perception-based opinions instead of experience-based ones, thereby creating informational bias. Consequently, findings concerning feasibility, technological integration complexity, and cost–benefit analyses may exhibit caution or ambiguity. In contrast, the smaller group with high or very high comprehension (16%) may have disproportionately influenced strategic or technically sophisticated recommendations, especially if they held managerial or ICT-related positions. This enables expert-driven viewpoints to shape overarching findings.

## 5. DISCUSSION OF FINDINGS

Below are the essential deductions from the responses.

### 1. Blockchain for Trust, Transparency, and Traceability

By establishing a distributed, impenetrable ledger of transactions, blockchain might greatly improve traceability and transparency among Ghanaian Oil Marketing Companies (OMCs). A time-stamped block that is available to authorised parties (such as the Bulk Oil Storage and Transportation Company, transporters, depots, regulators, and retailers) can be created for each supply chain event, including fuel lifting from depots, transportation, storage, and retail sales. This minimises the manipulation of volume, pricing, or quality data and lessens information asymmetry. By automating compliance checking (such as regulatory levies and quality standards), smart contracts can make sure that transactions are only carried out when certain requirements are satisfied. Thus, blockchain improves auditability, lowers the risk of fraud, diversion, and product adulteration, and replaces fragmented, paper-based records with a single source of truth, all of which increase actor confidence.

### 2. AI for Distribution, Forecasting, and Inventory Optimisation

In the supply chain for oil marketing, artificial intelligence (AI) can optimise key operational choices. In order to produce more precise demand estimates at the depot and retail levels, machine learning algorithms can examine past sales, seasonal trends, macroeconomic variables, and mobility patterns. By reducing stockouts and overstock scenarios that tie up working capital, this enhances inventory planning. Predictive analytics powered by AI can also identify the best times to place orders and maintain safety stock levels when demand is uncertain. Route optimisation algorithms in distribution can save transportation costs and enhance service quality by taking into consideration factors like delivery windows, fuel usage, and traffic conditions.

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Reinforcement learning models provide the ability to dynamically modify distribution plans over time in reaction to changes in supply or demand. In general, AI improves cost-effectiveness, responsiveness, and efficiency.

### **3. The Combined Effects of Blockchain and AI Integration**

Beyond their separate uses, blockchain and AI work together to produce synergistic benefits. Because blockchain prevents tampering and allows for real-time supply chain visibility, it guarantees high-quality, reliable data. Predictions and optimisation results are more accurate when AI models are trained on trustworthy, unchangeable datasets. AI may then examine transactional data stored on blockchains to find inefficiencies, anticipate fraud trends, and spot anomalies. Semi-autonomous supply chains can be made possible by smart contracts reinforced with AI decision rules. For instance, when demand spikes are predicted by predictive models, replenishment can be initiated automatically. When used in tandem, the framework enhances risk management, operational performance (cost, service level, lead time), and resilience to shocks like price volatility or supply shocks. Strategic agility, data-driven governance, and increased stakeholder confidence are all supported by the integrated system.

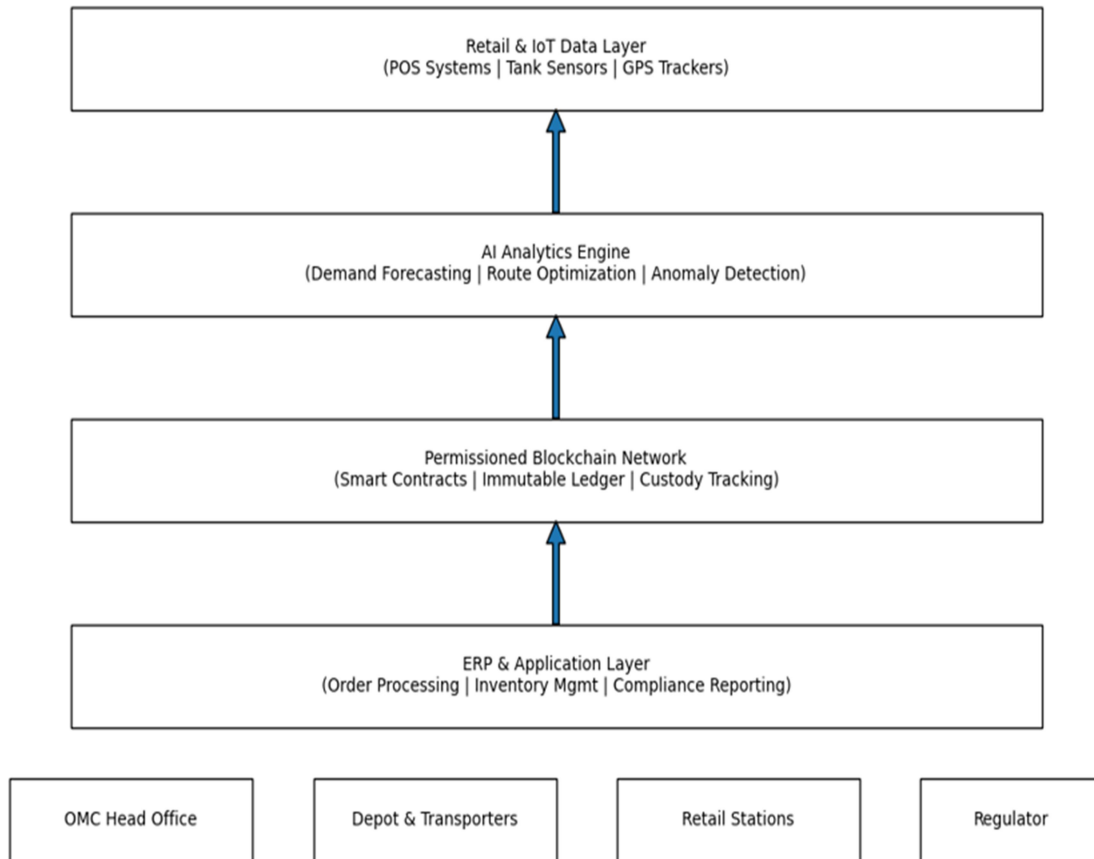
### **4. Adoption Factors in Organisations, Technology, and Regulations**

A number of interconnected elements influence adoption in Ghana's oil marketing industry. Support from upper management, digital preparedness, personnel expertise in blockchain and artificial intelligence, and the ability to manage change are all crucial from an organisational standpoint. Businesses must invest in employee training and match technology adoption with strategic goals. Feasibility is influenced by technological factors such as data quality, cybersecurity protections, integration with legacy enterprise systems, and infrastructure readiness (stable internet access, secure cloud services, interoperable systems). Clarity in regulations is also crucial. Data sharing, privacy, digital signatures, and the enforceability of smart contracts must all be covered by policies issued by data protection agencies and energy regulators. Industry-wide standards and incentives for digital innovation can hasten adoption across the ecosystem. Implementation runs the danger of fragmentation and limited impact in the absence of cooperative governance structures and cooperation between OMCs, regulators, and technology vendors. In conclusion, if strategy alignment, infrastructure maturity, and enabling regulations are met, an integrated blockchain-AI framework has the potential to revolutionise Ghanaian OMC supply chains.

### **Proposed Integrated AI-Blockchain Framework for Optimizing OMC Operations in Ghana**

Findings from interviews confirms Danquah (2017)'s identified critical intervention points within the Ghanaian oil marketing supply chain where information technology is used to improve operational efficiency, coordination, and transparency. These stages product request, approval, notification or authorization, product ordering, dispatch, receipt acknowledgement, forecourt updates, and end-to-end integration represent the core transactional workflow of Oil Marketing Companies (OMCs). While earlier IT interventions focused primarily on digitizing manual processes and integrating ERP systems, contemporary technological advancements such as Artificial Intelligence (AI) and blockchain provide a more transformative opportunity. Rather than simply automating existing processes, AI and blockchain can restructure OMC operations into predictive, secure, and transparent ecosystems.

This proposed integrated framework builds on Danquah’s process model and introduces a combined AI–blockchain architecture designed to enhance operational performance, reduce fraud, and strengthen trust across Ghana’s downstream petroleum supply chain.



**Figure 5: Visual representation of integrated framework**  
 Source: Author(s)

**Integration of Blockchain and AI Across the Product Request and Approval Stages**

In the conventional OMC framework, product requisitions are frequently initiated by retail stations based on regular tank measurements or sales projections. This reactive strategy may lead to stockouts, urgent restocking, or surplus inventory accumulation. The proposed methodology substitutes manual estimating with AI-driven predictive analytics for intelligent demand forecasting. Real-time data from IoT-enabled tank sensors and point-of-sale systems is integrated into machine learning models that evaluate previous consumption patterns, seasonal variations, regional demand trends, and pricing alterations. The AI system forecasts replenishment needs prior to stock levels attaining critical thresholds and autonomously initiates replenishment triggers. Upon generation, these requests are documented on a permissioned blockchain ledger.

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Smart contracts integrated within the blockchain validate certain circumstances, such as credit status, compliance requirements, inventory availability, and price policies, eliminating the need for several manual approval layers. Upon fulfilment of these conditions, approval is conducted automatically and openly. Only extraordinary instances necessitating managerial intervention are escalated. This technique minimises bureaucratic delays while preserving governance integrity and auditability. Notification, Authorisation, and Product Procurement: In traditional systems, post-approval communication across departments is typically sequential and fragmented, heightening the likelihood of data inaccuracies and delays. The proposed integrated framework enables blockchain smart contracts to promptly notify all pertinent stakeholders such as depot managers, transport coordinators, finance units, and compliance officers upon the granting of authorisation. Every notification is cryptographically authenticated and time-stamped, guaranteeing non-repudiation and resolving any questions over timing or validity.

The optimisation of product ordering is advanced by AI-assisted quantity assessment. The AI engine ascertains ideal order volumes by utilising safety stock calculations, economic order quantity principles, transportation efficiency metrics, and anticipated demand variability, instead of depending on fixed order numbers or manual computations. This data-centric methodology guarantees that every order corresponds with operational efficiency and cost reduction goals. The blockchain ledger synchronises order information among all stakeholders, eradicating information asymmetry between depots, headquarters, and retail outlets. Product Distribution and Logistics Oversight: The product dispatch phase constitutes a critical vulnerability within Ghana's oil marketing supply chain, characterised by significant risks of fuel diversion, adulteration, and unauthorised interruptions. The proposed system records dispatch data, including batch identity, loaded volume, tanker ID, and timestamp, on the blockchain at the loading site. This establishes an unalterable custody record that monitors the product from storage facility to retail location.

Concurrently, AI-driven logistics monitoring systems oversee tanker movements using GPS data streams. Machine learning algorithms evaluate route compliance, variations in journey time, and consistency in volume between loading and unloading locations. Any abnormality, including unanticipated route alterations or unaccounted volume reductions, prompts timely notifications to management. This dual-layer approach integrates blockchain's immutable recordkeeping with AI's real-time analytical capabilities, markedly enhancing transparency and mitigating fraud risk. Receipt Confirmation and Intelligent Resolution: Upon arrival at the retail station, IoT-enabled tank gauges autonomously measure the received fuel volume and confirm alignment with dispatch records. A digital confirmation is produced and recorded on the blockchain ledger, completing the transaction cycle. This obviates dependence on human receipt recording and diminishes reconciliation disagreements.

Smart contracts enhance the automation of financial settlement operations. Upon fulfilment of delivery criteria and digital verification, payment authorisation is automatically initiated in accordance with established contractual terms. This improves cash flow efficiency and diminishes administrative burdens linked to manual invoicing and verification processes. Forecourt Operations and Ongoing Surveillance: Danquah (2017) underscored the necessity of ongoing modifications to pumps and tanks to guarantee proper supervision. The integrated AI-blockchain framework substantially enhances this capability. AI-driven anomaly detection models continuously analyse real-time sales and inventory data from retail locations.

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These models juxtapose anticipated sales volumes with actual pump outputs and fluctuations in tank levels. Uncommon disparities may suggest gasoline contamination, leakage, or internal theft. Blockchain guarantees the secure storage of important performance data, preventing any retroactive modifications. Management dashboards offer visual analytics of station performance, facilitating data-driven decisions about replenishment cycles, promotional campaigns, and compliance oversight. This degree of transparency improves operational responsibility and fortifies trust between OMC headquarters and retail operators. Comprehensive Integration and System Architecture: The comprehensive integration of AI and blockchain throughout the supply chain creates a unified, intelligent ecosystem instead of fragmented digital solutions. The design comprises three interrelated components: an AI analytics engine, a permissioned blockchain network, and an integrated ERP/IoT infrastructure. The AI analytics engine conducts predictive forecasting, optimisation, and anomaly detection. The blockchain network operates as a decentralised trust framework, permanently documenting all essential transactions and executing smart contracts. Current ERP systems include operational interfaces that integrate with IoT sensors at distribution centers and retail locations. Collectively, these elements establish uninterrupted end-to-end transparency throughout refining, storage, distribution, and retail activities.

This integrated architecture eradicates data silos by synchronising information among stakeholders in real time. It facilitates automated compliance reporting to regulatory bodies, enhances audit preparedness, and bolsters governance transparency in Ghana's downstream petroleum industry. Operational Components of the Framework: The framework includes multiple essential functional modules. The Demand Forecasting Module use machine learning algorithms to predict consumption trends and initiate proactive replenishment. The Smart Contract Governance Module automates the processes of approvals, compliance verifications, and disbursement of payments. The Traceability Module documents custody transfers and product movements. The Logistics Optimisation Module improves route planning and delivery timing. The Anomaly Detection Module detects irregularities suggestive of fraud or inefficiencies. The Regulatory Reporting Module produces automatic compliance documents and performance dashboards. Each module engages through common data streams, guaranteeing that decisions rely on coherent and validated information.

### **Expected Operational Impact**

The combined AI-blockchain framework provides substantial operational enhancements for Ghanaian Oil Marketing Companies (OMCs). Predictive replenishment mitigates stockouts and emergency delivery. Route optimisation reduces transportation expenses and fuel usage. Unchangeable transaction records inhibit fraud and enhance accountability. Automated smart contracts expedite approvals and settlements. Real-time monitoring enhances supervision and adherence to regulations. By shifting from reactive, human overseen procedures to intelligent, automated solutions, OMCs may bolster supply chain resilience, mitigate operational risk, and promote stakeholder confidence.

## **6. CONCLUDING REMARKS**

This suggested integrated AI-blockchain architecture, based on Danquah's (2017) IT intervention model, revolutionises Ghanaian oil marketing processes into a predictive, transparent, and automated system. Instead of just digitising current procedures, it integrates intelligence and decentralised trust mechanisms throughout every phase of the supply chain from product requisition to final retail transaction.

The system utilises predictive analytics, smart contracts, and immutable transaction records to tackle coordination issues, fraud vulnerabilities, and inefficiencies present in Ghana's downstream petroleum sector. The outcome is a scalable, resilient, and future-oriented supply chain ecosystem that may facilitate sustainable growth in Ghana's oil marketing sector. The proposed integrated framework positions Artificial Intelligence (AI) and blockchain technologies as key and complementary in facilitating predictive, real-time, and automated supply chain operations inside Ghanaian Oil Marketing Companies (OMCs). IoT devices are prominently integrated in the operational periphery of the system, specifically at depots, tanker trucks, and retail service stations. Tank level sensors, pump meters, and GPS tracking devices consistently collect real-time data on fuel quantities, sales performance, and transportation activities.

This real-time operational data constitutes the fundamental input layer of the architecture. Artificial Intelligence functions at the analytical and decision-support level. AI algorithms analyse data supplied by IoT devices to execute demand forecasting, inventory optimisation, route planning, and anomaly detection. Machine learning algorithms forecast replenishment requirements prior to stock depletion and identify anomalous trends that may suggest diversion or adulteration. The Internet of Things (IoT) facilitates precise, real-time data acquisition, whereas Artificial Intelligence (AI) converts this data into usable insights, promoting proactive and optimised supply chain decisions. Future Research: It is advised that the proposed integrated AI-Blockchain framework for Ghanaian Oil Marketing Companies (OMCs) be validated for both conceptual innovation and internal logical coherence, as well as practical feasibility within Ghana's downstream petroleum sector. The validation will confirm that the framework is structurally robust, theoretically coherent, technologically feasible, and operationally pragmatic.

## 8. CONTRIBUTIONS TO KNOWLEDGE

Considering the study output, the framework utilizes predictive analytics, smart contracts, and immutable transaction records to tackle coordination issues, fraud vulnerabilities, and inefficiencies present in Ghana's downstream petroleum sector. The outcome is a scalable, resilient, and future-oriented supply chain ecosystem that may facilitate sustainable growth in Ghana's oil marketing sector. This offers the opportunity to refine policy and practice to optimise supply management within the sector.

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