**International Journal of Environmental Sciences**
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

# Adoption Of Big Data Analytics For Supply Chain Performance In Saudi Arabia's Private Hospitals: A TOE–SCOR Synthesis

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***Abstract***

***Background:*** *Private hospitals in the Kingdom of Saudi Arabia (KSA) face persistent supply chain challenges—stockouts, expiry losses, and long replenishment cycles—despite accelerating digital transformation. Big Data Analytics (BDA) can strengthen planning, sourcing, delivery, and returns; however, adoption pathways and performance effects remain fragmented across studies.*

***Objective:*** *To develop a practical framework for BDA adoption in healthcare supply chains in KSA by synthesizing determinants using the Technology–Organization–Environment (TOE) lens and mapping value mechanisms onto SCOR processes.*

***Methods:*** *We conducted a narrative synthesis of peer-reviewed and policy/industry literature (2013–2025); determinants were coded to TOE domains, and mechanisms were mapped to SCOR (Plan–Source–Make–Deliver–Return).*

***Results:*** *Relative advantage and compatibility emerged as the strongest technological drivers; top-management support and organizational readiness (including skills, data, and integration) were decisive organizational drivers; competitive pressure, group purchasing, unified procurement mechanisms, and supportive national policy acted as environmental catalysts. Illustrative mechanisms included improved demand forecasting (Plan), supplier scoring and traceability (Source), compounding data integrity (Make), cold-chain exception management (Deliver), and recall/returns analytics (Return).*

***Conclusions:*** *We propose a staged roadmap for KSA private hospitals: (1) foundational readiness and master data quality, (2) pilots in forecasting and supplier scorecards, (3) Deliver scale-up with cold-chain IoT and exception management, and (4) enterprise rollout with ROI governance. This approach aligns with national initiatives and can reduce stockouts and waste while improving service levels [1–8].*

***Keywords:*** *Big Data Analytics; Supply Chain; Technology–Organization–Environment (TOE); SCOR; Private Hospitals; Saudi Arabia*

***Abbreviations:*** *BDA (Big Data Analytics); SCOR (Plan–Source–Make–Deliver–Return framework); UDI (Unique Device Identification); GS1 (Global Standards 1); ERP (Enterprise Resource Planning); HIS (Hospital Information System); S&OP (Sales & Operations Planning); KPI (Key Performance Indicator); OTIF (On-Time-In-Full); 3PL (Third-Party Logistics); PHI (Protected Health Information); IoT (Internet of Things).*

## INTRODUCTION

### 1.1 The High-Stakes Environment of Healthcare Supply Chains

In the context of a modern hospital, the supply chain is far more than a back-office function; it is a critical determinant of clinical efficacy and patient safety. It functions as a significant cost and risk center, where failures have immediate and severe consequences. The seamless flow of materials—from high-alert medications and anesthesia supplies for the operating room to the infusion pumps and surgical devices essential for patient care—is directly dependent on the performance and resilience of procurement, inventory management, and logistics activities. A stockout of a critical pharmaceutical is not a mere inventory error; it can lead to a delayed procedure, a compromised treatment protocol, or a direct risk to a patient's well-being.

Similarly, a failure in the cold chain for a biologic or vaccine can render a high-value product inert, resulting in financial loss and a potential public health risk. The stakes are exceptionally high, demanding a level of precision, foresight, and control that traditional, reactive supply chain models struggle to provide.

### 1.2 Persistent Challenges in the KSA Private Sector

Despite the accelerating pace of digital transformation across the Kingdom, private hospitals continue to grapple with fundamental supply chain challenges. The most prominent among these are recurring stockouts of essential items and significant financial losses resulting from the expiration of perishable or slow-moving inventory. These issues are symptomatic of a deeper, systemic problem: profound data fragmentation.

Critical supply chain data is often trapped in functional silos, scattered across enterprise resource planning (ERP) systems, hospital information systems (HIS), specialized pharmacy management platforms, third-party logistics (3PL) telematics, and an increasing number of Internet of Things (IoT) sensors. Each system speaks a different language and captures a different piece of the puzzle. Conventional reporting methods, which typically rely on historical, aggregated data, are incapable of integrating these heterogeneous signals at the speed required for effective decision-making. This fragmentation creates critical blind spots, making it nearly impossible to anticipate demand shocks, such as those caused by epidemic surges or seasonal shifts in patient case mix. Furthermore, it conceals "silent losses", insidious issues, such as minor but cumulative temperature excursions in the cold chain or batch-level expiry risks that only become apparent when it is too late to act. Without a unified, analytical view of the end-to-end supply chain, hospitals are left in a perpetual state of reaction, fighting fires rather than preventing them. The application of BDA to healthcare supply chains is steadily increasing to address these issues.

### 1.3 The National Context as a Catalyst for Change

The operational challenges within private hospitals are unfolding against a backdrop of unprecedented national transformation in Saudi Arabia, which creates a uniquely fertile ground for BDA adoption. These external environmental factors act as powerful catalysts, providing both the strategic impetus and the foundational infrastructure for change.

First, the **Health Sector Transformation Program**, a core pillar of **Saudi Vision 2030**, establishes a clear national direction toward a healthcare system that is data-driven, patient-centric, and highly efficient. This top-down strategic mandate provides significant "air cover" for hospital leadership to champion and invest in digital and analytical capabilities. It reframes BDA projects not as discretionary IT upgrades, but as essential initiatives directly aligned with national priorities.

Second, the growing influence of **NUPCO**, the national company for unified procurement, is reshaping market dynamics. While primarily focused on the public sector, NUPCO's scale and standardization efforts are elevating expectations across the entire healthcare ecosystem.

Regarding service levels, traceability, and cost discipline. Private hospitals that interact with or compete in this environment face increasing pressure to adopt similar levels of data-driven sophistication in their own sourcing and logistics operations.

Third, and perhaps most consequentially, is the **Saudi Food and Drug Authority's (SFDA) mandate for Unique Device Identification (UDI)** . This regulation, which aligns KSA with global best practices, requires item-level identification for medical devices and anticipates the establishment of a national track-and-trace architecture. While this presents a significant compliance obligation, it also offers a transformative opportunity. The most pervasive internal barrier to successful BDA implementation is consistently identified as weak or inconsistent master data, including duplicate item codes, missing identifiers, and inaccurate vendor information. The process of becoming UDI-compliant forces an organization to undertake the rigorous and often politically challenging work of cleansing and standardizing its item master data. A forward-thinking hospital executive will recognize this dynamism not as a burden, but as a powerful accelerator. By

strategically framing the UDI compliance project as the foundational data governance phase of a broader BDA initiative, the regulatory deadline can be leveraged to drive the necessary internal changes. This approach transforms a mandatory compliance cost into a strategic investment that directly enables higher-value analytics applications, such as precise demand forecasting and rapid recall management, thereby accelerating the entire BDA journey and enhancing its ultimate return on investment.

# 2. METHODS

We conducted a narrative synthesis of literature from 2013 to 2025, encompassing healthcare logistics, pharmacy operations, medical device traceability, and the adoption of analytics. The search included peer-reviewed articles from databases such as IEEE Xplore, PubMed/PMC, and Scopus, as well as reputable industry white papers and KSA policy sources, including Vision 2030, SFDA, and NUPCO documents [1–13]. Search terms included "healthcare supply chain analytics," "SCOR healthcare," "Saudi UDI," and "NUPCO procurement." The selection criteria emphasized hospital relevance, determinants of analytics adoption, and KSA or GCC comparators. Findings were coded against the TOE framework's determinants—Technological, Organizational, and Environmental—and mapped to SCOR processes. The synthesis relies on secondary evidence, a limitation mitigated by triangulating cross-industry analytics literature with the specific KSA policy and infrastructure context [3–8, 11–13].

# 3. RESULTS

## 3.1 A Framework for Adoption: Key Determinants and Success Factors

To systematically analyze the complex interplay of forces shaping the adoption of BDA in hospital supply chains, the Technology–Organization–Environment (TOE) framework provides a robust and validated lens. This model posits that the decision to adopt and implement new technology is influenced by three distinct but interrelated contexts: the characteristics of the technology itself (Technology), the internal characteristics of the organization (Organization), and the external environment in which the organization operates (Environment). By examining the specific drivers, barriers, and enablers within each of these domains, a clear and actionable picture of the adoption landscape emerges.

### 3.1.1 Technological Determinants

The technological context concerns the attributes of BDA platforms and solutions themselves. The primary driver for adoption in this domain is **Relative Advantage**—the clear and compelling promise that BDA will deliver superior performance compared to existing methods. This advantage is manifested in tangible outcomes, including fewer stockouts, reduced expired waste, and improved clinical service levels. Another critical factor is **Compatibility** with the hospital's existing technology stack. BDA solutions must seamlessly integrate with legacy ERP, HIS, and pharmacy systems. Finally, **Interoperability**, particularly with emerging data standards like GS1 and UDI, is increasingly vital for enabling end-to-end traceability that supports patient safety and regulatory compliance. While **Perceived Complexity** can act as a barrier, this is often mitigated when solutions are designed to be modular and are supported by capable vendor partners.

### 3.1.2 Organizational Determinants

The organizational context is frequently the most decisive in determining the success or failure of a BDA initiative. Within this domain, **Top-Management Support** is the indispensable catalyst, translating strategic intent into the tangible allocation of resources. Equally decisive is **Organizational Readiness**, a multifaceted concept that encompasses (i) the quality and governance of the underlying data, (ii) the technical infrastructure for data integration, and (iii) the availability of human talent with skills in data analysis and engineering. Common barriers that undermine readiness include persistently siloed data, weak master data management, a scarcity of qualified analytics professionals, and the proliferation of disconnected point

solutions that create new silos. Enablers that foster readiness include the establishment of formal data governance councils, the creation of a centralized analytics Center of Excellence (CoE), and the use of modular pilots with clear, pre-defined Key Performance Indicator (KPI) baselines to demonstrate value quickly [4–6, 10–12].

### 3.1.3 Environmental Determinants

The external environment provides a robust set of incentives and supports the adoption of BDA. **Competitive Pressure** among private healthcare providers is a significant motivator, as hospitals seek to differentiate themselves based on patient experience, operational efficiency, and clinical outcomes. Similarly, the expectations of **accreditation bodies** increasingly include robust data management and performance transparency, further incentivizing investment in analytics. The most potent environmental catalysts are the supportive **national initiatives** within KSA. Vision 2030, NUPCO's unified procurement mechanisms, and the SFDA's UDI mandate collectively shape incentives and lower adoption barriers by promoting the standardization of data and fostering a collaborative ecosystem [3–7, 11–13].

**Table 1: TOE Framework Synthesis of BDA Adoption Factors**

| Determinant Domain | Drivers | Barriers | Enablers |
|---|---|---|---|
| **Technology** | Relative Advantage (fewer stockouts, less waste); Compatibility with existing ERP/HIS. Interoperability with GS1/UDI standards | Perceived Complexity; Legacy integration constraints | Modular, vendor-supported solutions; Standards-based integration (APIs); Master data alignment |
| **Organization** | Top-Management Support (resourcing); | Siloed data; Weak master data quality; | Analytics Center of Excellence (CoE); Data |
| **Determinant Domain** | Drivers | Barriers | Enablers |
| | Organizational Readiness (data, talent, integration); Cross-functional governance | Scarce analytics talent; Point solutions creating new silos | governance councils; Modular pilots with clear KPI baselines; Vendor SLAs tied to data quality |
| **Environment** | Competitive Pressure & Accreditation; Supportive National Policy (Vision 2030); Unified Procurement (NUPCO); Regulatory Mandates (SFDA UDI) | Heterogeneity in IT maturity across providers | Data standardization driven by policy; Mandated supplier collaboration; National digital health initiatives |

## 3.2 Unlocking Value Across the Supply Chain: BDA Applications and Performance Impact

To move from high-level strategy to concrete application, it is essential to map the potential of BDA onto the core processes of the supply chain. The Supply Chain Operations Reference (SCOR) model, with its five-stage framework of Plan–Source–Make–Deliver–Return, provides an ideal structure for this purpose.

### 3.2.1 Plan: From Reactive Ordering to Proactive Demand Sensing

In the **Plan** stage, BDA transforms demand forecasting into a proactive process of demand sensing. By fusing diverse data streams—including historical consumption patterns, patient case-mix data, supplier lead-time variability, and seasonality signals—analytics models can generate significantly more accurate forecasts. This enables the optimization of safety stock levels, thereby reducing stockouts while preventing overstocking. Furthermore, BDA enables sophisticated scenario planning, a capability of value in the KSA context for preparing for demand surges associated with events like the Hajj and Umrah seasons.

### 3.2.2 Source: Data-Driven Supplier Relationship Management

During the **Source** stage, BDA empowers hospitals to manage supplier relationships with analytical rigor. The creation of comprehensive **supplier scorecards** is a primary value mechanism that aggregates objective performance data, including on-time-in-full (OTIF) delivery rates, quality incidents, and temperature excursion data. This enables the negotiation of risk-adjusted contracts and data-driven allocation of business to the most reliable partners.

### 3.2.3 Make: Enhancing Pharmacy and Sterile Services

While hospitals are not traditional manufacturers, the **Make** stage of the SCOR model finds its parallel in internal value-adding processes, such as pharmacy compounding and central sterile services departments (CSSD). In these environments, analytics can strengthen batch scheduling, monitor environmental compliance, and improve yield monitoring for compounded medications.

### 3.2.4 Deliver: Ensuring Integrity from Warehouse to Ward

The **Deliver stage, encompassing logistics and distribution, holds immense potential for BDA, particularly through the use of** IoT. For temperature-sensitive products, **cold-chain IoT sensors** provide real-time data that enables proactive exception management. Predictive models can also provide more accurate estimated times of arrival (ETAs), improving receiving efficiency.

Furthermore, **lane analytics**, which assesses the historical performance of shipping routes, can guide strategic decisions to mitigate risks.

### 3.2.5 Return: Transforming Waste into Intelligence

In the **Return** stage, BDA transforms a chaotic process into a source of valuable intelligence. By digitizing return data, hospitals can identify the root causes of issues such as picking errors or ward-level overstocking. This is particularly critical for product recalls, where BDA, enabled by UDI traceability, can dramatically accelerate the identification and quarantine of affected products, improving patient safety and compliance.

### 3.2.6 The Cross-Cutting Impact of Transparency

Underpinning these improvements is the cross-cutting benefit of enhanced transparency, driven by the integration of UDI and GS1 standards into ERP and HIS systems. This item-level visibility eliminates ambiguity and reduces manual reconciliation effort, freeing up staff for more value-added analytical activities.

**Table 2: SCOR-Aligned BDA Value Mechanisms and Core KPIs**

| SCOR Process | BDA Value Mechanism | Core KPIs Impacted |
|---|---|---|
| **Plan** | Demand Sensing (fusing consumption, case-mix, seasonality); Scenario Planning (for surges like Hajj/Umrah) | Forecast Accuracy (MAPE, Bias); Service Level / Stockout Events; Expiry Loss (%) |

| | | |
|---|---|---|
| **Source** | Supplier Scorecards (OTIF, quality, excursions); Risk-Adjusted Contract Evaluation | On-Time-In-Full (OTIF) (%); Supplier Defect Rate; Working Capital (Days Inventory on Hand) |
| **Make** | Batch Scheduling Optimization (Pharmacy Compounding). Environmental Compliance Monitoring | Compounding Yield (%); Batch Compliance Rate |
| **Deliver** | Cold-Chain IoT with Real-Time Exception Alerting; Predictive ETAs & Lane Risk Analytics | Temperature Excursion Rate. On-Time Delivery (%); Expedition Costs |
| **Return** | Digitized Recall Response & Root-Cause Analytics; Waste & Expiry Analysis | Recall Response Time; Returns Rate (%); Expiry Loss (Value) |

# 4. DISCUSSION

## 4.1 A Strategic Roadmap for BDA Implementation

A successful BDA implementation is not a single event but a journey of organizational learning and capability maturation. A common cause of failure is attempting to achieve too much, too soon. To avoid this pitfall, a staged, pragmatic roadmap is essential. The proposed four-stage approach is designed to strike a balance between ambition and feasibility, building a solid foundation first, demonstrating value through targeted pilots, and then scaling capabilities across the entire enterprise.

### 4.1.1 Stage 0 – Foundations: Laying the Groundwork

This initial, non-negotiable stage is dedicated to establishing the bedrock upon which all future analytics capabilities will be built. Key activities include forming a cross-functional steering group, adopting GS1/UDI identifiers, cleansing master data (including items, vendors, and locations), defining data ownership, and implementing secure integration pipelines.

### 4.1.2 Stage 1 – Plan: Achieving Early Wins in Forecasting

With a solid foundation, the program moves to its first value-delivery stage, focusing on demand planning. Key activities include building a demand-forecasting sandbox, integrating consumption and lead-time data, baselining forecast accuracy (e.g., MAPE, bias), and deploying a consensus Sales & Operations Planning (S&OP) process for critical SKUs.

### 4.1.3 Stage 2 – Source: Optimizing Supplier Performance

Building on internal improvements, the focus shifts to external partners. This stage leverages data to drive better performance from the supplier base. Key activities include launching supplier scorecards (tracking OTIF, quality incidents, etc.) and embedding analytics into sourcing processes and contract reviews.

### 4.1.4 Stage 3 – Deliver: Mastering Logistics and Cold Chain

This stage tackles the complex challenges of logistics and distribution. Key activities include implementing cold-chain IoT for real-time monitoring on high-risk lanes, tracking biologics and vaccines with end-to-end visibility, standardizing root-cause codes for temperature excursions, and piloting predictive ETAs.

### 4.1.5 Stage 4 – Scale & Sustain: Embedding Analytics into the Operating Model

The final stage focuses on institutionalizing BDA as a core business capability. Key activities include establishing an Analytics Center of Excellence (CoE), publishing monthly KPI dashboards, linking savings to the budget, refreshing data governance annually, and aligning with NUPCO collaborations where relevant [3–7, 11].

**Table 3: The Four-Stage BDA Implementation Roadmap**

| Stage | Primary Objective | Key Activities | Expected Outcomes |
|---|---|---|---|
| **0: Foundations** | Establish clean, governed, and accessible data. | From steering group; Adopt GS1/UDI standards; Cleanse master data (item, vendor); Define data ownership | Trustworthy master data; Secure data integration pipelines; Clear governance structure |
| **1: Plan** | Demonstrate value via improved forecasting | Build forecasting sandbox; Integrate consumption & lead- time data; Baseline forecast accuracy (MAPE); Deploy S&OP for critical SKUs | Measurable reduction in forecast error; Reduced stockouts on critical SKUs; Cross-functional alignment on demand |
| **2: Source** | Drive supplier performance with data | Launch supplier scorecards (OTIF, quality); Embed analytics in bid evaluation; Integrate analytics into contract reviews | Objective supplier performance visibility; Data-driven sourcing decisions; Improved inbound reliability |
| **3: Deliver** | Enhance logistics and cold-chain integrity. | Implement cold-chain IoT on high-risk lanes; Track biologics/vaccines; Pilot predictive ETAs. | Reduced temperature excursions; Proactive exception management. Improved delivery predictability |
| **4: Scale & sustain** | Institutionalizing analytics as a core capability. | Establish analytics CoE; Publish executive KPI dashboards; Link savings to budget. Refresh data governance annually. | Enterprise-wide analytics capability; Sustained financial & clinical benefits. Culture of data-driven decision-making |

## 4.2 The Business Case and Financial Blueprint for BDA Investment

A compelling business case for BDA must transcend a narrow focus on cost reduction and speak to the hospital's dual mission of financial stewardship and clinical excellence. The economic case should be framed around a balanced scorecard of benefits, explicitly connecting financial gains to improvements in patient care, such as fewer missed medication doses or operating room delays.

To provide a concrete financial blueprint, an illustrative business case for a hypothetical 250-bed private hospital is presented. Assuming an annual consumables spend of SAR 60 million, a staged BDA program is projected to achieve significant improvements in service levels, stockouts, expiration losses, and expedited costs. These operational improvements translate into an estimated total direct annual benefit of approximately **SAR 2.73 million**. Against estimated Year-1 investment costs of **SAR 1.8 million** (for data

engineering, tooling, telemetry, and change management), this yields a compelling first-year ROI of approximately **52**%, comfortably meeting standard financial hurdles for approval.

**Table 4: Illustrative BDA Business Case Financial Model**

| Financial Component | Baseline / Assumption | Target Improvement | Year 1 Value (SAR) |
|---|---|---|---|
| **ANNUAL BENEFITS** | | | |
| Avoided Stockout Impact | 180 events/year | -35% (proxy value) | 2,000,000 |
| Financial Component | Baseline / Assumption | Target Improvement | Year 1 Value (SAR) |
| Expiry Loss Reduction | SAR 1.08M/year (1.8%) | -30% | 360,000 |
| Expedition Cost Reduction | SAR 1.2M/year | -25% | 300,000 |
| Working Capital Gains | 10% cost of capital | 5 fewer days of inventory | 68,000 |
| Total Annual Benefit | | | 2,728,000 |
| YEAR 1 COSTS | | | |
| Data Engineering & Integration | | | (900,000) |
| Analytics Tooling | | | (400,000) |
| Telemetry & Gateways | | | (300,000) |
| Change Management & Training | | | (200,000) |
| Total Year 1 Cost | | | (1,800,000) |
| FINANCIAL RETURN | | | |
| Year 1 Net Benefit | | | 928,000 |
| Year 1 ROI | | | 51.6% |

### 4.3 An Operational Playbook for Execution and Governance

To translate the roadmap into tactical execution, a focused 6- to 9-month release plan provides a framework for delivering value rapidly. This playbook prioritizes foundational work (Months 0–2), platform setup and baselining (Months 2–4), pilot deployment (Months 4–6), and program expansion (Months 6–9). Effective data governance is critical and should be based on the principle of **domain-oriented ownership**, where accountability for data quality resides with the functional teams that create and use the data (e.g., Pharmacy governs the item master, Supply Chain governs the vendor master). This structure is supported by a **shared business glossary** that provides unambiguous definitions for all key KPIs.

### 4.4 Risk Management and Sustainability

A proactive approach to risk management is essential. A formal risk register should be established to identify and mitigate threats across data, process, technology, regulatory, and financial domains. It is also well-documented that large-scale transformation projects fail "less due to algorithms and more due to sociology". Therefore, a deliberate and well-resourced change management plan is not optional. Success depends on making the benefits of analytics tangible and relevant to the daily work of frontline staff by communicating the clinical impact and co-creating solutions with users.

## 5. CONCLUSION

The Adoption of Big Data Analytics within the supply chains of private hospitals in KSA is both a timely imperative and a tractable endeavor. BDA must be approached as a strategic, capability-building initiative, rather than a simple technology procurement project. The journey is best navigated through a pragmatic, staged roadmap that prioritizes foundational data governance, proves value through targeted pilots, and scales methodically. The uniquely supportive national context, including Vision 2030 and the SFDA's UDI mandate, should be leveraged as a powerful Accelerants to drive internal change [1–8, 11–13]. By adopting this framework, hospitals can effectively reduce costly stockouts and waste, while also improving clinical service levels and ensuring regulatory compliance. Future research should focus on rigorously quantifying the causal impact of BDA on clinical and financial outcomes, as well as exploring the interface between private hospital analytics and national platforms, such as NUPCO, to unlock system-wide efficiencies.

**Declarations**

**Ethics approval:** Not applicable (secondary synthesis). **Patient consent:** Not applicable.
**Funding:** None. **Conflicts of interest:** None declared. **Data availability:** Not applicable.

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