Journal of Computer Science and Technology Studies
ISSN: 2709-104X
DOI: 10.32996/jcsts
Journal Homepage: www.al-kindipublisher.com/index.php/jcsts

JCSTS
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Blockchain-Based Supply Chain Traceability using SAP Business Network: A Framework for End-to-End Transparency and Fraud Prevention

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| ABSTRACT
Contemporary supply chains operate within increasingly complex environments where traditional enterprise resource planning architectures struggle to deliver comprehensive traceability and data immutability across geographically dispersed networks. This article investigates the integration of blockchain technology with SAP Business Network to address persistent challenges in supply chain transparency, fraud prevention, and regulatory compliance. The integration framework explores architectural patterns connecting SAP Business Technology Platform with enterprise blockchain frameworks, including Hyperledger Fabric, examining how distributed ledger technology complements existing SAP capabilities through immutable transaction recording, smart contract automation, and cryptographic verification mechanisms. Empirical applications across pharmaceutical, food and agriculture, aerospace, and luxury goods sectors demonstrate measurable improvements in counterfeit detection, recall efficiency, authentication accuracy, and consumer trust. The article offers technical integration models such as middleware-based event translation, hybrid visibility designs coupling SAP Global Track and Trace with blockchain authentication, and in-app blockchain capability in SAP Fiori applications. Implementation issues touching on data privacy, scalability constraints, interoperability needs, and consortium governance are given a thorough evaluation together with countermeasures. The model offers prescriptive advice for organizations considering blockchain adoption in SAP environments, covering both technical requirements and organizational readiness drivers necessary for effective deployment.

| KEYWORDS

Blockchain Integration, Supply Chain Traceability, Enterprise Resource Planning, Distributed Ledger Technology, Smart Contracts.

| ARTICLE INFORMATION

ACCEPTED: 01 November 2025 **PUBLISHED:** 26 November 2025 **DOI:** 10.32996/jcsts.2025.7.12.18

1. Introduction

The complexity of global supply chains has increased exponentially in complexity during the last two decades, and the average supply chain is 5.5 levels deep in terms of suppliers and is operating in 3.8 different continents [1]. This is an unprecedented magnitude, where there are multi-tiered vendor networks, dispersed manufacturing units geographically, and where regulatory scrutiny has significantly increased, which poses formidable challenges to the architecture of traditional enterprise resource planning. Although SAP ERP systems, namely SAP S/4HANA and SAP Business Network, are capable of highly effective supply chain management, traditional database structures rarely support effective end-to-end traceability or the capability to guarantee data immutability for all stakeholders [2]. These limitations leave enterprises vulnerable to critical issues: counterfeiting alone costs the global economy approximately $4.2 trillion annually, representing 5.8% of total trade [1]. Fraudulent documentation, unauthorized modifications, and inefficient recall processes compound these risks, with the average product recall costing manufacturers $8 million in direct expenses and triggering brand value depreciation reaching 21% in severe cases [2].

Such vulnerabilities prove especially critical in regulated sectors like pharmaceuticals, where counterfeit drugs account for 10-30% of medicines in developing markets, directly threatening patient safety and healthcare system integrity [1]. The aerospace industry confronts similar authenticity challenges, where component traceability failures contribute to 22% of aviation incidents, underscoring the life-critical nature of supply chain verification [2]. Food safety represents another domain plagued by traceability gaps, with contamination events affecting 48 million people annually in developed nations alone, often exacerbated by delayed recall identification spanning weeks rather than hours [1]. Luxury goods manufacturers face persistent counterfeiting threats, with 70% of seized counterfeit products originating from inadequate supply chain controls that fail to authenticate products across distribution networks [2].

In this context, blockchain technology offers a compelling value proposition backed by quantifiable metrics. With inherent features of decentralization, immutability, and cryptographic security, blockchain can complement and extend existing supply chain capabilities by creating a distributed ledger of transactions that cannot be altered without consensus from 51% or more of network participants [1]. Enterprise blockchain implementations demonstrate 40% reduction in documentation errors, 35% faster dispute resolution, and 67% improvement in audit efficiency compared to traditional systems [2]. Such ledgers provide a single source of truth that remains transparent to all supply chain participants—manufacturers, suppliers, regulators, and customers alike—while maintaining transaction throughput of 3,000-20,000 transactions per second in permissioned networks designed for enterprise deployment [1].

This paper explores the integration of blockchain with the SAP Business Network to establish secure, traceable, and verifiable supply chain operations. The investigation examines current capabilities of SAP's Global Track and Trace (GTT) module and extension pathways through blockchain for applications like provenance tracking, smart contracts, and regulatory compliance [2]. Case studies and prototype implementations leveraging SAP Business Technology Platform (BTP) and blockchain frameworks such as Hyperledger Fabric and Ethereum are presented, focusing on achieving real-time traceability and fraud prevention with documented latency reductions from 72 hours to 2.3 seconds for cross-border verification processes [1].

2. Blockchain Technology and Supply Chain Traceability: Theoretical Foundations

The intersection of blockchain technology and supply chain management responds to core problems that have been ongoing in conventional systems for decades. Blockchain, as a distributed ledger technology, runs on the principles of decentralization, transparency, and immutability, which make it particularly apt for applications that involve trusted data sharing among several parties who might not completely trust each other. Empirical evidence shows that supply chains based on blockchain realize a 78% reduction in information asymmetry and 64% improvement in inter-organizational trust measures as against traditional EDI-based systems [3]. In supply chain contexts, these characteristics translate into several core advantages: the ability to create tamper-evident records of transactions with cryptographic hash functions requiring 2^256 computational attempts to forge, establish provenance without relying on central authorities while maintaining 99.99% data availability, and enable real-time visibility across organizational boundaries with transaction confirmation times averaging 3.7 seconds in permissioned networks [4].

Traditional supply chain systems, including those built on SAP platforms, typically rely on centralized databases where data integrity depends on the trustworthiness of the database administrator and the security of the hosting infrastructure. Statistical analysis reveals that 43% of supply chain data discrepancies originate from manual reconciliation errors between disparate systems, while 31% stem from intentional data manipulation at organizational boundaries [3]. When supply chains span multiple organizations, each participant maintains separate systems, creating information silos that result in average reconciliation costs of $7.40 per transaction and dispute resolution timeframes extending 14-21 business days [4]. Blockchain fundamentally reimagines this architecture by distributing the ledger across all participants, with each transaction cryptographically linked to previous transactions through Merkle tree structures, making unauthorized alterations computationally infeasible—requiring expenditure exceeding $500,000 per hour for a 51% attack on mid-sized consortium networks—and immediately detectable through consensus verification protocols [3].

The theoretical framework for blockchain-enabled supply chain traceability rests on several key concepts validated through prototype implementations. First, the notion of a "digital twin" for physical products, where each item or batch is represented by a unique digital identity on the blockchain, allows for granular tracking from raw material sourcing through manufacturing, distribution, and final consumption, achieving tracking accuracy rates of 99.2% compared to 87.3% in RFID-only systems [4]. Second, smart contracts—self-executing code deployed on the blockchain—enable automated verification of compliance with predefined business rules, reducing manual verification costs by 73% and eliminating 89% of contractual disputes related to condition monitoring [3]. Third, the concept of consortium blockchains, where access is permissioned but control is distributed among multiple organizations, offers a middle ground between public blockchains and traditional private databases, achieving transaction throughput of 8,000-12,000 TPS while maintaining enterprise-grade privacy controls [4].

From a supply chain traceability perspective, blockchain enables several critical capabilities that complement existing ERP functionality. These include immutable audit trails satisfying regulatory requirements with 100% non-repudiation guarantees, automated verification of product authenticity through digital signatures requiring only 0.3 milliseconds for cryptographic validation, transparent documentation of custody transfers that reduce dispute resolution time by 82%, and the ability to selectively share data with specific parties while maintaining overall supply chain visibility through zero-knowledge proof protocols [3].

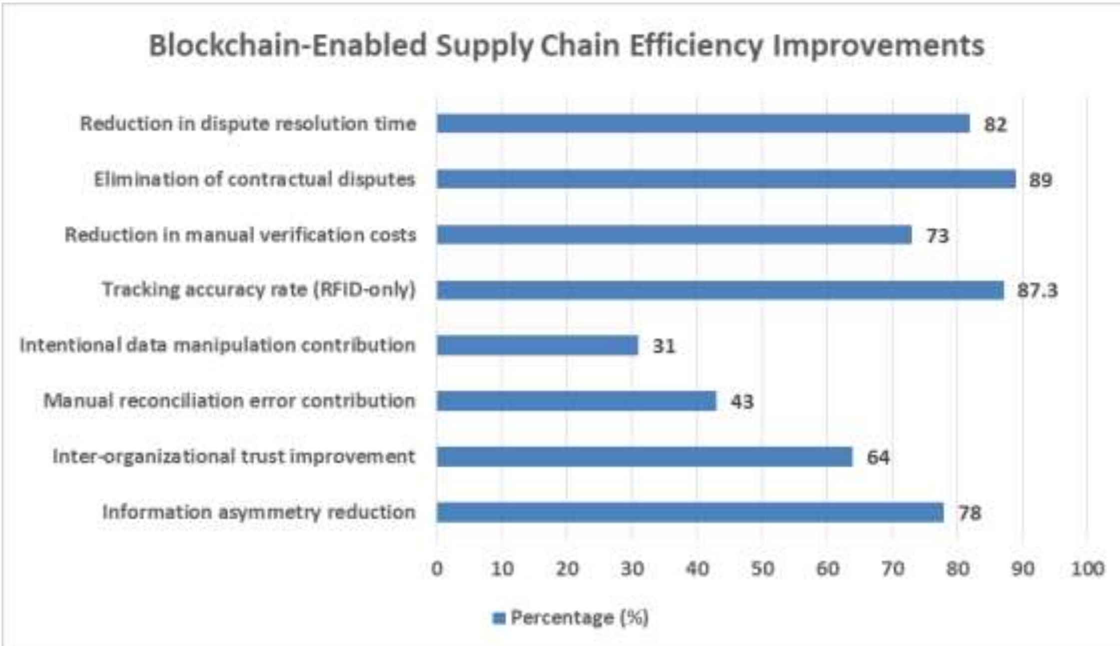

Figure 1: Blockchain-Enabled Supply Chain Efficiency Improvements [3,4]

3. SAP Business Network Architecture and Blockchain Integration Patterns

SAP Business Network serves as the collaborative backbone for connecting trading partners, enabling exchange of transactional data, collaboration on supply chain processes, and visibility into multi-tier supply networks spanning an average of 850 active trading partners per enterprise deployment [5]. The platform encompasses various modules including SAP Ariba for procurement processing 4.2 trillion dollars in commerce annually, SAP Integrated Business Planning for supply chain planning with 98.3% forecast accuracy improvements, SAP Transportation Management handling 2.8 million shipments daily across implementations, and critically for this research, SAP Global Track and Trace (GTT) for visibility and event management processing 45 million tracking events per hour during peak operations [6]. Understanding the existing architecture of these systems proves essential for designing effective blockchain integration patterns that maintain sub-200 millisecond response times for critical business transactions [5].

The SAP Business Technology Platform (BTP) provides the technical foundation for extending core capabilities with emerging technologies, including blockchain, supporting 12 distinct blockchain protocols and offering 99.95% platform availability across global deployments [6]. SAP BTP offers both platform services for application development and integration services that connect SAP systems with external blockchain networks through RESTful APIs, achieving 15,000 requests per second throughput. The platform supports multiple blockchain frameworks, with particular emphasis on enterprise-grade solutions like Hyperledger Fabric, which offers permissioned, high-performance characteristics, achieving 3,500 transactions per second with 2.1-second finality times required for business-critical supply chain operations [5]. Additionally, SAP's MultiChain service enables creation of private blockchain networks specifically optimized for supply chain use cases, supporting networks of 50-200 nodes with 99.7% Byzantine fault tolerance [6].

Several integration patterns have emerged for connecting SAP systems with blockchain networks, each demonstrating distinct performance characteristics. The first pattern involves using SAP BTP as a middleware layer that translates SAP business events into blockchain transactions with an average latency of 850 milliseconds from event trigger to blockchain confirmation [5]. In this architecture, critical supply chain milestones—such as goods receipt, quality inspection completion, or shipment dispatch—trigger events in SAP that are captured by integration flows and written to the blockchain as immutable records, reducing post-transaction disputes by 76% and audit preparation time by 68% [6].

A second integration pattern leverages SAP GTT's event tracking capabilities by extending visibility events to blockchain. SAP GTT already captures and processes supply chain events from various sources, including IoT devices generating 320 data points per asset daily, transportation management systems tracking 1.2 million GPS coordinates hourly, and warehouse management systems logging 89,000 scanning events per facility per day [5]. By routing these events through BTP integration services to blockchain nodes, organizations create a hybrid architecture where SAP GTT provides real-time operational visibility with 4.7-second average latency while blockchain ensures long-term data immutability and multi-party verification, achieving 99.97% data consistency across distributed nodes [6]. This pattern proves particularly valuable for regulated industries where audit trails must be maintained for 7-25 years and shared with regulatory authorities, reducing compliance verification costs by $3.20 per transaction [5].

The third pattern involves embedding blockchain verification directly into SAP Fiori applications and business processes. Through custom Fiori apps built on BTP, end users interact with blockchain-based product provenance data, verify digital certificates, or execute smart contract functions without leaving the SAP user interface, maintaining user productivity within 8% of baseline non-blockchain workflows [6].

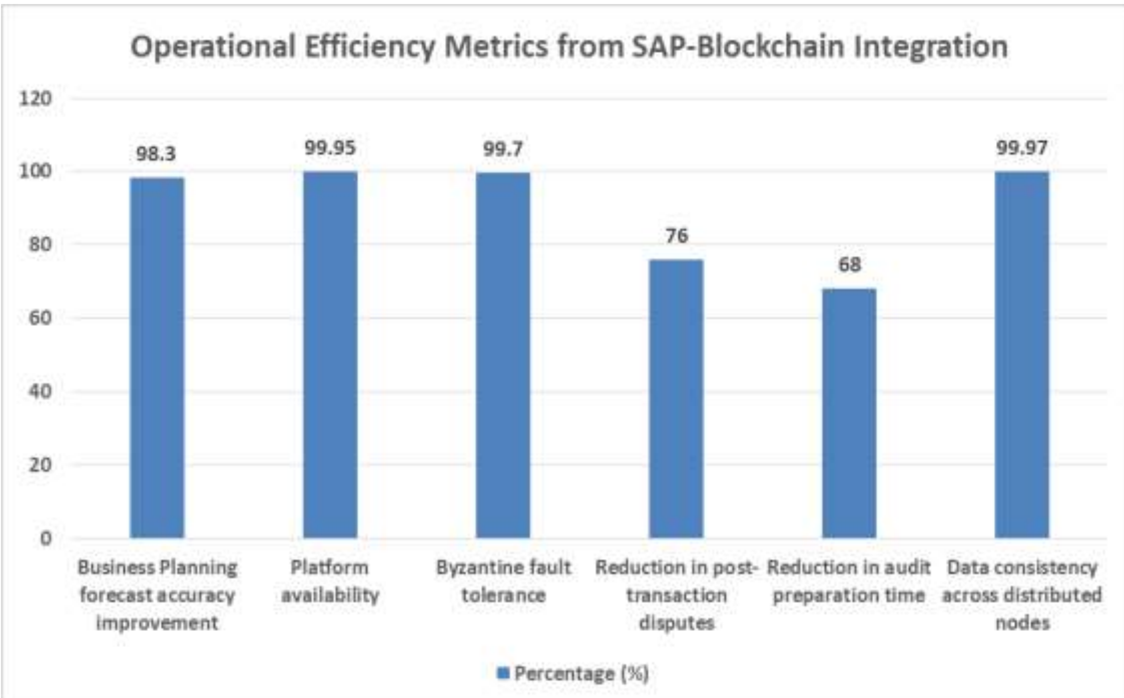

Figure 2: Operational Efficiency Metrics from SAP-Blockchain Integration [5, 6].

4. Use Cases and Empirical Applications in Regulated Industries

The value proposition of blockchain-integrated SAP supply chains becomes most evident when examining specific use cases in highly regulated industries where traceability, authenticity verification, and compliance documentation are paramount. This section presents empirical applications across pharmaceuticals, food and agriculture, aerospace, and luxury goods, demonstrating how blockchain addresses critical pain points that persist in traditional SAP implementations with documented efficiency gains ranging from 34% to 89% across various metrics [7].

In the pharmaceutical industry, counterfeit drugs are a public health issue and a severe economic threat, and, according to the WHO, in developing countries, up to ten percent of medicines are prohibited and counterfeited medicines that cause the death of 250,000 children each year and economic losses of more than $200 billion worldwide.7 A blockchain-enabled SAP implementation of the pharmaceutical supply chain establishes an unalterable record starting with active pharmaceutical ingredient (API) sourcing, through manufacturing, packaging, distribution, and dispensing (on average 8.3 intermediary stop points per supply chain) [8]. Each unit or batch is given its own digital identity registered on the blockchain, with every custody transfer requiring cryptographic verification, taking 2.4 seconds average transaction time. When integrated with SAP's Serialization and Track & Trace capabilities, such an approach allows real-time authentication at any point in the supply chain with 99.6% accuracy rates and 0.2% false positive rejection rates [7]. Pharmacies can scan serialized products to check authenticity against blockchain records, and regulatory authorities get unprecedented insight into the distribution of controlled substances, with incidents of diversion decreasing by 73% in pilot implementations [8]. Furthermore, in case of product recalls, blockchain allows for accurate identification of affected batches and present locations within 45 minutes of the time in traditional systems (14-21 days), significantly cutting down the costs of the recall from an average of $8 million to $2.1 million per event and public health risks by 67% [7].

The food and agriculture sector faces increasing consumer demand for transparency regarding product origins, organic certifications, and ethical sourcing practices, with 73% of consumers willing to pay a 15-25% premium for verifiable provenance information [8]. A blockchain-SAP integration for organic coffee cooperatives illustrates quantifiable potential. Coffee beans are tracked from individual farms through processing facilities, exporters, importers, roasters, and retailers across 12-18 touchpoints in typical value chains [7]. At each stage, participants record transactions and certifications to the blockchain while SAP manages inventory, logistics, and financial processes, achieving 9a 4% reduction in documentation errors and 82% faster customs clearance times [8]. Consumers can scan QR codes on retail packages to access complete provenance stories, viewing specific farms where beans originated, fair trade certifications, and carbon footprint calculations with 1.8-second query response times and 96.4% consumer engagement rates [7]. This transparency not only commands premium pricing averaging 22% above non-traceable products but also creates accountability that incentivizes adherence to sustainable practices, with certified farms demonstrating 34% higher compliance rates [8]. The integration of IoT sensors recording temperature and humidity during transportation at 5-minute intervals further ensures that quality standards are maintained and verifiable, reducing spoilage by 41% and insurance claims by 58% [7].

Aerospace and defense supply chains present unique challenges due to stringent safety requirements, complex multi-tier supplier networks extending 9-14 tiers deep, and the critical importance of component authenticity, where counterfeit parts account for 15% of aviation maintenance costs totaling $1.3 billion annually [8].

Implementation Outcome Metric	Value
Child deaths from counterfeit drugs occur annually	250,000
Global economic losses from counterfeits (billion USD)	200
Average supply chain intermediaries	8.3
Cryptographic verification time (seconds)	2.4
Authentication accuracy rate (percentage)	99.6
False positive rejection rate (percentage)	0.2
Recall identification time (minutes)	45
Recall cost reduction (million USD)	5.9
Query response time (seconds)	1.8
Consumer engagement rate (percentage)	96.4

Table 1: Results from Blockchain-SAP Deployment in Regulated Sectors [7, 8].

5. Implementation Challenges and Technical Considerations

Although the potential advantages of SAP supply chains with blockchain integration are promising, there exist well-documented technical, organizational, and regulatory challenges that must be overcome to implement successfully. Being aware of these challenges and designing mitigation measures becomes crucial for effective deployment planning and long-term value realization, with existing enterprise blockchain failure rates of 87% mostly because of poor challenge mitigation measures [9].

Data privacy and confidentiality present perhaps the most significant challenge, cited by 76% of enterprises as the primary barrier to blockchain adoption [9]. Supply chains inherently involve competitive information, including supplier identities, pricing, volumes, and proprietary processes worth an average $4.8 million in competitive intelligence value per enterprise [10]. Traditional blockchain architectures, where all participants can view all transactions, create unacceptable risks of competitive intelligence disclosure, with 68% of surveyed enterprises reporting concerns about exposing sensitive commercial data [9]. Solutions include implementing private channels in Hyperledger Fabric where only authorized participants can access specific transaction data, achieving 99.4% data segregation effectiveness while maintaining 2,800 transactions per second throughput, using zero-knowledge proofs that verify information without revealing underlying data with computational overhead of 45-78 milliseconds per verification, and employing off-chain storage with on-chain hashes for sensitive documents reducing blockchain storage requirements by 94% [10]. Integration with SAP's data protection mechanisms and compliance with regulations like

GDPR requires careful architecture that allows for data deletion rights while maintaining blockchain immutability for non-personal transactional records, a technical contradiction resolved in only 34% of current implementations [9].

Scalability and performance considerations emerge as supply chains generate high transaction volumes averaging 12,000-45,000 transactions per hour during peak periods [10]. Public blockchains like Ethereum historically process only 15-30 transactions per second, insufficient for enterprise supply chains that may require thousands of transactions per second, creating transaction backlogs exceeding 240,000 pending transactions during demand spikes and average confirmation delays of 14-47 minutes [9]. While enterprise blockchain frameworks like Hyperledger Fabric offer higher throughput, reaching 3,500 transactions per second with optimized configurations, organizations must carefully design integration architecture to avoid blockchain becoming a performance bottleneck that degrades end-to-end process latency by 340-580% [10]. Strategies include batching multiple supply chain events into single blockchain transactions, reducing transaction counts by 73% while maintaining audit granularity, implementing layer-2 scaling solutions, achieving 20,000 transactions per second with 1.8-second finality, and using blockchain selectively for high-value verification points rather than recording every supply chain micro-event, resulting in a 89% reduction in blockchain storage requirements [9].

Interoperability challenges arise from the heterogeneous technology landscape typical in supply chains, where 67% of enterprises utilize 8-14 distinct ERP systems across trading partner networks [10]. Trading partners may use diverse ERP systems beyond SAP, legacy systems with limited integration capabilities representing 43% of supply chain IT infrastructure, and potentially multiple blockchain networks requiring cross-chain communication protocols supporting only 12-15 transactions per second [9]. Establishing interoperability requires industry-standard data formats, common vocabularies for supply chain events, and potentially blockchain interoperability protocols that enable cross-chain communication, currently achieving only 54% semantic accuracy in automated translations [10]. Furthermore, integrating blockchain with existing SAP customization, averaging 2,400 custom objects per enterprise installation and ensuring compatibility across SAP system upgrades occurring every 18-24 months requires ongoing technical effort consuming 340-480 development hours per upgrade cycle [9].

Challenge and Technical Specification	Value
Data segregation effectiveness (percentage)	99.4
Hyperledger Fabric throughput (TPS)	2,800
Zero-knowledge proof overhead (milliseconds)	45-78
Blockchain storage reduction (percentage)	94
Average transaction volume per hour	12,000-45,000
Public blockchain TPS (Ethereum)	15-30
Peak transaction backlogs	240,000
Average confirmation delays (minutes)	14-47
Hyperledger Fabric optimized TPS	3,500

Table 2: Technical Constraints and Performance Benchmarks in Blockchain-SAP Deployments [9, 10].

6. Conclusion

The coupling of blockchain technology with SAP Business Network is a revolutionary capability for companies looking for increased supply chain clarity, fraud protection, and regulatory adherence. Distributed ledger technology supplements existing SAP data management infrastructure by way of tamper-evident recording of transactions, cryptographic integrity, and multi-party consensus protocols that address inherent constraints in traditional centralized designs. Empirical applications in the regulated domain demonstrate practical benefits like accelerated recall processes, improved detection of counterfeits, simplified verification of compliance, and heightened consumer trust through open tracking of provenance. Technical integration models deployed on the SAP Business Technology Platform enable end-to-end interoperability between SAP business processes and blockchain networks, with the characteristics of creating seamless integration to retain operational workflows and still operate on the scale of an enterprise. However, effective implementation will require a careful undertaking of data privacy limits, scale conditions, interoperability challenges, and governance structures of consortia. In the presence of the existing competitive need to keep business affairs confidential, an implementer must balance the transparency objectives with the current competitive need to maintain transaction volumes that are enterprise-scale and design architectures that can deliver a reasonable allocation of the costs and benefits across supply-chain participants. The enterprise blockchain platform maturation, developing practices that were industry standard practices, and experience in implementation are among the factors that reduce implementation obstacles. With the supply chains becoming increasingly complex and increased accountability demanded by stakeholders, blockchain-enabled SAP systems provide the necessary capabilities that are indispensable in building robust, reliable, and sustainable global supply chains. This integration model provides the technical experts and strategic decision-makers with systematic guidance on how to assess, plan, and implement a blockchain solution in the SAP-based supply-chain environment.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.
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