

ORIGINAL RESEARCH ARTICLE

The role of semantic technologies in addressing systems and data challenges in pharmaceutical supply chains

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Abstract

As one of the world's most complex and critical networks, the pharmaceutical supply chain (PSC) relies heavily on effective data integration and interoperability. Seamless data exchange is essential to support product availability, ensure end-to-end traceability, and facilitate informed decision-making. This study identifies data and systems challenges within the Saudi Arabia PSC and examines how semantic technologies (ST) can assist in addressing them. A qualitative study was conducted using purposive sampling and snowball techniques with semi-structured interviews, followed by thematic content analysis to identify PSC data and systems challenges. The identified challenges were analyzed from the perspective of whether they could be addressed using ST, based on insights from the existing literature. The present study identified seven key challenges in the PSC, emphasizing data integration, standardization, quality, analysis, and clarity, and areas where ST may provide full or partial support. This study provides original insights by identifying key themes and sub-themes through qualitative analysis, highlighting the complexities affecting data and systems integration within the Saudi PSC. Additionally, it provides a literature-informed mapping of ST capabilities to the identified challenges, identifying areas that may be fully, partially addressed, or remain beyond the scope of ST. The findings are further interpreted through the lens of institutional theory to explain how governance structures, organizational practices, and stakeholder coordination influence interoperability and data integration within the Saudi PSC.

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1. Introduction

The pharmaceutical supply chain (PSC) is one of the most complex and critical supply chains (SCs) globally due to its direct impact on human life and national health systems. Unlike other sectors, delays or disruptions in the PSC can immediately affect patient outcomes, public safety, and healthcare delivery.¹ Recent research has highlighted that essential medicine shortages—exacerbated by pandemics and geopolitical crises—are now a global concern, affecting healthcare systems across both developing and industrialized nations.¹ These disruptions not only risk patient health but also strain healthcare infrastructures, undermine public trust, and increase economic pressure on

governments. The PSC encompasses all organizational, operational, and value-adding activities necessary for the development, production, and delivery of drugs to consumers in a safe condition.² Therefore, effective PSC management is pivotal to enhancing public access to essential medications.³

Despite increased international collaboration and digital transformation efforts, the pharmaceutical sector continues to face persistent challenges in systems and data integration. Regulatory complexity, inconsistent technology adoption, and limited standardization across regions act as significant barriers to effective SC coordination.⁴ While interdisciplinary and cross-border partnerships are essential for standardizing best practices and scaling innovative solutions, hesitation to fully adopt advanced digital systems remains a core obstacle. These systems and data integration issues continue to limit traceability, delay data sharing, and constrain the capacity of SC actors to respond to demand shifts efficiently.⁴

Semantic technologies (ST) focus on understanding and connecting the meaning behind computer-based content and what users are trying to express. The goal is to improve how different types of content are searched, organized, used, and even generated. ST techniques generally aim to make sense of large or complex datasets, even when there is no prior knowledge or structure provided for them.⁵ ST encompasses a range of tools and methods, including terminological systems that offer structured ways to represent data, along with advanced schema definitions and syntactic frameworks that support precise interoperability between heterogeneous sources.⁶ Among these semantic components, ontologies stand out as machine-readable knowledge structures that use globally unique identifiers to enhance data integration. They are particularly valuable in domains like personalized healthcare, where they help uncover new insights into disease mechanisms.^{7,8} Knowledge graphs add further capability by organizing information as interconnected nodes and relationships, making it possible to model and explore complex associations within large datasets.⁹

A well-known implementation of these technologies is the Semantic Web, which is conceived as an evolution of the traditional web to assign explicit meaning to data, enabling collaboration between humans and machines.¹⁰ ST offer a consistent structure for reusing, combining, and interpreting data from multiple sources. They facilitate data integration by converting heterogeneous data into a valid and reliable knowledge base.¹¹ In data-intensive environments such as PSCs, which are often characterized by fragmented systems and inconsistent formats, ST have the potential to enable semantic interoperability,

automated reasoning, and scalable data integration.

In our previous study¹², we explored how ST, including ontologies and knowledge graphs, can be combined with blockchain technology to enhance data interoperability, security, and traceability across various domains, including SCs. The study highlighted the technical challenges and potential of integrating semantic indexing, resource description framework data, and ST-driven reasoning mechanisms with decentralized blockchain infrastructures. The present study moves toward implementation by examining the practical challenges of data and systems fragmentation in the national PSC. Specifically, it explores how ST can address interoperability gaps in the Saudi PSC, offering grounded insights that move beyond theoretical frameworks into real-world organizational contexts.

1.1. Global context of pharmaceutical supply chains

Pharmaceutical SCs around the world operate under varying models of governance and coordination, which can be classified primarily as decentralized and centralized structures.¹³ In decentralized models, procurement and distribution responsibilities are dispersed among various healthcare stakeholders, including individual healthcare providers, regional authorities, or healthcare institutions. While this structure allows for local flexibility and responsiveness, it often results in inefficiencies such as fragmented data flows, inconsistent procurement practices, limited traceability, and reduced coordination across the SC.¹⁴ [Figure 1](#) illustrates the structure of a decentralized PSC model.

In contrast, centralized systems consolidate procurement and distribution under a single national authority or regulatory body. This enables greater standardization, improved oversight, and enhanced visibility across the SC.^{14,15} Centralized replenishment policies have been shown to improve coordination, minimize overall system costs, and enhance SC visibility compared to decentralized approaches, particularly in pharmaceutical contexts where constraints such as expiry dates and regulations are critical.^{16,17} [Figure 2](#) shows the structure of a centralized PSC model.

In recent years, many countries have shifted from decentralized to centralized PSC models to strengthen accountability, optimize logistics, and improve public health responsiveness. One notable example is China, where the implementation of the National Volume-Based Procurement system has achieved significant cost savings and supply efficiencies through centralized purchasing.¹⁸ Another notable case is Saudi Arabia, which has been undergoing a transition to centralized pharmaceutical procurement and broader PSC integration since 2009,

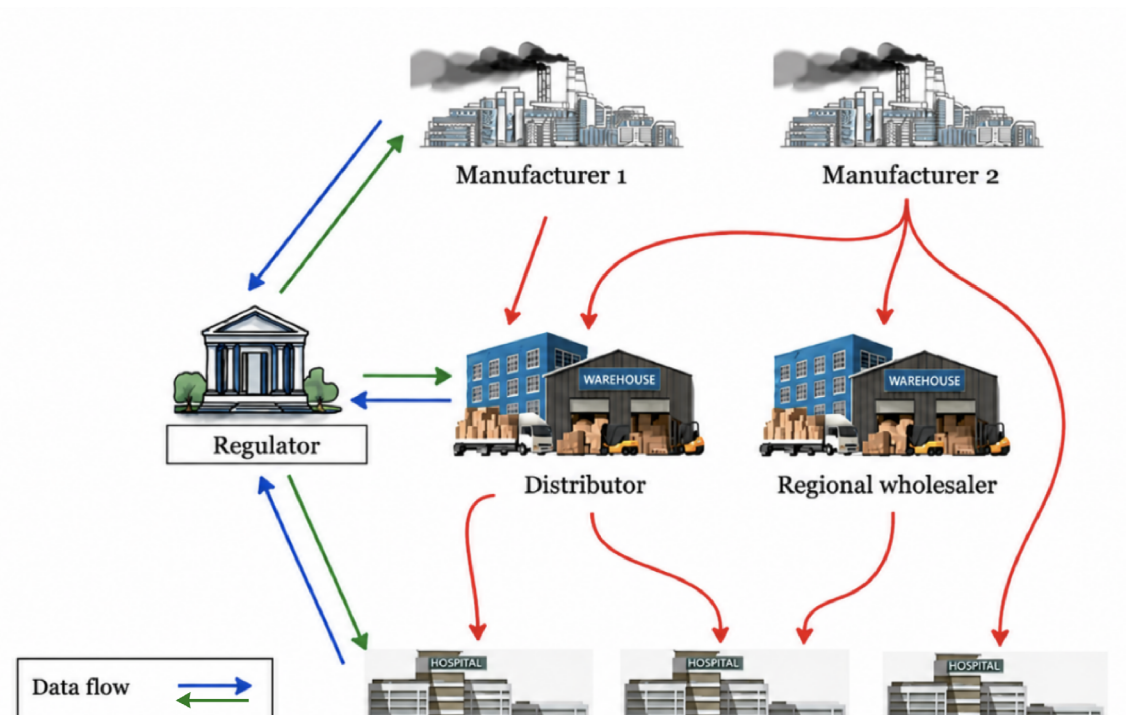


Figure 1. Structure of a decentralized pharmaceutical supply chain

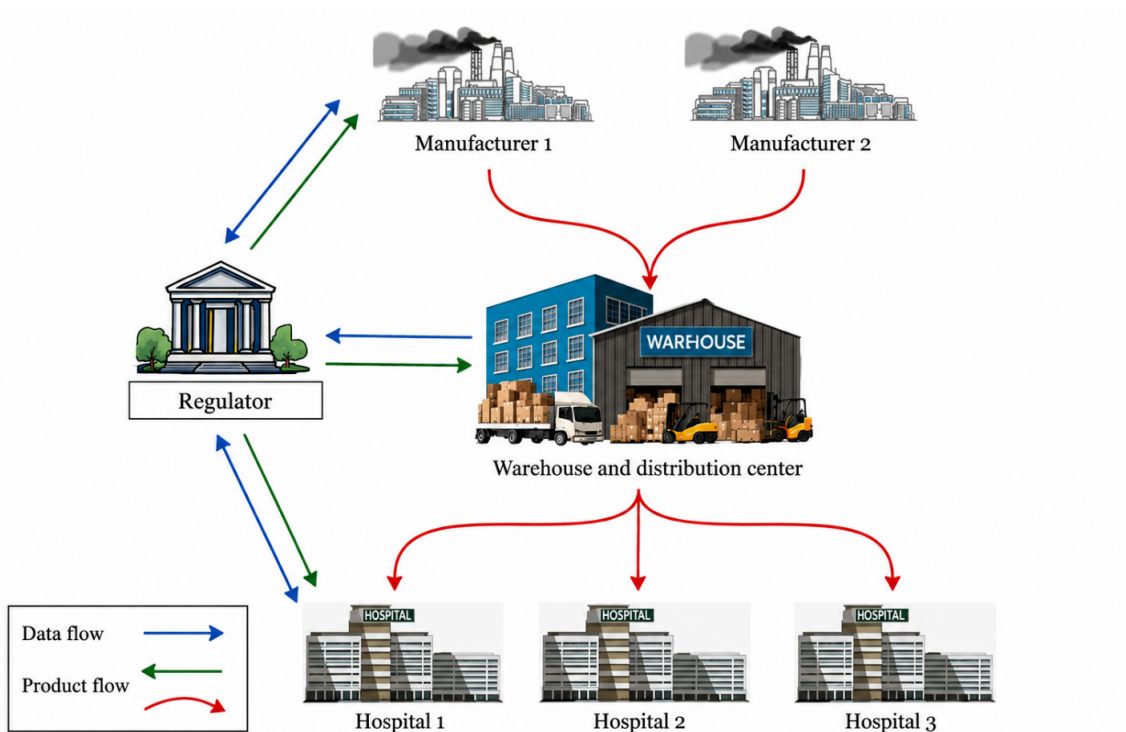


Figure 2. Structure of a centralized pharmaceutical supply chain

following the establishment of the National Unified Procurement Company (NUPCO).¹⁹ Therefore, Saudi Arabia offers a timely and relevant case of a centralized PSC system for investigating remaining persistent data and systems challenges.

1.2. Saudi Arabia's pharmaceutical supply chain

Saudi Arabia's PSC represents a particularly compelling context for examining data and systems challenges in emerging centralized PSCs, due to its rapid institutional transformation and extensive digital reform agenda. Under Saudi Vision 2030, the country has introduced wide-ranging reforms across pharmaceutical regulation, procurement, and digital infrastructure, aiming to enhance efficiency, transparency, and resilience within the healthcare sector.²⁰ These reforms reflect a broader national shift toward innovation-driven and knowledge-based systems, with digital technologies positioned as key enablers of cross-sector integration.

Significant progress has been achieved through the centralization of procurement and distribution functions under national authorities, most notably through the establishment of unified procurement mechanisms and national-level coordination structures.¹⁹ In parallel, the deployment of advanced digital traceability and regulatory oversight tools by national authorities further signals Saudi Arabia's transition toward a centralized PSC model.²¹ Collectively, these developments position the Saudi PSC as a policy-driven and increasingly centralized SC undergoing continued digital transformation, where interoperability is shaped by both technological capabilities and institutional arrangements.

Despite these advances, persistent challenges remain in the coordination and integration of data and systems across the Saudi PSC. The coexistence of heterogeneous information systems, varying data standards, and organizational silos across regulatory, procurement, and healthcare delivery actors continues to limit end-to-end visibility, interoperability, and effective decision-making. These challenges highlight a critical gap between institutional centralization and the practical integration of data and systems required to support efficient and resilient PSC operations. From an institutional theory perspective, this gap reflects the distinction between formal institutional arrangements (e.g., regulations and centralized governance) and their implementation through organizational practices and inter-organizational coordination.^{22,23} This makes Saudi Arabia a highly relevant and timely context for identifying, in detail, data and systems integration challenges in centralized PSCs and examining the potential of ST to address them. Its national

scale, structured reform programs, and ongoing reliance on digital platforms provide a rich empirical setting for investigating how semantic approaches might improve interoperability, data coherence, and cross-stakeholder coordination within centralized PSCs.

Three key stakeholders within the Saudi PSC form the basis of this study's investigation. The Saudi Food and Drug Authority (SFDA)²¹ serves as the primary regulatory body in Saudi Arabia, responsible for ensuring pharmaceutical safety, quality, and compliance, while advancing national digital traceability and regulatory information systems. NUPCO¹⁹ oversees centralized procurement, warehousing, and distribution across public healthcare institutions.²⁴ The King Abdullah bin Abdulaziz University Hospital (KAAUH)²⁵ represents the healthcare provider perspective, functioning as a direct client of NUPCO and operating under the SFDA's regulatory framework. Together, these stakeholders capture the regulatory, logistical, and clinical dimensions of the Saudi PSC, and their interactions shape the data and systems integration challenges examined in this study. [Figure 3](#) illustrates the structure of the centralized Saudi PSC and the relationships among its key stakeholders.

1.3. Research aim and contribution

This study aims to identify persistent data and systems integration challenges within centralized PSCs, using Saudi Arabia's PSC as a case study. In addition, it examines the extent to which ST can address the identified challenges. We approach these aims by investigating the following five research questions:

- (i) What is the state of the art within the Saudi PSC?
- (ii) What are the existing challenges in the integration of systems and data within the Saudi PSC?
- (iii) What are the key features or properties of the PSC systems in Saudi Arabia?
- (iv) What are the primary applications and uses of systems and data in the Saudi PSC?
- (v) What are the current challenges within the Saudi PSC that ST can address?

By answering these research questions, this study contributes to the growing body of research on digital transformation in healthcare SCs. Specifically, the present study makes two key contributions:

- (i) It identifies seven main themes and 25 sub-themes through qualitative analysis of stakeholder interviews, offering new insights into how technical and organizational complexities affect data integration, interoperability, and operational coordination in the Saudi PSC. The findings are further interpreted through the lens of institutional theory to explain how

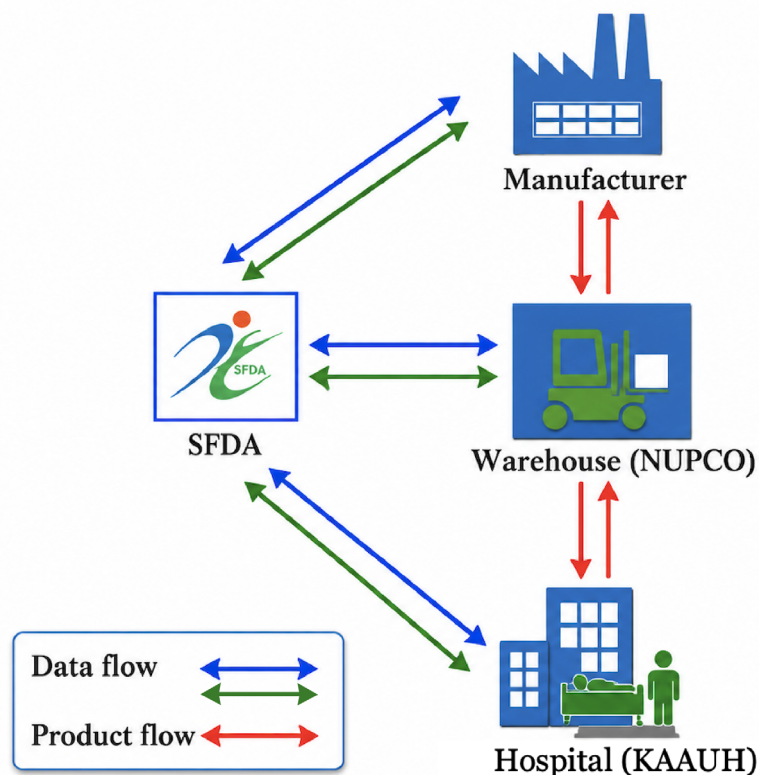


Figure 3. Centralized Saudi pharmaceutical supply chain structure. Adapted from Ref.²⁶

governance structures, organizational practices, and stakeholder coordination influence interoperability and data integration within the Saudi PSC.

- (ii) It maps ST approaches to the identified challenges, particularly in enabling shared understanding, knowledge representation, and improved data reuse.

While Saudi Arabia's PSC serves as a case study, the findings may be applicable to other similarly complex and regulated PSCs in general.

1.4. Approach to addressing the research questions

This study adopted a qualitative approach to identify existing challenges within the Saudi PSC. Selected challenges were subsequently mapped to potential ST solutions. Semi-structured interviews were conducted in 2023 with representatives from the three key stakeholders involved in the Saudi PSC: SFDA²¹, NUPCO¹⁹, and KAAUH.²⁵ A thematic content analysis was performed to identify challenges, with particular attention to technical issues related to systems and data flow. Among the recurring themes, data integration was highlighted

as a critical factor influencing the effectiveness of PSC operations. The thematic findings are detailed in Section 4. To explore the potential of ST to address these challenges, relevant semantic approaches were mapped to a subset of the identified challenges through a targeted review of the literature in Section 5.

1.5. Structure of the study

This study is organized into six sections. Section 1 serves as the introduction, including background information on the purpose of the study and an overview of the research questions and contributions of the study. Section 2 reviews related academic work on the challenges faced by PSCs and presents institutional theory as a conceptual lens. Section 3 provides the methodology applied in this study, which involves thematic content analysis and semi-structured interviews. Section 4 presents the results of the study, illustrating the main themes and sub-themes with supporting interview quotes. Next, Section 5 discusses the findings, answers the research questions, and maps some of the identified challenges to ST approaches. Finally, Section 6 presents the conclusion.

2. Literature review

This section reviews prior research relevant to our study. Because there are only a few works that directly examine data integration challenges within PSCs, we also include studies on data management and interoperability in broader SC contexts. This review is structured around three primary areas. The first examines SC challenges, with particular attention to the specific issues faced, the methodologies applied to address them, and the key findings reported in the literature. The second focuses on the application of ST, specifically through a targeted review of studies that explore ST's role in addressing systems and data challenges. The third introduces institutional theory as a conceptual lens for understanding how governance structures, organizational practices, and stakeholder coordination shape interoperability and data integration within PSCs.

Several studies have examined data-related challenges in modern SCs and highlighted the importance of digitalization for improving visibility and coordination. Evangelista *et al.*²⁷ identified numerous challenges related to SCs, including poor transparency, fragmented data, and weak coordination. However, their approach leverages technologies such as blockchain and the Internet of Things (IoT). Accordingly, they stated that digitalization should enhance visibility, support real-time decision-making, and enable better data sharing and the integration of sustainable practices.

According to West *et al.*²⁸, inefficiencies, waste, sustainability issues, transparency, traceability, data integration, and food safety are important challenges. They suggest using data-sharing methods such as data consolidation, advanced analytics, and digital transformation. Their findings show that data-centric solutions can alter food production, distribution, and consumption.

Nimmagadda *et al.*²⁹ focused on connectivity challenges between geographic and operational databases and the resulting fragmentation of SC models. Their proposed approach, an ontology-based framework, combines big data and data structuring techniques, resulting in optimized costs and improving integration efficiency in global SC operations.

Mincuzzi *et al.*³⁰ stated that the key driver of success in modern SCs is the ability to use data from many sources. However, the frequent generation of this data in diverse formats presents significant integration challenges. Their methodology suggests a message-oriented middleware solution that facilitates seamless data integration and promotes collaboration. Their findings indicate that this

approach optimizes the whole system by enabling real-time information sharing, especially in the inbound logistics of automotive manufacturing.

Above all, most studies emphasize operational efficiency or digitalization. Das *et al.*³¹ outlined key data challenges in the pharmaceutical sector, including data generation, architecture, integration, and security. Their framework conceptualizes Big Data and focuses on integrating heterogeneous pharmaceutical manufacturing data. They demonstrated that big data technologies can improve quality control and efficiency. Ma *et al.*³² addressed the challenge of increasing complexity and sustainability demands in the PSC. Their approach to addressing these challenges was to conduct an empirical analysis using data from 298 Chinese PSC managers, employing structural equation modeling. They found that digital transformation significantly enhances sustainable SC performance. Musamih *et al.*³³ reviewed studies identifying a range of challenges in SC data management, such as heterogeneous data formats, lack of standardization, and weak interoperability. Their approach was to propose a blockchain-based architecture to improve drug traceability in healthcare SCs. Their findings indicate that this approach enhances transparency, data integrity, and logistical efficiency.

Regarding the role of ST in addressing systems and data challenges, Auer³⁴ discussed how ST plays a vital role in enabling data interoperability across complex SC networks. It supports a shared understanding through semantic standards and vocabularies such as SCORVoc, where stakeholders can exchange data in a consistent, machine-readable format. This promotes seamless integration, simplifies supplier onboarding, and enables SC data to relate to other enterprise domains. Leveraging flexible models such as the resource description framework and knowledge graphs, ST allows for scalable, cross-system data sharing and improves alignment across organizational boundaries.

Reyero *et al.*³⁵ highlighted the substantial potential of ST in addressing a wide range of challenges by leveraging the structured formalization of machine-understandable knowledge. ST enables the development of more accurate and equitable models across various domains, including machine learning, natural language processing, and social media. ST contributes significantly to tasks such as controlling access to sensitive information, supporting reasoning and clustering in artificial intelligence (AI) systems, and extracting structured arguments from unstructured text.

Moreover, Ben Sassi and Yanes⁵ stated that ST gives computer systems a range of useful abilities, such as making sense of data and handling different types of data

sources. This helps them better understand what people are trying to say and uncover insights that were previously unattainable. By aiming to automatically grasp meaning, ST goes beyond the limitations of traditional technologies.

Institutional theory provides a useful perspective for understanding why organizations facing similar regulatory environments may nevertheless experience different outcomes when implementing digital technologies and sharing information. Scott²² stated that organizations are influenced not only by technological capabilities but also by institutional arrangements, including regulations, governance structures, organizational norms, and stakeholder expectations. These institutional factors shape organizational behavior and influence how technologies are adopted, implemented, and used across organizational boundaries.

Building on this perspective, Pishdad *et al.*²³ argued that successful technology implementation depends on the institutionalization of technology within organizations, where organizational culture, social structures, and management practices determine whether technology becomes embedded in routine operations rather than remaining a purely technical solution. By applying institutional theory to interoperability, Hjort-Madsen³⁶ demonstrated that interoperability challenges within public-sector information systems are not solely technical but are also shaped by organizational, political, and governance factors affecting coordination across institutions. Similarly, Manda and Backhouse³⁷ identified political, strategic, and organizational barriers as key obstacles to interoperability and information sharing in digital government initiatives. More recently, Kasiwi *et al.*³⁸ showed that fragmented institutional behavior, weak cross-organizational coordination, and insufficient governance mechanisms continue to impede semantic and technical interoperability despite ongoing digital transformation initiatives.

Collectively, these studies suggest that interoperability challenges cannot be understood solely as technical problems but arise from the interaction between technological capabilities and institutional arrangements. Institutional theory therefore provides an appropriate conceptual lens for interpreting how governance structures, organizational practices, and stakeholder coordination contribute to the systems and data integration challenges identified in the Saudi PSC.

Although previous studies have examined PSC challenges and the capabilities of ST, these streams of research have largely developed independently. Limited attention has been given to understanding how data and

systems challenges are experienced by key stakeholders within the Saudi PSC and how ST may help address those challenges in practice. There is a lack of qualitative studies that capture stakeholder perspectives across regulatory, procurement, and healthcare-provider settings while systematically relating the identified challenges to ST capabilities. To address this gap, the present study investigates data and systems challenges within the Saudi PSC through qualitative inquiry and explores the potential role of ST in addressing the identified issues.

3. Methodology

This study adopted a qualitative case study design, aimed at uncovering systemic and data-related challenges within the Saudi PSC. This approach supports an in-depth exploration of complex contextual phenomena within real-life settings.

3.1. Research design

This study is grounded in thematic content analysis, a qualitative method that offers a structured process for identifying and interpreting recurring patterns within interview data.³⁹ Through this approach, key challenges within the Saudi PSC were identified. Subsequently, a review of relevant literature was conducted to explore the problem-solving potential of ST, enabling the mapping of suitable solutions to the identified challenges. The qualitative case study design was employed to explore workflows, data flow, and integration challenges within the Saudi PSC as an illustrative example. It was selected for its ability to provide an in-depth understanding of complex, context-specific issues that are not easily captured through quantitative methods.⁴⁰

The Saudi PSC was chosen for three main reasons. First, Saudi Arabia's Vision 2030 has accelerated healthcare system expansion, increasing the demand for efficient and digitally integrated PSC operations.²⁰ Second, ongoing regulatory reforms offer a unique opportunity to investigate how governance and digitalization shape SC integration. Third, the growing adoption of technologies such as AI and enterprise resource planning (ERP) systems provides a timely context for studying technological alignment in healthcare logistics.

3.2. Participants and recruitment

The study focuses on three key entities within the Saudi PSC: (i) SFDA, which serves as the national regulator; (ii) NUPCO, responsible for central procurement and distribution; and (iii) KAAUH, representing healthcare service providers. A combination of purposive and snowball sampling was employed. Purposive sampling

ensured that participants possessed relevant expertise in PSC operations, regulatory affairs, or digital systems. Subsequently, additional experts were identified through the snowball technique.⁴¹

A total of six semi-structured interviews were conducted with eight domain experts ($n = 8$) in Riyadh. Each interview lasted between 60 and 150 min. A bilingual (Arabic–English) interview protocol was used, and informed consent was obtained from all participants. Due to accessibility constraints, stakeholders from manufacturers and importers were excluded. While this does not cover the full SC, the focus on a regulator, a procurement company, and a healthcare provider helps identify key data integration and interoperability challenges.

Qualitative analysis involves interpretive judgment. As the interview questions were primarily technical and operational in nature, focusing on systems, data management, and SC processes, the impact of personal perspectives on data collection in this study is limited. The first author has a technical background and is familiar with the PSC domain but had no prior professional relationship with the participants. To minimize potential bias, coding decisions and thematic interpretations were reviewed throughout the analysis process, and the findings were continuously checked against the interview transcripts and supported by participant quotations.

Participant contributions were not evenly distributed across the dataset. The number of coded quotations was as follows: P2 contributed 8 quotations; P1, P4, and P5 contributed 7 each; and P3, P6, P7, and P8 contributed 4 each. The difference in the number of coded quotations was primarily due to variations in engagement with the interview questions. To reduce the risk of bias arising from uneven participation, thematic interpretations were based on patterns observed across the dataset rather than on the views of individual participants.

3.3. Data collection

Data were collected using semi-structured interviews, which are well-suited for exploring technical and organizational challenges in depth. Each session began with an explanation of the study's objectives and assurances of confidentiality. Interviews were conducted in person using a bilingual protocol to ensure both conceptual accuracy and linguistic clarity. Interview questions focused on systems, data, and coordination issues across stakeholder organizations.

3.4. Data analysis

The interview data were analyzed using thematic content analysis, a qualitative method effective for identifying and

interpreting patterns within textual data.³⁹ The process involved transcribing the interviews in Arabic, translating them into English, and manually coding the transcripts. All interviews were conducted in Arabic and translated into English for analysis by the first author, who is proficient in both Arabic and English and familiar with the PSC context.

To enhance translation accuracy and preserve the meaning of technical and regulatory terminology, a formal back-translation procedure was employed. The English translations were independently translated back into Arabic by an academic colleague, and the resulting versions were compared with the original Arabic transcripts to verify conceptual equivalence and resolve any discrepancies. The translated transcripts were also reviewed by the team to ensure consistency and clarity of interpretation. During the coding process, the original Arabic transcripts were consulted whenever clarification was required.

Initial codes were generated from recurring concepts and were then grouped into sub-themes and overarching themes through iterative synthesis. This process resulted in the identification of seven main themes and 25 sub-themes, as detailed in Section 4.

The coding process was conducted manually by the team and involved iterative refinement of codes, sub-themes, and themes. To enhance the credibility of the analysis and reduce subjective bias, the emerging coding structure and thematic interpretations were reviewed and discussed with the team throughout the analysis process until agreement was reached on the final thematic framework. The study adopted a consensus-based coding approach rather than a formal independent inter-coder reliability assessment.

A purposive sampling strategy was employed to ensure representation from the principal stakeholder groups involved in the Saudi PSC, including the regulator, the central procurement organization, and a healthcare provider. Coding was conducted iteratively throughout the analysis process. Most of the main themes emerged during the early stages of coding, while the final interviews primarily reinforced previously identified patterns and did not generate additional main themes. Specifically, the final interview reinforced existing themes without generating additional principal themes. This indicated that thematic saturation had been reached at the level of the seven principal challenges identified in the study. While additional interviews may have provided further contextual examples and nuances, they were considered unlikely to alter the overall thematic structure of the findings.

Following the thematic analysis, structured mapping tables were developed to align specific ST capabilities with relevant challenges identified in the data. This mapping

drew on existing domain literature and was contextualized to the operational landscape of the Saudi PSC. Challenges were categorized based on whether ST could provide full or partial support in addressing them; challenges beyond the scope of ST were excluded.

The classification was guided by the extent to which ST could directly address the underlying causes of each challenge. A challenge was classified as fully addressable when its primary causes related to data representation, semantic interoperability, data standardization, or information integration and could therefore be addressed directly through ST. A challenge was classified as partially addressable when semantic technologies could substantially improve the situation, but additional organizational, governance, policy, technological, or process-related interventions were also required. Challenges were considered beyond the scope of ST when their underlying causes were predominantly human, cultural, regulatory, or institutional in nature and could not be effectively addressed by ST alone. The results of this mapping exercise are presented in Section 5.5.

3.5. Data validation

To ensure methodological reliability, two validation strategies were employed: first, process validation was carried out through systematic documentation of the sampling, transcription, translation, and coding procedures, ensuring transparency and consistency throughout the study. Coding decisions and theme development were reviewed iteratively during the analysis process. Second, expert validation was performed by sharing preliminary findings with selected participants from the SFDA, NUPCO, and KAAUH. Their feedback was used to confirm contextual accuracy and strengthen the interpretive reliability of the results.

4. Results

This section presents the empirical findings obtained from the thematic content analysis of interviews with key stakeholders in the Saudi PSC. The aim is to describe the main technical challenges that influence data and systems integration across the Saudi PSC. While many of these challenges are related to data, several unexpected issues emerged that were not directly data-related. These include problems associated with access policies, regulatory alignment, and education or training gaps. The challenges related to data are data integration, quality, analysis, trust, and standardization. Overall, the challenges were structured into seven main themes and 25 sub-themes in Table 1.

4.1. Data integration

Data integration has three sub-themes; the first one is the different maturity levels of stakeholders' systems for applying required regulations. One of the participants said, "Some stakeholders are not yet ready to be integrated with our system, even though it is designed to be integrated with them, because their systems are not sufficiently mature" (P5). Another participant stated, "We are aware that technical readiness levels differ across stakeholders' systems, and we take this into account" (P8).

Table 1. Main themes and sub-themes of challenges in the Saudi pharmaceutical supply chain

Main themes	Sub-themes
Data integration	(i) Different maturity levels of stakeholders' systems (ii) Lack of internal collaborative culture (iii) Delays in operational synchronizing
Data quality and standardization	(i) Lack of mechanisms to prevent data redundancy (ii) Lack of data standardization (iii) Lack of advanced tools for data manipulation (iv) Data fragmentation across different sources
Data trust and clarity	(i) Lack of systems and data trust (ii) No clear specifications for drug unit measurements (iii) Customer predictions and demand forecasting challenges
Data planning and analysis	(i) Lack of using data planning tools (ii) Little or no use of data analysis tools (iii) Studying inventory monitoring manually
Access policy and responsibility	(i) Limitations to appropriate access policy mechanisms (ii) Lack of post-delivery information (iii) Autonomy issues, priority settings and healthcare delivery
Regulatory alignment	(i) Lack of compliance with regulations (ii) Lack of regulations in a voluntary platform (iii) Adapting to rapidly changing regulations (iv) No regulations to manage free goods

The second sub-theme is the lack of an internal collaborative culture, which causes ineffective data sharing and integration within the organization. As one participant stated, “Each department within the organization is reluctant to share data with the other departments, as it is perceived as proprietary” (P6). Another participant stated, “Sometimes we do not share our data with other departments because they have not requested it” (P8).

The third sub-theme of data integration is the delay in data operational synchronization. One participant stated, “Another concern is the slow reflection of operations in the systems, as other departments are waiting for updated data on these operations” (P3). Another participant added, “We often have to wait for the data to become available in the system” (P7).

4.2. Data quality and standardization

Data quality and standardization are the second main theme among the challenges identified in the Saudi PSC, including four sub-themes. The first is the lack of mechanisms to prevent data redundancy. One participant stated, “We have a large volume of data that cannot be downloaded in a single file; instead, multiple Excel files must be downloaded, viewed, and analyzed to identify the duplication” (P1). Another participant added, “We need a technology that can identify duplication” (P3).

The second sub-theme is the lack of data standardization due to the use of different codes for the same item across various systems in different organizations. One participant said, “Mapping is a common procedure between hospitals and NUPCO, as each party uses its own codes; however, this leads to delays and waiting times” (P8). Another participant mentioned, “Accurate data integration requires the unification of codes” (P6). Moreover, a participant stated, “Manual code mapping is required because our codes differ from NUPCO’s; consequently, each planner must map each code, a process that can take four months to map approximately 900 items” (P1). According to another participant, “Each stakeholder uses its own coding system, for example, our organization, NUPCO, and SFDA, which makes comprehensive mapping extremely difficult” (P2). Additionally, a participant stated, “The coding problem stems from the absence of a unified standard for identifiers; each stakeholder uses its own codes, which hinders data integration and requires manual mapping” (P5).

The third sub-theme of data quality and standardization is the lack of improvements in data manipulation, viewing, and medication dispensing processes. As a participant mentioned, “We need improvements on the planning side, data manipulation, and viewing, either for operational data

or planning data” (P2). Another participant said, “One difficulty concerns the patient dispensing process, which is still under development in hospitals” (P5).

Data fragmentation is the last challenge within data quality and standardization. The data is scattered across different sources, formats, and stakeholders. A participant noted, “The challenge at hand is data fragmentation” (P4). According to another participant: “We face difficulties due to fragmentation across external systems and are attempting to consolidate these systems into a single platform” (P5).

4.3. Data trust and clarity

Data trust and clarity consist of three sub-themes. The first is the lack of trust in data, leading some stakeholders to rely on requesting reports from other stakeholders. A participant indicated, “By the end of each week, some clients (hospitals) request inbound and outbound stock reports; rather than relying on their own data, they depend on our systems and data” (P4). Another participant mentioned, “Although PSC data are available, their accuracy varies. Hospital data are often inaccurate, making it difficult to integrate hospital systems with the Drug Track and Trace System (DTTS)” (P5).

The second sub-theme is the absence of agreed-upon, clear specifications for drug unit measurements. A participant said, “Unit measurement must be unified to ensure accurate data integration” (P6). Another participant shared:

Clients or hospitals often link their authorization to a specific unit of measurement. At NUPCO, orders are standardized using a 3 mL unit, while some clients place orders in doses or boxes. Although the item description remains consistent, a conversion factor is required to reconcile these different units (P3).

Difficulties in achieving data clarity for customer predictions and demand forecasting represent the third sub-theme. According to a participant, “We are working on improving customer predictions and demand forecasting; the aim is to narrow the gap by predicting current stock levels, although it is more effective to rely on patient-level consumption data” (P4). A similar concern was expressed by another participant, who stated, “*Enhancing clients’ predictions and demand forecasting is one of our goals that we are working on*” (P8).

4.4. Data planning and analysis

Data planning and analysis have three sub-themes, including the lack of use of data planning tools. This

challenge is common among some Saudi PSC stakeholders. A participant shared, "Reorder points are currently determined based on human judgment, as no formal planning tool is available to support assurance. Seasonal information is derived from manufacturer communications regarding shortages, and NUPCO availability lists are not available" (P2). Moreover, in some organizations, there is little or no use of analysis tools for all available data. The same participant said, "We use data in general, but not the data related to PSC activities. Although such data exist, they are not utilized because there is no engine to process them" (P2). Another participant stated, "Analysis and reporting are performed manually using Excel spreadsheets; for example, item quantities are calculated by aggregating total quantities across batches, and then we must combine them all to get only one item quantity" (P1).

Another participant shared, "Although data are available across the PSC, most of them are not utilized, as analysis focuses only on data aligned with internal goals" (P5). The same participant mentioned, "Data within our system represents a significant resource and a huge treasure that could be used in many ways. Currently, the data are used primarily for misuse detection and for comparing drugs to verify whether they are registered" (P5). A participant added, "We have plenty of data, but we don't know how to use it effectively" (P7).

Furthermore, stock monitoring tables are analyzed manually and daily. A participant mentioned, "We must revise stock monitoring tables daily and check what is available and what is not. It is based on specific requirements, supply, and demand" (P7).

4.5. Access policy and responsibility

The access policy and responsibility comprise three sub-themes. The first is the limitation of appropriate access policy mechanisms. A participant shared:

We need access to hospital data, which is required due to variations in staff practices. The aim is to address issues at their root cause by gaining visibility into the final stages of hospital processes and operating at the customer level (P4).

Another participant added, "We often need access to other stakeholders' data, but we do not have the necessary permissions" (P6).

The second sub-theme is the lack of post-delivery information, as a participant stated, "Our role ends when we deliver the order; we do not know anything about it or when they will consume it again" (P4).

The third sub-theme is the existence of autonomy issues, such as providing their own codes instead of

using the main authority codes, priority settings, and implications for resource allocation and healthcare delivery. As a participant stated, "There are restrictions applied to health centers and hospitals, including monthly and maximum limits. As all health centers operate under NUPCO's control, NUPCO has the authority to set these restrictions" (P4).

4.6. Regulatory alignment

Another key theme is regulatory alignment, which includes five sub-themes. The first is the lack of compliance with SFDA regulations among suppliers, hospitals, and pharmacies. A participant stated, "Our issue with the DTTS is the significant gap between systems; although processes are clear on their side, they are not fully enabled on ours" (P2).

The second sub-theme is the lack of regulations governing a voluntary platform for overstock sharing. According to a participant, "Clients always show their overstock, but no one takes it; it needs to be regulated more" (P2).

The third sub-theme is adapting to rapidly evolving regulations, as a participant said, "Significant delays are experienced. Based on prior experience before NUPCO, stock availability was better; under NUPCO, processes have become more complex—not due to NUPCO itself, but because regulations are introduced rapidly, limiting the ability to adapt immediately" (P1). Another participant added, "There are frequent changes in regulations, and we sometimes need time to adapt to them" (P3).

The last sub-theme is the absence of regulations governing the management and distribution of complimentary items delivered to main storage areas as gifts. A participant stated, "Some items are provided as free goods, such as needles, but they are delivered without caps, rendering them unusable" (P4).

4.7. Education, training, and awareness

Education, training, and awareness form the final key theme. The first sub-theme is the lack of education and training programs for nursing staff. A participant stated, "We face challenges related to staff behavior, particularly last-minute ordering" (P2). Another participant shared, "Nurses are often perceived as placing emotionally driven requests, which can result in ordering quantities beyond our actual need" (P1). Moreover, a participant stated, "Nurses often order more medication than is required" (P7).

Another sub-theme is the lack of stakeholders' awareness and engagement in the procurement cycle. According to a participant, "An issue arises when communicating

with pharmaceutical companies, as they are not aware of all expedited items due to the use of different codes and identifiers” (P1).

A third sub-theme is the lack of personnel with specialized skills, such as expert-led key performance indicators (KPIs). A participant mentioned, “On both the planning and storage sides, there is no expert available to define key performance indicators” (P2).

The fourth sub-theme concerns the need for additional training programs to deal with data and aggregation processes. A participant shared:

Our system does not perform aggregation directly; aggregation is handled by the respective authorities within their own systems. Although this may be difficult for authorities to implement at the initial stages, it is expected to become more feasible over time (P8).

The final sub-theme is the lack of an expedite team to improve the SC cycle. One participant stated:

To enhance efficiency, we propose establishing a new department called the Expedite Team. It will be responsible for following up, expediting, and facilitating communication between end-users, pharmaceutical companies, and the internal planning team, serving as a backbone for hospitals regarding the supply process (P1).

5. Discussion

This section addresses the research questions by discussing the interview findings. It is divided into subsections corresponding to the five research questions: (i) the state of the art of the Saudi PSC; (ii) systems and data integration challenges; (iii) key features of the Saudi PSC; (iv) current systems and data applications; and (v) the exploration of the potential of ST for the Saudi PSC.

5.1. The state of the art of Saudi pharmaceutical supply chain

By integrating the perspectives of the three stakeholders—SFDA, NUPCO, and KAAUH—we aim to provide a comprehensive understanding of the current landscape of the Saudi PSC. Thus, this section forms the foundation for informed discussions of the Saudi PSC landscape.

The role of SFDA is to regulate and supervise many aspects of the Saudi PSC processes and stakeholders, involving manufacturers, warehouses and distributors, pharmacies, and health ministry hospitals. Accordingly, from the perspective of the SFDA, NUPCO is considered

a warehouse and a distributor, and KAAUH is considered a government hospital. At the forefront, SFDA emphasizes collaboration among all Saudi PSC entities by setting guidelines and ensuring compliance with regulations. As an example, their rules are based on the Global Standards (GS1) organization⁴², which will be explained further in Section 5.3. The goal is to create a common base for Saudi PSC products by identifying, capturing, and sharing important related information. The SFDA also makes sure that manufacturers follow Good Manufacturing Practices and distributors follow Good Distribution Practices.⁴³

The SFDA has several objectives; the main ones are preventing counterfeit drugs, ensuring medical equipment and drug safety, enabling recalls, and forecasting drug availability.²¹ Regarding the use of technologies, SFDA makes use of modern technologies for different purposes. For instance, the DTTS ensures the authenticity and traceability of medications through various stages of the entire SC. The vigilance system, which is known in Arabic as *Tiaquz*, is used by hospitals to report side effects, pharmacological errors, any drug quality issues, food poisoning, and defects in medical devices and supplies.²¹ The Saudi Drug Registration (SDR) system is used by drug companies to facilitate the registration of medicinal, herbal, and health products for both human and veterinary use, as mentioned in Section 5.4. SFDA also makes use of application programming interfaces (APIs) for achieving interoperability within the entire SC.

While SFDA acknowledges the significance of data analytics in accomplishing various objectives, it appears that they predominantly utilize it to achieve their own goals, with limited utilization of available data analytics capabilities for broader PSC-related purposes. Data within the Saudi PSC has been described as a valuable asset, which means that such data can provide benefits for multiple purposes and aspects related to the Saudi PSC.²¹

The second key entity in the Saudi PSC is NUPCO, which is a semi-governmental company that acts as a central primary entity in managing Saudi PSC procurement and distribution processes. NUPCO's role is to ensure efficient medication and medical equipment procurement and distribution for government hospitals. It is also responsible for the availability of essential healthcare products. NUPCO provides two innovative services for clients: procurement from suppliers and logistics services. NUPCO's aim is to deliver several benefits for the Saudi PSC: centralizing the procurement process, maintaining consistency in procurement, and facilitating a more streamlined approach to the Saudi PSC. In addition, it helps standardize SC practices, leading to cost savings and improved efficiency.

Moreover, NUPCO has numerous objectives, including focusing on demand planning, predicting consumer behavior, improving forecasting accuracy, and providing efficient stock management. Regarding the use of technologies, NUPCO makes use of robust systems, including the System Analysis Program (SAP), which is a software provider that offers business process management solutions to organizations across all sectors and sizes.⁴⁴ In addition, NUPCO utilizes Warehouse Management Systems (WMS) and ERP systems to handle data related to procurement, storage, and financial transactions.⁴⁵ However, the primary system is the SAP warehouse system, which plays a crucial role in managing contracts, purchase information, and orders. Talent is another advanced system that is being used and is considered middleware for data exchange between their internal systems; these are discussed in detail in Section 5.4.

Additionally, NUPCO has established integrated portals for improving SC efficiency, such as the Hospital Ordering System (HOS) for clients and the Advanced Shipment Notice (ASN) for vendors.⁴⁶ Moreover, NUPCO provides data for analysis to teams throughout the procurement cycle, including the logistics team, demand planning team, talent team, operations, supply, vendors, and customer services. Hence, this data is crucial for creating KPIs. An example of NUPCO data analysis is the demand planning department's use of historical consumption data from clients to make data-driven recommendations.

Another objective is to predict consumer behavior accurately, which assists in better understanding forecasting and consumption patterns. Accordingly, NUPCO is working on some projects like "Delivery to Department" to directly integrate with hospital systems and commit to continuous improvement. Currently, NUPCO is working on improving forecasting accuracy and providing efficient stock management by conducting workshops for hospitals.

Moreover, NUPCO controls the purchase and distribution of medications in hospitals such as KAAUH. In the past, KAAUH managed its own SC processes, but now, NUPCO is responsible for most of these processes. This direct relationship reflects a shift toward centralized and regulated procurement within the Saudi PSC and indicates an increase in government involvement. KAAUH has many objectives, some of which are to provide excellent healthcare with a special emphasis on women's health and child development. It is dedicated to tailoring care to the specific needs and preferences of each person, considering their voice and input. KAAUH promotes a comprehensive approach to healing and well-being; ensuring safe, efficient, and reliable patient care is a top priority.²⁵

In terms of technology, KAAUH is using several systems: for instance, TrakCare and Dose systems for inventory management, as discussed in Section 5.4. Their key role is to internally ensure that medications are available when needed. Additionally, KAAUH uses the HOS system for ordering items directly, adopting modern e-commerce practices.

Regarding the use of data analysis in KAAUH, they heavily rely on Excel spreadsheets as the main analysis and reporting tool. For the planning process, KAAUH utilizes Oracle for its SC activities; however, the absence of its core I-Supplier functionality results in manual planning using Excel sheets.⁴⁷ This highlights an area where more investment in modern technologies could improve the overall efficiency of the Saudi PSC.

In summary, there is an increased focus on digital transformation, automation, and seamless integration between various Saudi PSC stakeholders. The aim is to minimize manual processes and improve data flow for more efficient operations. While there are some challenges that SFDA faces related to stakeholders' integration and aggregation, there is a clear commitment to ensuring the safety, authenticity, and availability of pharmaceutical products in Saudi Arabia. SFDA recognizes and accepts the challenges during the initial phases, but it is confident that stakeholders will adapt over time.

The efforts of NUPCO to improve the Saudi PSC are enormous, including the challenges they are facing and the multiple strategies they are adopting. The findings indicate that NUPCO plays a key role in ensuring the reliable and effective supply of medications and medical equipment to government hospitals. KAAUH's primary responsibility is to internally ensure medicine availability. It uses Oracle for its SC operations, but it cannot use I-Supplier, which is a function in Oracle; thus, planning must be done manually using Excel spreadsheets, which slows the process and increases the workload on staff.

However, with the gradual improvement of Saudi PSC processes, there are still some important aspects to focus on, such as demand planning, data integration, efficient workflow management, systems interoperability, and the utilization of technologies.

From an institutional theory perspective, these findings suggest that centralized governance and regulatory reforms alone are insufficient to achieve effective interoperability. While institutions such as the SFDA establish formal rules, standards, and governance mechanisms, successful implementation also depends on how these are adopted and embedded within the organizational practices of stakeholders such as NUPCO and healthcare providers.

The persistence of manual processes, heterogeneous systems, and coordination challenges indicates that institutional alignment and technological implementation must evolve together to achieve effective data integration across the Saudi PSC.

5.2. Systems and data integration

Regarding the second research question—the efficient integration of systems and data within the Saudi PSC—all established main and sub-themes contribute to the understanding of this challenge.

As discussed in Section 4.1, one of the primary challenges related to data integration is the varying maturity levels of stakeholders' systems in meeting regulatory requirements. Prior research suggests that organizations with higher levels of digital and knowledge maturity are better positioned to leverage innovation and improve organizational capabilities and strategic alignment.⁴⁸

Another challenge is the delay in operational synchronization. This slows down the organization's work processes, consequently affecting the entire SC. Synchronization in distributed systems is challenging because of the absence of shared memory, unreliable networks, independent failures, and clock desynchronization.⁴⁹

Additionally, an insufficient internal collaborative culture can affect the smooth integration of data across the SC. Prior research suggests that internal integration and cross-functional collaboration are critical enablers of information sharing and SC performance.⁴⁷ Consequently, a lack of internal collaboration may reduce the quality of data analysis within the organization and across external stakeholders.

Data quality and standardization, as discussed in Section 4.2, represent significant challenges that impact systems and data integration. They encompass several sub-challenges, including the lack of data duplication and redundancy mechanisms. As discussed in the literature, failing to use the necessary functions, such as master data capabilities, to manage shared information across systems delays the organization's ability to integrate critical data within a unified platform.⁵⁰

The second challenge stated in Section 4.2 is common among all involved stakeholders and arises from the use of different codes for the same item among organizations. This requires applying a mapping process, which can be time-consuming, labor-intensive, and error-prone. Stakeholders apply the mapping process as a solution to address the challenge of data standardization. Code mapping includes generating a mapping table that links

each organization's code with a standardized code.¹⁹ It permits translation between different codes and assists in ensuring consistent data representation. Though organizations view code mapping as a potential solution in the Saudi PSC, it presents significant technical challenges. For instance, the volume of data to be mapped can be overwhelming, making the process time-consuming and resource-intensive, particularly when performed manually.²⁵ Furthermore, inconsistencies in code mapping can cause SC interruptions, affecting the timely delivery of items and services. Moreover, handling contracts among stakeholders in systems with diverse coding approaches presents difficulties in terms of maintenance, data flow, compatibility, and interoperability.²⁵

Additionally, as discussed in Section 4.2, data fragmentation across diverse sources and formats increases data quality issues, which in turn affects data integration across the entire SC. A study confirms that fragmented and heterogeneous systems severely constrain the usability and integrability of data across organizational units.²⁵ Moreover, as stated in Section 4.3, challenges related to data trust and clarity present significant obstacles. The absence of trust in some systems and data, along with the complexity of achieving data clarity for customer predictions and demand forecasting, has a substantial impact on the accuracy of the decision-making process. A study reports that there is a need to create trust as a foundation for facilitating data sharing to promote active involvement from all relevant stakeholders.⁵¹

Furthermore, as discussed in Section 4.3, we found that the absence of clearly defined and agreed-upon specifications for unit measurements leads to persistent and recurring confusion. This issue not only wastes time and resources but also increases the risk of overstocking in hospitals due to the repeated acquisition of identical items.

In Section 4.4, we identified that the lack of adequate data planning and analysis tools can slow down operational processes, provide inaccurate results, and delay the optimization of SC activities. A study suggests that analytical models are valuable tools for optimizing decision-making in SC processes. One of the primary challenges in SC management is ensuring resilience by addressing the ripple effect, which refers to the propagation of disruptions impacting the chain's performance.⁵² Therefore, to reduce the likelihood of errors, it is imperative to plan and evaluate the data that is currently accessible before disseminating it.

The challenges in access policy and responsibility are evident as well, as discussed in Section 4.5. There are limitations in establishing appropriate access policy mechanisms and issues related to autonomy in providing codes, priority settings, and resource allocation, as well

as the lack of post-delivery information sharing. These factors significantly contribute to integration difficulties within the Saudi PSC. Access control is a common security mechanism to control data sharing between involved parties. However, a study stated that it is a virtual resource and not sufficient because physical access has a considerable effect on the protection of information and systems, and access control mechanisms must become capable of handling dynamically changing situations.⁵³

Regulatory alignment, as discussed in Section 4.6, remains a key challenge in the integration of systems and data. The lack of compliance with and implementation of robust regulations among some suppliers and authorities, coupled with the difficulty of adapting to rapidly evolving regulations, can obstruct the alignment of processes and data sharing across the entire SC. SFDA regulations are based on GS1 standards. However, as highlighted in recent studies, to fully implement GS1 standards, organizations must improve their understanding of both system-level interactions and organizational coordination structures.⁵⁴

Recent findings by Salma *et al.*⁵⁵ confirmed that fragmented systems, legacy infrastructure, and the lack of interoperable data standards continue to undermine integration efficiency and increase systemic SC inefficiencies. Sinthiya *et al.*⁵⁶ noted that an effective plan for implementing SC standards should involve coordinated stakeholder decision-making and structured training programs as part of the system adaptation process.

The last concern that has an impact on the Saudi PSC systems and data integration discussed in Section 4.7 is related to education, training, and awareness aspects. Inadequate education and training programs for nursing staff and suppliers, as well as the lack of awareness and engagement among suppliers in the procurement cycle, can hinder the capacity of the SC to adapt and utilize data effectively. A thorough approach is required to address the underlying causes of data integration difficulties. Charoo *et al.*⁵⁷ noted that most data integration challenges are the result of poor-quality culture, corporate or individual behavior, leadership, processes, or technology. Some data integration findings, such as contemporaneous documentation, should be considered potentially unintentional outcomes.

From an institutional theory perspective, these findings suggest that many of the identified integration challenges are not solely technological but are also shaped by institutional factors, including governance structures, organizational practices, regulatory arrangements, and stakeholder coordination. Although centralized governance provides a common regulatory framework, institutional differences in organizational practices

and technology implementation continue to influence interoperability and information sharing across the Saudi PSC. This helps explain why integration challenges persist despite ongoing digital transformation initiatives.

In brief, the challenges associated with systems and data integration include data integration, data quality and standardization, data trust and clarity, data planning and analysis, access policies, regulatory alignment, training, and education. All these aspects emphasize the need for comprehensive technological, organizational, and institutional strategies to address them effectively.

5.3. Key features of the Saudi pharmaceutical supply chain

This section addresses our third research question by discussing the main features of the Saudi PSC based on the perspectives of SFDA, NUPCO, and KAAUH. The key properties are assurance, regulations and standards, trust and accuracy, tracking and tracing, PSC resilience, interoperability, and efficiency.

Initially, SFDA is the main observer of the whole Saudi PSC; for this reason, its perspective is significant. Saudi PSC achieves assurance by actively working toward the SFDA objectives that address medication safety in the entire SC. Regarding regulations and standards, SFDA engages with the International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use (ICH), which provides internationally recognized guidelines to ensure consistency in pharmaceutical safety, quality, and efficacy across regulatory systems.⁵⁸

Furthermore, SFDA adheres to the global GS1 standards for the establishment of identification systems. GS1 is a nonprofit organization responsible for administering industry-driven data and information standards.⁴² SFDA cooperates with GS1 for medication tracking, defining barcodes, and setting conditions for food and drug items.

Considering trust and accuracy, SFDA is working on easing operations for manufacturers through the unification of codes and the use of global standards. However, even if Saudi PSC data are available, availability alone is not sufficient; SFDA recognizes that the reliability and correctness of the data are vital for ensuring usability. For Saudi PSC tracking and tracing, SFDA has established the SDR system for pharmaceutical registrations and the DTTSystem for tracking the movement of pharmaceuticals after the registration process is completed. Additionally, SFDA has adopted two-dimensional barcodes as a tracking mechanism for medications. However, not all involved Saudi PSC stakeholders are prepared for integrating with SFDA systems, which poses difficulties in seamless tracking processes across the entire SC.

In terms of Saudi PSC resilience, SFDA has implemented measures for its information technology systems, such as backups, contingency plans, and server preparations. Additionally, SFDA's engagement with the ICH institution helps provide pharmaceutical guidelines to support PSC efficiency and standardization.

In addition, NUPCO places a strong emphasis on transaction accuracy to ensure assurance in its processes, which affects the entire Saudi PSC. This commitment comprises a combination of quality control measures, data integrity practices, and compliance with standards to foster confidence in the reliability of transactions. However, there are some limitations regarding assurance for health centers and hospitals controlled by NUPCO. As NUPCO has hospitals' monthly limits and maximum limits, it has the authority to set these limitations. Nevertheless, NUPCO prioritizes assurance by employing backup plans, testing procedures, and conducting workshops.

Additionally, NUPCO follows SFDA regulations and standards; for example, in warehouse processes, NUPCO cannot open any warehouse without an approval certificate from SFDA, which conducts inspections of relevant requirements, including warehouse facilities and refrigeration systems. For the dispatching process to hospitals, a regulated process using unique identifiers is followed, and vendors are instructed to comply with these requirements. For instance, damaged items are rejected upon delivery. However, some suppliers under NUPCO control do not fully comply with SFDA regulations regarding tracking, as they are not actively participating in the tracking and tracing process. For example, some suppliers do not have a Global Location Number (GLN) account. However, NUPCO itself complies with SFDA standards; the approval process, including certificates and inspections by SFDA, demonstrates the high regulatory and quality standards within the Saudi PSC.

Moreover, NUPCO places a high level of trust in its system, emphasizing the accuracy of quantities. Thus, clients seek inbound and outbound order information from NUPCO systems, which proves trust in data accuracy and system reliability. NUPCO understands that the purpose of tracking is to facilitate recall processes. However, as tracking and tracing involve different systems, several challenges arise. A main challenge is that some suppliers are not actively participating in the tracking and tracing processes. This may be due to several reasons, such as the absence of appropriate systems on the supplier's end or limited awareness of tracking and tracing requirements. Therefore, NUPCO suggests involving additional technologies to improve tracking and tracing effectiveness.

Moreover, NUPCO contributes to resilience by

conducting new projects such as the Transportation Management System. This system can control, manage, and track transportation capacity and delivery cycles while providing optimized routes for delivery. Additionally, NUPCO is investing in advanced technologies to enhance Saudi PSC resilience. For example, it uses system features that alert suppliers to deliver shipments within the required timeframe; otherwise, penalties may be applied.

Furthermore, NUPCO has implemented contingency plans to ensure the efficient and immediate supply of medications to patients under various circumstances. It also pays attention to analyzing integration details using a live interactive dashboard developed and managed by the talent team.

In KAAUH, there is a need for technological improvements, particularly in relation to planning tools, to enhance the overall operational assurance. Assurance, from the perspective of KAAUH, is specifically tied to the implementation of the "I-Supplier" module within its main system, Oracle. An example involving the use of telecommunications systems in KAAUH highlights a specific case where the current systems struggled to manage a high volume of calls efficiently. KAAUH adheres to SFDA regulations and standards; for instance, KAAUH is responsible for implementing standards in the medication procurement process. This includes utilizing the NUPCO role not only for medications they currently possess but also for those they may not yet have. This strategy aims to streamline the tender process and subsequent direct purchases, with a strong focus on following the regulations and standards.

Additionally, KAAUH relies on a central data source for defining and managing information about materials and medications. Accordingly, KAAUH contributes to trust and accuracy in its processes. However, due to the lack of direct visibility into consumption, KAAUH is required to make estimations based on the provided average monthly utilization. Therefore, the challenge of limited consumption visibility is recognized, leading to the need for estimation in the absence of complete information. Regarding tracking and tracing in the Saudi PSC from the perspective of KAAUH, the organization is required by SFDA to use the DTTS system, which requires GLN information for received drugs. However, KAAUH does not update data within the DTTS system regularly.

There is a lack of resilience within the Saudi PSC due to insufficient planning features integrated into KAAUH's systems. However, there are contingency plans and buying-on-account processes in place. Buying-on-account serves as an alternative approach in cases of supplier absence or other issues. KAAUH has successfully implemented

interoperability by customizing and integrating its systems, providing an efficient solution for managing different aspects of its technical operations. The efficiency of KAAUH's operations is acceptable and effective; the processes and systems in place are performing well in meeting the operational demands. KAAUH currently experiences a manageable workload, which contributes to its perceived efficiency. However, there is a need for technological advancements, especially in planning tools, to improve operational efficiency.

Viewed through the lens of institutional theory, these findings demonstrate that the key features of the Saudi PSC are shaped not only by technological capabilities but also by institutional arrangements. While centralized governance, regulatory standards, and national initiatives provide a common institutional framework, differences in organizational practices and technology implementation influence how effectively these features are realized across stakeholders. This suggests that achieving interoperability and SC resilience requires alignment between institutional governance and organizational implementation.

In summary, the Saudi PSC stakeholders are focusing their combined efforts on improving assurance, regulations and standards, trust and accuracy, tracking and tracing, PSC resilience, interoperability, and efficiency.

5.4. Applications of systems and data in the Saudi pharmaceutical supply chain

This section discusses how the three major stakeholders (SFDA, NUPCO, and KAAUH) use the main systems and data applications in the Saudi PSC.

The SFDA plays a crucial role in overseeing pharmaceutical trading in the Saudi Arabian market; hence, their primary uses and applications of systems and data are of significant importance. The various uses of systems in SFDA encompass the establishment of regulations, managing legislation and stakeholders, communication, drug registration, drug tracking, and reporting of drug side effects. The primary system application in the SFDA is the establishment of regulations. SFDA governs the Saudi PSC processes, ensuring medications adhere to specific criteria and are compliant with regulatory requirements. Regulatory compliance, tracking, and monitoring of drugs throughout the Saudi PSC fall under the purview of the SFDA. Furthermore, SFDA oversees the regulation of medication manufacturing, distribution agents, and warehouse operations, applying important guidelines and standards such as Good Manufacturing Practice for manufacturing and Good Distribution Practice for distributors.⁵⁹ Another application of the SFDA is related to legislation and stakeholders.

There are four main stakeholders in pharmaceutical trading: manufacturers, warehouses (including suppliers and distributors like NUPCO), pharmacies, and health ministry hospitals. SFDA uses multiple channels for communication, including a website, email, telephone number, administrative paperwork, letters, and social media. All regulations are publicly displayed for 90 days for feedback from governmental authorities.

Internally, SFDA's systems handle three key systems: SDR, DTTS, and *Tiaquz*. SDR operates in the pre-marketing stage, facilitating the licensing of drugs in Saudi Arabia. SDR is designed for drug companies to register medicinal, herbal, and health products for both human and veterinary use to achieve regulatory approval. Another internal application is the DTTS system, the most widely used in SFDA, and it operates in the post-marketing stage. It aims to focus on tracking drug movement after registration; SFDA extracts information from SDR and enters it into DTTS, employing two-dimensional barcodes for accurate tracking. The third use of internal systems involves interaction with hospitals through the *Tiaquz* system, which also operates in the post-marketing stage. *Tiaquz* enables the reporting of side effects, drug shortages, and defects in pharmaceutical products.

Regarding data uses within SFDA, several aspects are considered, including data analytics, data searching, data accuracy, data collection and management, data exchange, and integration.

Microsoft Power BI is utilized for data analytics, which is limited to focusing only on specific SFDA objectives such as recalling, preventing counterfeiting, ensuring safety, and forecasting expiry dates.⁶⁰ Furthermore, challenges in data searching exist due to system difficulties in retrieving specific information within the vast repository, which indicates a need for a more efficient data-displaying system. SFDA encounters challenges in maintaining data accuracy, particularly in hospitals. Thus, SFDA aims to minimize data misuse, with selective utilization of data for only the SFDA-specific goals described above.

For data collection and management, SFDA collects and manages data related to pharmaceutical trading from manufacturers, suppliers, warehouses, pharmacies, and Ministry of Health hospitals. For example, information for drug registrations and compliance with pharmaceutical trading regulations is obtained from manufacturers through the SDR system.

Furthermore, SFDA aims to achieve direct data exchange and integration through its systems. Consequently, SFDA mandates that all involved parties in the Saudi PSC utilize its systems via APIs. Additionally, they enforce the use

of registration numbers by providing a Global Trade Item Number to standardize data exchange and enhance compatibility.

The primary applications of systems and data in NUPCO are crucial within the overall Saudi PSC, given its fundamental role as the only central procurement company for medication supply in Saudi Arabia.

The key applications of systems encompass warehouse management, data management and integration, handling financial transactions, demand planning and forecasting, order receiving and managing, procurement, tenders, billing, regulatory compliance, traceability and dispatching, KPIs and dashboards, and supplier verification. The WMS is the first major use of systems in NUPCO. It manages day-to-day warehouse operations, such as integrating with suppliers through ASN and managing contracts. Another warehouse management approach is the use of a voluntary platform called Shark to track inventory, fulfill orders, and manage overstock.

The Talent system uses data management and integration as a central platform to gather data that other systems need, manage authorizations, and process data. Moreover, the SAP system, which stands for Systems, Applications, and Products in Data Processing, facilitates financial transaction management. This system manages financial transactions, order processing, and supplier payments; authorizes shipments; processes Goods Receipt for suppliers; and integrates with the Talent system.⁶¹

Another application of NUPCO systems is demand planning and forecasting, which is facilitated by Blue Yonder. This system provides demand and supply plans for forecasting and consumption recommendations, optimizing inventory, and suggesting product movements based on demand. Furthermore, order receiving and management are achieved through the HOS portal. Government hospitals place orders, and NUPCO manages inventory based on these orders. HOS portal services are designed to enable clients to track their inventory and check their order status.

Procurement, tenders, and billing represent essential system applications managed by the ERP system. This system streamlines business processes such as generating reports, managing orders and bills, and incorporating ASN to facilitate procurement processes and enhance interaction with suppliers. Overall, it manages procurement cycles, contracts, and tendering processes.

Compliance with SFDA regulations and obtaining relevant certifications for warehouse operations are key approaches adopted by NUPCO to achieve regulatory compliance. Traceability and dispatching involve NUPCO

integrating with the DTTS system to enforce SFDA tracking standards, ensuring traceability and validating serial numbers. Additionally, NUPCO integrates suppliers with a transportation management system for efficient cycle tracking. For dispatching, NUPCO follows SFDA regulations and integrates GLNs for accurate record-keeping.

Moreover, KPIs and dashboards serve as another key system application in NUPCO. Monitoring KPIs through dashboards aids decision-making and ensures efficient SC management. These aspects are handled by the talent and technical teams, with the goal of efficiently resolving integration issues, analyzing data, and creating interactive reports.

Supplier verification is another system application that requires suppliers to provide a Goods Receipt for their products. Moreover, suppliers are required to have an account on Supplier Relationship Management for NUPCO verification. This includes ensuring compliance with SFDA regulations to be eligible for NUPCO to handle their proposals. NUPCO utilizes data for various purposes, such as data planning and analysis, data integration for financial processes, data sharing and exchanging, data mapping, data generation, tender management, and regulatory compliance.

In data planning and analysis, historical data and consumption patterns from government hospitals received from HOS and managed by SAP, Blue Yonder, and WMS are utilized to understand the overall demand. Engaging with clients to identify their requirements results in the creation of precise demand forecasts. NUPCO's demand planning department provides insights to streamline data analysis and reporting to eventually facilitate effective decision-making.

Data integration for financial processes involves syncing SAP with financial transactions, ensuring alignment between financial processes and SC operations, and streamlining payment processes for suppliers. Moreover, data sharing and exchange entail linking systems to enable seamless data exchange between NUPCO and hospitals, providing real-time visibility into inventory, order status, and historical data. Additionally, implementing APIs ensures secure and efficient data sharing with clients' systems.

Data mapping in NUPCO addresses challenges in code unification; it involves collaboration with specialized teams and establishing data standards for consistency. Furthermore, data generation includes generating data to simplify reporting, capture operational requirements, and perform analysis by NUPCO's various teams involved in

the SC cycle. In terms of order fulfillment, data is captured to inform supply teams of shortages or overstocks, track normal and emergency orders, and ensure efficient delivery timelines. Tender management involves managing tender data and processes when clients agree. This facilitates transparent and efficient procurement processes through contract creation between clients and suppliers.

Regarding data regulation, data compliance in NUPCO includes enforcing data security measures such as access controls and encryption, and ensuring compliance with SFDA regulations for warehouses and distribution processes. In addition to implementing tracking and tracing standards for dispatched orders to adhere to SFDA regulations, including the DTTS system, standards for data entry and uniformity in serial numbers and pallets are also enforced.

The applications and uses of systems and data in KAAUH play a crucial role, especially considering its position as one of the end users in the Saudi PSC. The applications and uses of systems involve ordering and communication, planning, procurement, and inventory management.

The first application of systems is ordering and communication, which involves accessing Purchase Order lists through the HOS portal and placing orders. KAAUH is able to monitor its inventory and order status through the system. There is another ordering process called “On Behalf Of,” which is only used in cases of shortages from the main supplier, NUPCO. However, NUPCO’s approval is always required before ordering from other suppliers.

Furthermore, KAAUH can order directly from the overstock marketplace, Shark. However, this capability is not effectively utilized for two reasons: first, due to an overstock of the same medications, and second, because KAAUH is unable to establish relationships with different suppliers later. Specifically, ordering is performed through the HOS portal, and communication is conducted via email, with Excel sheets provided for confirming availability, which serve as the primary communication and verification tools.

The second system application involves demand planning. KAAUH interacts with NUPCO in its role as a client through HOS to submit demands, allowing NUPCO to plan its consumption and needs. The entire process, including ordering, is subject to NUPCO’s approval. Oracle is used for transactions but not for planning. Although there is a function in Oracle called “I-Supplier” that can be used for planning, KAAUH does not have access to it for several reasons. It has been observed that “I-Supplier” has limitations in covering details such as generic and trading

information, and its adaptation is challenging due to cost and operational constraints. Moreover, a contingency plan is in place due to the expected increase in transaction volume by 2025.

The third application of systems within KAAUH is procurement. NUPCO involves both direct purchases and arranging tenders between KAAUH and chosen drug companies. NUPCO manages the submission, revision, and adjustment of demands during the government tender processes through systematic planning.

The inventory management system application is managed internally by the Dose system. It acts as a bridge between TrakCare, the warehouse system, and the outpatient department, ensuring real-time alerts for medication needs. The Dose system manages inventory efficiently by maintaining safety stock and automating orders triggered by stock levels. The distribution center serves as an internal warehouse for temporary storage, and it manages orders for both inpatient and outpatient departments. Furthermore, there is a plan to enable NUPCO to log into a portal to check warehouse availability.

There are three aspects in terms of data use within KAAUH: data management, data sharing, and data planning. Data management is a critical aspect, with issues arising from different coding systems, such as manual mapping efforts and challenges in integrating external systems. Thus, as a current practical solution, KAAUH applies what they call “cleaning as receiving,” which means mapping the codes for each medication received one by one manually. For data sharing, the API protocol is applied to a shared folder in OneDrive. However, the shared folder requires manual updates and poses challenges in maintaining accurate and up-to-date information. Moreover, data planning is achieved manually due to the absence of a planning module in the system used: Oracle. The DC system has a planning role, and KAAUH’s planner has control over both the warehouse and the DC system. However, in emergency situations, KAAUH may request that NUPCO arrange direct shipment from suppliers to KAAUH.

The effective use of data is central to the SFDA’s mission of ensuring a safe and transparent pharmaceutical trading environment. NUPCO leverages a broad collection of systems and data applications to streamline Saudi PSC operations by integrating systems and adhering to regulations. This fragmentation across systems illustrates how technical factors can influence and shape information flows.

While the Saudi PSC operates within a centralized and policy-driven governance framework, the findings indicate

that operational and digital integration challenges remain. Issues such as manual planning processes, inconsistent coding practices, fragmented systems, and uneven compliance across stakeholders suggest that institutional centralization does not automatically translate into full interoperability or digital maturity. The findings, therefore, highlight a distinction between governance maturity and operational integration maturity, emphasizing the need for continued technological and organizational development.

This distinction is consistent with institutional theory, which suggests that formal governance structures and regulatory frameworks provide the institutional foundation for digital transformation, while effective implementation depends on their translation into organizational practices, stakeholder coordination, and technological capabilities across participating organizations. Accordingly, interoperability reflects both institutional alignment and operational implementation capabilities.

5.5. Exploring the potential of semantic technologies for the Saudi pharmaceutical supply chain

This section examines the applicability of ST to challenges identified in the Saudi PSC, as derived from thematic content analysis. Challenges were grouped into two categories: those for which ST may provide substantial support and those for which ST may provide partial support. Challenges considered beyond the scope of ST were not included in the analysis.

The mapping was guided by relevant literature; the Saudi PSC is marked by fragmented data, system incompatibility, regulatory complexity, and a diverse stakeholder landscape. These factors formed the basis for linking specific ST applications to selected identified challenges. The outcomes are presented in two structured tables, aligning challenges with potential ST applications.

The proposed ST mapping should be interpreted as a conceptual assessment informed by existing literature and stakeholder interviews rather than an empirical validation of ST solutions. The study identifies areas where ST may offer full or partial support for the challenges identified in the Saudi PSC; however, successful implementation would also depend on organizational, governance, and technological factors. Future work is therefore needed to develop and evaluate prototype implementations within the Saudi PSC context.

From a theoretical perspective, this study contributes by interpreting the identified challenges through the lens of institutional theory. The findings suggest that interoperability and data integration within the Saudi PSC are shaped not only by technological capabilities

but also by institutional arrangements, including governance structures, organizational practices, regulatory frameworks, and stakeholder coordination. This extends existing discussions on ST by demonstrating that their successful implementation depends on both technological capabilities and the broader institutional context.

Semantic technologies—including mapping, annotation, validation services, knowledge representation, data modeling, and the semantic web—address SC data challenges by enabling semantic interoperability across heterogeneous systems.⁶² Ontologies provide a shared conceptual model that standardizes the meaning of data elements across organizations, reducing inconsistencies in coding and data representation.⁶³ Knowledge graphs facilitate the integration and linking of distributed information sources, improving data visibility, discoverability, and information retrieval across stakeholders.⁶⁴ Linked data enables the interconnection of information across distributed systems through shared identifiers and semantic relationships, facilitating data integration and information exchange among stakeholders.⁶⁵

Furthermore, semantic harmonization techniques support the alignment of data structures and terminologies, enabling more effective communication and coordination between organizations operating under different systems and standards. Semantic harmonization involves integrating data from multiple sources into a shared framework where information has a consistent meaning, thereby improving interoperability and facilitating data exchange across heterogeneous systems.^{66,67} Through these mechanisms, ST can help address several of the integration and interoperability challenges identified in the Saudi PSC. The classifications presented in [Tables 2](#) and [3](#) were assigned according to the criteria described in Section 3.4.

5.5.1. Challenges fully supported by the proposed semantic technology approaches

Based on the criteria defined in Section 3.4, four challenges were classified as receiving full support from ST: (i) code diversity, (ii) inconsistencies in measurement units, (iii) data accuracy and quality, and (iv) aggregation process management. Each of these is linked to multiple challenge themes identified in Section 4, including data integration, standardization, trust, and regulatory alignment.

For instance, code diversity is a primary barrier to system interoperability in the Saudi PSC, which may be addressed through semantic mapping and ontologies. Although the SFDA has proposed the use of the Global Trade Item Number as a unifying standard, this has not been universally implemented. Semantic mapping, via a

Table 2. Challenges fully supported by the proposed semantic technology approaches

Identified challenge	Challenge-related themes	Proposed semantic technology approach
Code diversity	(i) Data integration (ii) Data quality and standardization (iii) Data trust and clarity	(i) Ontologies (ii) Semantic mapping (iii) Knowledge graphs
Inconsistencies in measurement units	(i) Data integration (ii) Data quality and standardization (iii) Data trust and clarity	(i) Ontologies (ii) Semantic annotation (iii) Linked data
Data accuracy and quality	(i) Data trust and clarity (ii) Education and training (iii) Access policy and responsibility	(i) Ontology-driven data cleaning (ii) Semantic validation services
Aggregation process management	(i) Regulatory alignment (ii) Education and training (iii) Data quality and standardization	(i) Ontology-driven rules (ii) Semantic metadata enrichment (iii) Linked data

Table 3. Challenges partially supported by the proposed semantic technology approaches

Identified challenge	Challenge-related themes	Proposed semantic technology approach
Pharmaceutical supply chain visibility	(i) Data quality and standardization (ii) Data trust and clarity (iii) Access policy and responsibility	(i) Semantic data modeling (ii) Linked data (iii) Semantic web
Inventory monitoring	(i) Data planning and analysis (ii) Access policy and responsibility (iii) Education and training	(i) Ontologies (ii) Semantic annotation
Data analytics	(i) Data planning and analysis (ii) Data trust and clarity (iii) Access policy and responsibility	(i) Knowledge graphs (ii) Ontology-driven rules
Search and retrieval	(i) Data trust and clarity (ii) Data quality and standardization (iii) Access policy and responsibility	(i) Knowledge graphs (ii) Linked data

shared ontology-based model, may provide a scalable and adaptive alternative.⁶⁸

Integrating diverse pharmaceutical and healthcare data sources into a unified structure enables cohesive patient histories and more effective care coordination across systems.⁶⁹ Unit measurement differences between stakeholders such as NUPCO and hospitals can be mitigated using semantic annotation. Semantic modeling and ontologies allow the automated conversion and alignment of unit data^{68,69}, reducing manual reconciliation.

In the case of data accuracy and quality, semantic layers offer mechanisms for embedding consistent terminology and metadata. This ensures alignment of reporting standards across providers¹², while ontology-driven data cleaning helps detect and resolve inconsistencies.⁵⁰

Product aggregation processes are critical for shipment

tracking and serialization, which can be improved through semantic enrichment, linked data, and integration with context-aware systems, including IoT and blockchain-based traceability framework.⁷⁰ The challenges classified as receiving full support from the proposed ST approaches are presented in [Table 2](#).

5.5.2. Challenges partially supported by the proposed semantic technology approaches

Semantic technologies may also provide partial support for other SC-related challenges such as PSC visibility, inventory monitoring, data analytics, search and retrieval, and interoperability and decision-making. In these cases, ST provides significant enhancements but may require complementary organizational, governance, regulatory, or technological measures for successful implementation. For example, PSC visibility can be enhanced by integrating

IoT data with semantic models.^{71,45} Inventory monitoring benefits from ontology-based standardization and dynamic rules.⁷¹ ST also unifies disparate datasets, improving analytics, searchability, and reasoning through linked data and knowledge graphs.⁷²

Table 3 presents the challenges classified as receiving partial support from the proposed ST approaches.

These findings reinforce that the proposed mappings represent conceptual relationships between ST and the identified challenges rather than validated implementation outcomes. Their practical effectiveness will depend on the specific organizational and institutional context in which they are applied.

5.6. Areas of convergence and divergence among key stakeholders

Although several challenges were observed across all stakeholder groups, the perception, impact, and prioritization of these challenges differed according to each organization's role within the Saudi PSC. SFDA primarily emphasized regulatory compliance, traceability, and standardization, reflecting its regulatory oversight role. NUPCO focused on procurement efficiency, coordination, and visibility across the SC, consistent with its centralized procurement function. KAAUH emphasized operational continuity, timely access to medicines, and effective inventory management as a healthcare delivery institution.

Despite these differing priorities, all stakeholders recognized the importance of improved interoperability, data quality, and cross-organizational information exchange. These areas of convergence suggest common opportunities for collaboration, while the differences highlight the need for stakeholder-specific implementation strategies.

From an institutional theory perspective, these differences reflect the distinct institutional roles and responsibilities of the stakeholders, while their shared priorities demonstrate how common governance structures and regulatory frameworks shape collaborative objectives and coordination mechanisms across the Saudi PSC.

5.7. Semantic technologies in relation to alternative approaches

While ST offers a promising approach to improving interoperability and data integration, they should not be viewed as the sole solution to PSC challenges. Alternative approaches include shared ERP systems, regulatory mandates for standardized data formats, and industry standards such as GS1.^{42,45} These approaches can improve consistency and coordination but often require substantial

organizational alignment or system standardization.

In contrast, ST can facilitate interoperability across heterogeneous systems by enabling the integration of diverse data structures and terminologies without requiring all stakeholders to adopt a uniform technological infrastructure. Consequently, ST should be viewed as a complementary mechanism that can operate alongside broader governance, regulatory, organizational, and technological initiatives rather than as a standalone solution.

6. Conclusion

In this study, we examined the current state of the Saudi PSC through a qualitative study involving three key national stakeholders: SFDA, NUPCO, and KAAUH. Through thematic content analysis, the study identified seven main themes and 25 sub-themes, highlighting challenges related to data integration, data quality, and standardization, as well as broader issues such as trust, communication, planning, regulatory alignment, access policies, and education.

From a theoretical perspective, this study contributes by interpreting the identified challenges through the lens of institutional theory. The findings suggest that interoperability and data integration within the Saudi PSC are shaped not only by technological capabilities but also by institutional arrangements, including governance structures, organizational practices, regulatory frameworks, and stakeholder coordination. This extends existing discussions on ST by demonstrating that their successful implementation depends on both technological capabilities and the broader institutional context.

These findings offer valuable insights for the key stakeholders involved in the Saudi PSC, particularly regulators (e.g., SFDA), procurement authorities (e.g., NUPCO), and healthcare providers (e.g., KAAUH). The findings are intended to support decision-making related to interoperability, data governance, and SC integration within the Saudi healthcare ecosystem. They may also provide relevant insights for stakeholders operating in other centralized and highly regulated SC environments facing similar interoperability and data integration challenges.

The findings reveal that systems and data integration are central to the overall effectiveness of the Saudi PSC. Despite ongoing efforts in digital transformation, progress is slowed by the use of incompatible systems, fragmented data sources, and limited coordination among stakeholders. Addressing these issues will require improved alignment and the implementation of proactive strategies

that support seamless data exchange, interoperability, and real-time operational visibility.

The perspectives gathered from SFDA, NUPCO, and KAAUH demonstrate a shared focus on improving regulatory compliance, pharmaceutical traceability, and operational transparency. However, achieving full integration remains a work in progress that will depend on stronger collaboration, clear governance structures, and strategic investment in both technological and organizational capabilities.

To help address these challenges, the study proposes the use of ST as a conceptual framework for enhancing data integration, management, and interoperability. ST offers potential solutions to common issues such as inconsistent coding, variations in measurement units, data accuracy, and aggregation processes within the Saudi PSC. Additionally, semantic layers can improve visibility, ensure consistency in inventory monitoring, and strengthen data analysis, search, retrieval, and decision-making. However, their successful implementation depends on complementary organizational, governance, regulatory, and technological measures.

The adoption of ST should be viewed as a phased sociotechnical transformation rather than a single implementation activity. An initial phase may focus on the development of shared ontologies, data standards, and stakeholder alignment. Subsequent phases could involve pilot implementations within selected SC processes, followed by broader integration across regulators, procurement authorities, suppliers, and healthcare providers. Given the scale and complexity of the Saudi PSC, such efforts are likely to require a multi-year implementation horizon aligned with the ongoing digital transformation objectives of Saudi Vision 2030.

This study provides an exploratory qualitative investigation of key stakeholders within the Saudi PSC. The sample was intentionally limited to representatives from the regulator, the central procurement authority, and a healthcare provider based in Riyadh and did not include manufacturers or importers due to accessibility constraints. Consequently, the findings should not be viewed as statistically representative of the broader Saudi PSC ecosystem. Rather, they provide an in-depth understanding of challenges experienced by major stakeholders and identify areas for future investigation involving a wider range of organizations and geographic regions.

Future studies should develop and evaluate prototype ontologies or semantic models tailored to the specific needs of the Saudi PSC or empirically explore the policy

and organizational factors that influence the adoption of ST. These efforts could support broader goals under Saudi Vision 2030 by contributing to the development of a transparent, efficient, and resilient national PSC.

Although the present study focuses on Saudi Arabia, the findings suggest that interoperability challenges in centralized PSCs often arise from a combination of data standardization, system heterogeneity, governance, and stakeholder coordination issues. These insights may be relevant to other highly regulated centralized SCs undergoing digital transformation, particularly those seeking to improve integration, transparency, and data-driven decision-making.

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Ethics approval and consent to participate

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Availability of data

Data are available from the corresponding author upon reasonable request.

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