Blockchain anchored supply chain automation

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Increasing globalization, e-commerce usage, and social awareness are leading to increased consumer demand for variety, value, convenience, immediacy, verifiable authenticity and provenance, ethical materials sourcing and manufacturing, regulatory compliance, and services after sales. Fulfilling this increased complexity of consumer demand has required supply chains to evolve into multienterprise networks with numerous flow paths in production, merchandising, and fulfillment involving many organizational/institutional handoffs, to effectively manage a large number of complex products with shorter life cycles and high transaction volumes. The supply chain management models of today place higher demands on automation and require a transition from the traditional paradigm of planning followed by long-loop execution for a handful of segments to a paradigm of managing a portfolio of end-to-end instrumented data-rich microsegmented supply chains that are monitored and adjusted in near real time. These essential aspects and challenges of supply chain management require the supporting information technology to also evolve. In this paper, we propose a novel reference software architecture to address the complex requirements of modern supply chains that also integrates blockchain into several layers of the stack. We present several examples where this reference architecture is applicable, and then demonstrate through a use case in production that integrating blockchain technology helps with providing visibility, documenting provenance, and allowing permissioned data access to facilitate the automation of many high-volume tasks such as reconciliations, payments, and settlements.

Introduction

Supply chains have indeed come a long way, but the road ahead is even more exciting. In the mid-20th century innovation in supply chain management—perhaps more appropriately termed logistics management—was centered on improving the labor-intensive operations in warehouses through palletization and pallet lifts. Advanced multivariable in-memory optimization solutions from the 1990s allowed quick synchronization of factory production plans and schedules to changes in demand. Coupling them with Enterprise Resource Planning (ERP) systems and data networking in the late 1990s facilitated optimization of performance across procurement, production, warehousing, and transportation departments. For example, Walmart [1] combined real-time store demand and inventory visibility with product supply cross-docking enablement to ensure superior product assortments that were better aligned with consumer demand. Dell [2], on the other hand, pioneered the supply chain control tower concept to track inventory depletion rates, and supply availability and replenishment supplemented with demand shaping to enable then an innovative configure to order direct-to-consumer sales model.

Concurrently, with the signing of the World Trade Association's Marrakesh Agreement in 1994 by 124 countries, companies globalized their supply chains to take advantage of low-cost country sourcing with the resultant explosion of global trade. This drove the need for a company's supply chain management to encompass its suppliers and customers, thereby creating the extended global supply chain [3]. Recognizing the growing

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complexity inherent in managing extended supply chains, Pittiglio Rabin Todd & McGrath and AMR Research defined and developed the supply-chain operations reference (SCOR) model in the mid-1990s. SCOR provided a framework linking business process, metrics, and supporting technology requirements to facilitate collaboration among supply chain participants [4]. Furthermore, this spawned the practice of managing a portfolio of end-to-end microsegmented supply chains [5]. However, data exchange underpinning such collaboration relied on multiple transmission methods such as telephone, facsimile, e-mail, and in the case of some advanced companies on data exchange hubs such as E2Open and GT Nexus. The development of data format standards and data exchange protocols such as Electronic Data Interchange (EDI), RosettaNet, and GS1 helped some, but a lack of industry alignment on a common set of standards hampered widespread adoption of a uniform protocol with its affiliated benefits [6–8]. The advent of the Internet and its ubiquitous presence lowered the cost of data exchange, thereby bringing more supply chain participants into the realm of electronic data exchange. Unfortunately, the prevalence of multiple data exchange formats and standards meant that a Human-in-the-Loop was required to interpret and act upon the data exchanged in most cases, thereby rendering the process time-consuming, prone to errors, and costly.

While this organizing framework was exceedingly useful then, and continues to be useful today, it is not adequate for today's needs—thanks to the "Amazon Effect" [9, 10], which has triggered a revolution of epic proportions across the globe—with significantly increased consumer expectations of convenience and immediacy, in addition to demands for choice, price, and verifiable authenticity and provenance, that further amplified the volatility and uncertainty always inherent in supply chains. Furthermore, efficient execution of global trade demands timely and constant compliance to an ever-changing landscape of multicountry distinct regulatory and consumer advocacy frameworks and reporting; examples to name a few include RoHS, Conflict Minerals, Drug Supply Chain Security Act, Unique Device Identification, Rainforest Alliance, Non-GMO Project, USDA Organic, and Fair Trade. All of which results in an extremely difficult and shifting supply chain landscape, especially for multi-product global supply chains with multiple sourcing, manufacturing, distribution and retailing centers, wherein the effects of volatility and uncertainty are further compounded by complexity and ambiguity related challenges! Governance around regulations such as General Data Protection Regulation (GDPR) also need to be factored in, especially when working across borders or business entities. As a result, "today's supply chains do much more than just physically move materials and product from place to place. In an increasingly digital world, supply chains are the backbone of an information ecosystem in which a connected and carefully coordinated set of movements and actions must be tracked at every level, in order to maximize efficiency and meet customer demands for increased flexibility, visibility, and transparency" [11].

A manifestation of this philosophy is evident in the characteristics of Industry 4.0 [12]. "Industry 4.0 is a name given to the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of Things (IoT), cloud computing, and cognitive computing. Industry 4.0 fosters what has been called a 'smart factory.' Within modular structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions. Over the IoT, cyber-physical systems communicate and cooperate with each other and with humans in real time both internally and across organizational services offered and used by participants of the value chain" [13]. So much so, traditional supply chain planning-oriented tools are inadequate to serve today's needs. Specifically, decision support systems need to be supplemented with timely regulatory/legal and socially relevant compliance data, partitioned and appropriately structured to support multiple constituencies that microsegmented supply chains encounter—e.g., governmental/nongovernmental agencies, consumers, returns/recall management, shippers, carriers.

While tools to enhance visibility, performance monitoring, decision support, etc., are available, the heterogeneity and complexity inherent in supply chains, coupled with the need for rapid accurate responses in a high-transaction-volume environment, renders responsive cost-effective management without automation impossible [14, 15]. Specifically, the following areas could benefit from further improvement.

1) Although the market is saturated with various supply chain tools, gaps exist in support for near-real-time reconciliation and decision support that rely on data resident in multiple systems.
2) While the supply chain ecosystem within an organization has been greatly optimized with automation and process optimizations, frictions do remain when the same supply chain process transcends organizational boundaries due to lack of trust.
3) While incumbent supply chain tool vendors have developed good intra-enterprise process optimization solutions, they have been slow in bringing to market solutions enabled by newer technologies such as IoT/sensors, blockchain, and artificial intelligence (AI) that address inter-enterprise friction points.

Based on learnings from building proofs-of-concept and larger scale solutions, we believe that incorporation of AI, IoT, and blockchain should help [16] as follows:

1) extending process optimization (and reducing friction) across organizational boundaries;
2) enabling end-to-end (E2E) visibility and traceability;
3) tracking provenance;
4) reducing documentation and increasing ease of use;
5) automating routine rules-based tasks and delivering improved analytics; and
6) migrating away from relying on Sales & Operations Planning (S&OP) processes that have often proven to be static and siloed, which impedes optimization of service levels and asset/cost performance, to an automated exception management response system that effectively incorporates demand, price, and supply considerations.

Blockchain in supply chain

Blockchain, which had its origins in creating the Bitcoin digital cryptocurrency, is recognized as being useful in a wide variety of business applications that typically span functional and organizational boundaries. While the costly proof-of-work approach to adding blocks to mine cryptocurrency was necessary for anonymous permissionless networks, a more cost-effective consensus-based approach to enable a permissioned blockchain network is applicable to managing supply chains.

Given the considerable number of participants in a supply chain, effective end-to-end integration and collaboration can be provided by attributes inherent in blockchain—immutability, provenance, permissioned access, distributed ledger, privacy, and security. This also makes it an appropriate repository for processed/aggregated data gathered from IoT devices, subscriptions to third-party data, regulatory compliance acknowledgments, and links to transactional data. As a consequence, blockchain provides the ideal backbone for provisioning, sharing, and exchanging data and facilitates the automated execution of business regulations and rules, contracts, and settlements [17–19].

Hyperledger is an “open source collaborative effort created to advance cross-industry blockchain technologies,” which is hosted by the Linux Foundation, and includes more than 250 active organizations as members. Contributions include the development of frameworks, e.g., identity and contracts, and tools, e.g., modelers, visualizers, and benchmarks, necessary to accelerate adoption and ecosystem development.

Hyperledger Fabric [20] is an enterprise-grade permissioned distributed ledger technology platform with capabilities to extend process optimization beyond organizational boundaries with trust and confidence, by making available the following:

1) a shared ledger, with an append-only distributed system of record enabling provenance;
2) pluggable consensus methods to enable flexibility in supporting business model(s) evolution;
3) privacy and security through transaction authentication and verification enabling permissioned access to trusted data.
4) endorsement of transactions by relevant participants engendering trust and rapid reconciliation of disputes;
5) smart contracts, with business terms and conditions embedded in the transactions enabling automation;
6) modularity that permits easy expansion and contraction of business networks and models.

These help to address some of the key challenges faced in supply chain ecosystems today by providing a base set of comprehensive technologies on which secure supply chain solutions can be built [21, 22]. Some of the key areas include the following.

1) Irrefutable proof of transaction (Trust)—Blockchain enables the creation of irrefutable proof of transactions via a consensus mechanism, in which only the verified (and agreed) transactions are recorded in the distributed ledger; providing trust and automatically documenting transactions at no incremental cost.
2) Provenance (Traceability)—Due to fragmented nature of interactions among the multiple parties in a supply chain, ample opportunities arise for discrepancy in recording a transaction. High volume of transactions coupled with the multitude of ways in which valid transactions can be completed creates a need for traceability to efficiently address dispute reconciliation and resolution. This friction and associated waste can be greatly reduced with automation that leverages provenance provided by blockchain technology.
3) Incentivization of usage of IoT and Artificial Intelligence (AI) technologies—The use of blockchain provides a secure target for storing data drawn from across the supply chain. With permissions, this makes available a rich data set that spans multiple entities and geographies permitting end-to-end supply chain integration/
optimization with superior insights provided by AI technologies.

While the benefits of blockchain-based solutions in the supply chain domain are evident [23, 24], not all challenges associated with managing supply chains well can be addressed by automation. This is quite true of supply chain resilience and risk management, both of which require human judgment to address the tradeoffs appropriate to the business needs of a specific company and its constituents along points in time. Blockchain-based solutions can greatly assist in procuring, assembling, and presenting necessary data to facilitate rigorous scenario

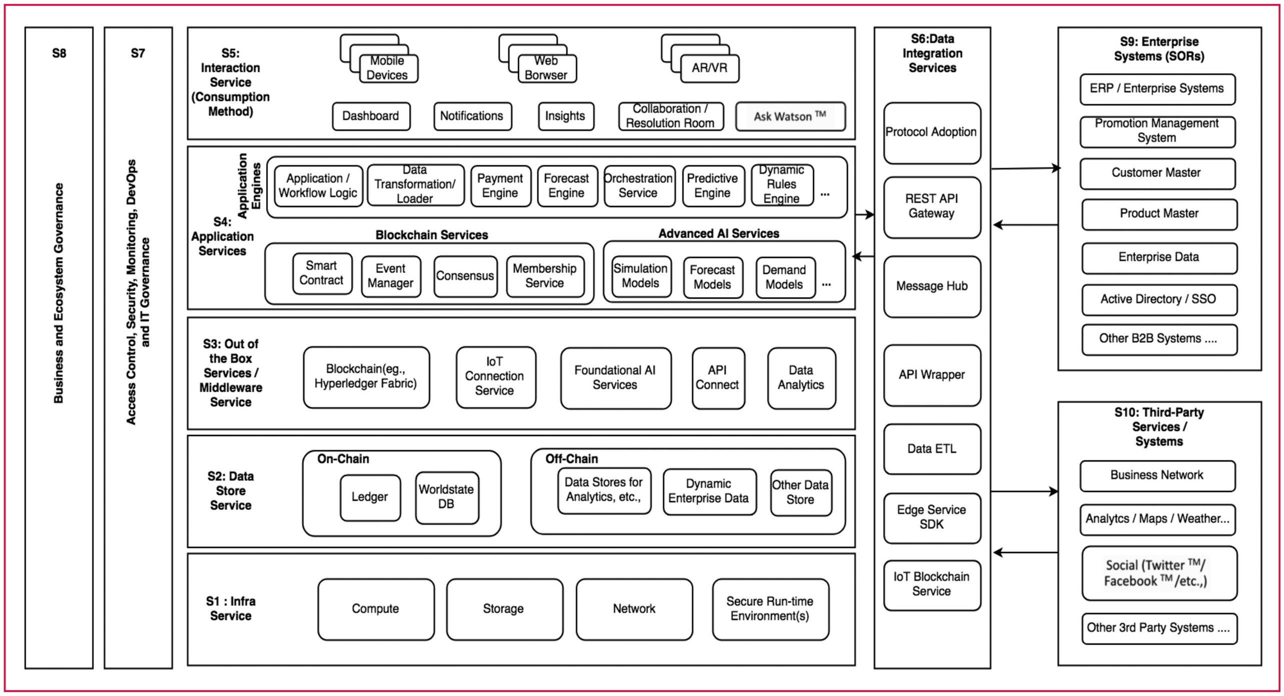

Figure 1

Blockchain-embedded supply chain solution reference architecture.

analyses-based decision making. To do so calls for a fundamentally different approach to architecting solutions different from traditional ERP-based architectures in the following ways.

1) End-to-end solution—Blockchain solutions can optimize the supply chain process across all transactional suppliers, shippers, regulators, banks, etc.
2) Distributed systems of record (SoR)—Blockchain enables us to fundamentally redefine storage of SoR data across enterprise boundaries in a trusted manner.
3) Data access granularity—Blockchain enables easy sharing of data across all permissioned stakeholders involved in a transaction.
4) Data governance—Participants in the supply chain will need to define the governance framework for all aspects of data storage, location, privacy, access, usage, permissions, etc.

In the following sections of this paper, we describe the reference architecture that provides the foundation for developing blockchain anchored supply chain solutions.

Reference architecture

Automated supply chains that aim to be self-correcting and near real time need to prepare, organize, and utilize internal data that may be stored in silos across disparate ERP systems, incorporate relevant external data sets for insights as needed, embrace in-house and externally developed machine learning models, export intermediate alerts and results to external dashboards, applications, and execution systems, and at the same time maintain the integrity and provenance of data and business processes. Such supply chain solutions require to be built on a microservices architecture permit for rapid customization and reconfiguration as and when needed.

Our supply chain solution reference architecture therefore includes several technology services to support the realization of this vision as shown in **Figure 1**. The specific purpose and function of each service category is explained below.

S01) Infrastructure services: This service category provides the compute, storage, and network required for realizing the functionality of the other service categories. The infrastructure needs to auto scale up/down to respond to ebbs and flows in transaction volume, analytics complexity, near-real-time processing needs, and the unpredictable size of external data. These services could be resident either on-cloud or on-premise, or a combination of both depending on security and privacy requirements.

S02) Data store services: Data powers modern supply chains. Such data includes historical data from SoR, streaming data from activity in physical stores or ecommerce, news, social media, video feeds, pricing, and IoT data. The source of business data could come from SoR (S09) or third-party systems/services (S10), the components in the integration service help to transform the data to the form needed by the solution, and the transformed data get stored in the data store service (S02) for the solution to use it. This service can include on-chain data stored on the blockchain ledger and off-chain data are stored externally, e.g., Hadoop, No SQL, or Relational Database Management System (RDBMS) data stores.

S03) Out-of-the-box services: Services in this group comprise middleware, blockchain, IoT, data analytics, Application Programming Interface (API), and AI services.

a) Middleware services: One set of services in this group prepares the data for consumption by the application services. Examples of data preparation functions typically include aggregation of internal data for specific time epochs, geographies, product, and customer segments, etc.

   A second set gathers data efficiently from IoT devices. Examples include sensor-enabled trucks to report location through various stages of delivery, periodic state reporting to monitor quality of goods in-transit, certifications, etc.

   A third set of services creates data usage logs by specific services. Such logs could be used for allocating capacity, determining compliance, or for billing purposes.
b) Core blockchain services: Blockchain platform services, e.g., Hyperledger Fabric that supports delivery of blockchain application-specific services. Typical examples would include membership services, peer definitions, network partitions, data channels, consensus mechanisms, block ordering mechanisms, etc.
c) IoT connection services: For supply chain use cases, core components could include the following:
   i IoT platform for device integration (such as device registration, connectivity, and management);
   ii IoT blockchain service enables business networks to use IoT devices to supply data to blockchain transactions;
   iii message hub for data queuing and distribution.
d) Foundational AI services: This represents the foundational services, such as machine learning, language translator, natural language classifier/understanding, conversational Q&A, etc.
e) Application programming interface (API) connect services: This service category quickly creates APIs and microservices based on Node.js and Java runtimes. API Connect supports creating and testing APIs offline. APIs are created within the developer toolkit. The developer toolkit includes a command line interface and API designer graphical user interface. Also, it helps to manage the life cycle of the APIs.
f) Data analytics services: This is a library for statistical functions, e.g., Statistical Package for the Social Sciences (SPSS), that can be called by the application layers.

S04) Application services: This group of services includes core supply chain functions, such as order management, procurement, inventory management, warehouse management, operations management, supplier relationship management, etc., delivered as microservices to deliver a comprehensive valuable service/product to the market.

Each microservice leverages three key technology components.

a) Blockchain application services: These provide smart contracts, provenance, usage metering, and settlement services. Smart contracts are derived from the business process flows and associated business process rules. They may be written in Go-lang, Javascript, or other smart contract formats. Provenance services are provided to support business decisions. The blockchain can also capture the usage of in-house and third-party models and services.
b) Advanced AI services: This group of services provides the analytics and operations insights. Services could include demand forecasting, shelf life estimation, evaluation of supplier risk, fulfillment optimization, etc. Algorithms and models may be incorporated from external sources as well. These would be exposed as microservices as well, with well-defined inputs and outputs.
c) Application engines: This service category provides orchestration and workflow for business processes by determining, summoning, sequencing, and executing the right microservices. The collaboration/process/workflow management, business logic, and data analytic reports are supported in the blockchain application by this service to serve users with different roles. Adherence to ISO/TC 184 standards for automation systems and integration will have to be a key aspect of services orchestration management.

Also, the compliance on Anti Money Laundering (AML), Know Your Client (KYC), International Organization for Standardization (ISO), GDPR, etc., for the end-to-end processes and cross-organizational changes is ensured by accommodating them in the dynamic rules engine. Rules are seeded from information captured in layers S07 and S08 ingested via interfaces in S10.

S05) Interaction services: These services provide the supply chain user with interfaces and insights for consumption. Examples of interaction services directly consumed by supply chain practitioners via dashboards, alerts, notifications, and alternative scenario modeling. The interactions could be through AI-powered automated collaboration rooms, chat systems such as “Ask Watson” that provide answers to queries. The consumption modalities could include smart phones, tablets, laptops, purpose optimized devices, and Augmented Reality and Virtual Reality (AR/VR).

S06) Data integration services: Successful supply chains depend on effective cross-functional and cross-enterprise collaboration/integration. So, this demands an easy to use set of data integration services to facilitate trusted data exchange across heterogeneous enterprise systems operated by multiple stakeholders. This important requirement is satisfied by the following set of services.

a) Protocol adaptors: This relates to various protocols in asynchronous and synchronous modes such as http, https, SFTP, DB, Java Message Service (JMS), Enterprise Java Beans (EJB), Simple Object Access Protocol (SOAP), or REpresentational State Transfer (REST) based, eXtensible Markup Language (XML)-based web-services standards, etc.
b) API wrapper: This is to create a wrapper for the external APIs to be consumed by the internal solution. This way the external changes to the service/API are isolated only to the integration service and the external APIs will not be impacted by changes made to the internal services in the solution.
c) IoT blockchain service:
   i Enable business networks to use IoT devices to supply data to blockchain transactions.
   ii Abstract devices from contracts. Watson IoT Blockchain service can provide data mapping and filtering between devices and blockchain contracts.
   iii IoT data filtering. Not all device events need to be sent to the blockchain. The platform is configured to filter events so that only key life-cycle events that need to be preserved and shared are recorded.
d) Message Hub: This is a scalable, distributed, and high-throughput message bus in the cloud, available as a fully managed IBM Cloud service as a real-time messaging engine.
e) Data extract-transform-load (ETL): This is to represent the ETL (set of ETL Tools) for a data warehousing environment. It also represents the process of validating, detecting, and correcting the inaccurate incoming data or existing data based on the business rules and procedures.
f) Edge services/Software Development Kit (SDK): The edge services allow data to flow safely from the Internet into the provider cloud and into the enterprise.
   The integration services will use the dynamic rules engine services to take care of the cross-organizational changes and processes related validation during data/message exchange.
   Primary integration pattern is to expose a set of REST endpoints/APIs through an application server tier developed using Node.js or Java.
   When there is need to integrate with existing enterprise systems, an integration hub (e.g., IBM Integration Hub/DataPower) can be used to support various integration patterns (events based, message based, etc.) and to perform required data and protocol transformations prior to the invocation of the REST endpoints.
   For scheduled tasks, a scheduler service can be used to run scheduled and recurring tasks through invocation of REST APIs.

S07) Access control, security, monitoring, DevOps, and IT governance: These services address cross-cutting concerns, such as identity and access management, certificate and key management, log management, monitoring (systems, application, security etc.), and storage management (SAN, backup solutions etc.). Capabilities offered here will need to integrate with blockchain solutions. The IT operations management and supply chain solution life-cycle management are managed through a set of DevOps tools. This would support agile operations—continuous integration, testing, automated build cycle, and release management. Also, it supports easy collaboration, communication, tracking, quality verification, and integration from governance perspective.

S08) Business and ecosystem governance: relevant services span the following three categories.

a) Bilateral transaction related agreements: Services in this category span order/shipment/settlement visibility and reconciliation and resolution requirements.
b) Bilateral relationship related agreements: Services in this category span parameters that govern qualification (KYS, process qualification, etc.), performance monitoring/management, and regulatory and consumer advocacy compliance related requirements.
c) Multilateral-related requirements: Services in this category span parameters related to ecosystem governance policy definition and management, multilateral performance compliance and reporting, supplemented by multiparty transaction related services, e.g., order/shipment/settlement visibility, reconciliation and resolution requirements and regulatory and consumer advocacy compliance related requirements.

Supply Chain Opportunity	Supply Chain Solution Functionality
Invoice Reconciliation & Settlement Management	• Automated 3-way match + Settlements • Permissioned Data Access + Rapid Dispute Resolution Support
Asset Performance/Usage Monitoring & Management	• Remote asset performance monitoring & management • Remote licensed manufacturing asset usage & metering
SC Integrity & Product (Food, Drugs, Parts, etc.) Provenance Management	• Product provenance and integrity management • Gray market, counterfeit management • Safety/recall management
Multi-tier Supplier Order & Production Risk Monitoring & Management	• Supplier qualification & performance management • BOM-specific materials supply risk management • Order/Production/WIP status monitoring/dynamic rescheduling
Contract Labor Management	• Contract labor qualification & performance management • Contract labor usage metering & settlements management
Consignment Inventory & Trade Promotions/Royalty Monitoring & Management	• Consignment inventory monitoring & settlements management • Trade promotions/royalty disbursement metering & settlement management.
In-transit Goods Monitoring & Management	• Multi-entity (shipper, freight forwarder, customs, carrier, etc.) product routing and transfer monitoring & management • Regulatory compliance management
Post-sales Warranty & Services Management	• Product usage and performance monitoring & management • Customer usage specific product/services recommendation management

Figure 2

Blockchain anchored supply chain opportunities.

S09) Enterprise systems (SoR): This service represents the current IT enterprise portfolio of the client. This could be a mix of on-premise and on-cloud deployed systems/services. The key applications are as follows:

a) identity management systems;
b) promotion management systems, order/vendor/customer/inventory management systems, enterprise data;
c) payment systems;
d) other B2B systems;
e) device data, dashboards, etc.

S10) Third-party/social media services: There is a growing use of third-party and social media data, which supplements internal data, for enhancing supply chain decision making and management. There are multiple sources for such data, including device-based IoT data, which are subscribed to or purchased on a pay-per-use basis. For example, social media analysis would help with product sentiments, reputation analysis, influence analysis, precision marketing, consumer trends, etc., which is useful for design, replenishment, and markdown processes. Other services, such as news, maps, weather, etc., play a key role in risk estimation, demand forecasting, inventory positioning, and labor estimation.

Third-party analytic services can utilize data provisioned by the data store (S02) by leveraging the services tool kit exposed in the integration services (S06).

Reference Supply Chain (SC) architecture in action

In the earlier section titled “Blockchain in Supply Chain,” we laid out the rationale for why and how blockchain technology can drive significant improvement in supply chain performance through automation. As mentioned earlier, the supply chain management models of today demand automation to support the paradigm of managing a portfolio of end-to-end instrumented data-rich microsegmented supply chains that are managed in near real time [25].

Supply chains with a need for multiparty reconciliation, multifunction inter-enterprise privacy and trust, and regulatory and contractual compliance and having a high volume of transactions will benefit most from an application of IoT, blockchain, and AI technologies. Of these technologies, blockchain is critical as it enables access to trusted data, which permits the application of AI to drive automation. In the interim, there is a tremendous opportunity for value-add in enabling manual/semiautomated decision support—a logical progression towards an automated end state, thereby justifying the need for blockchain to be at the forefront of transforming supply chain management. A listing of such uses cases is captured in **Figure 2**.

We will now elaborate the potential for automation and the significance of benefits that can be realized by automation by choosing an example from Figure 2—invoice reconciliation and settlement management.

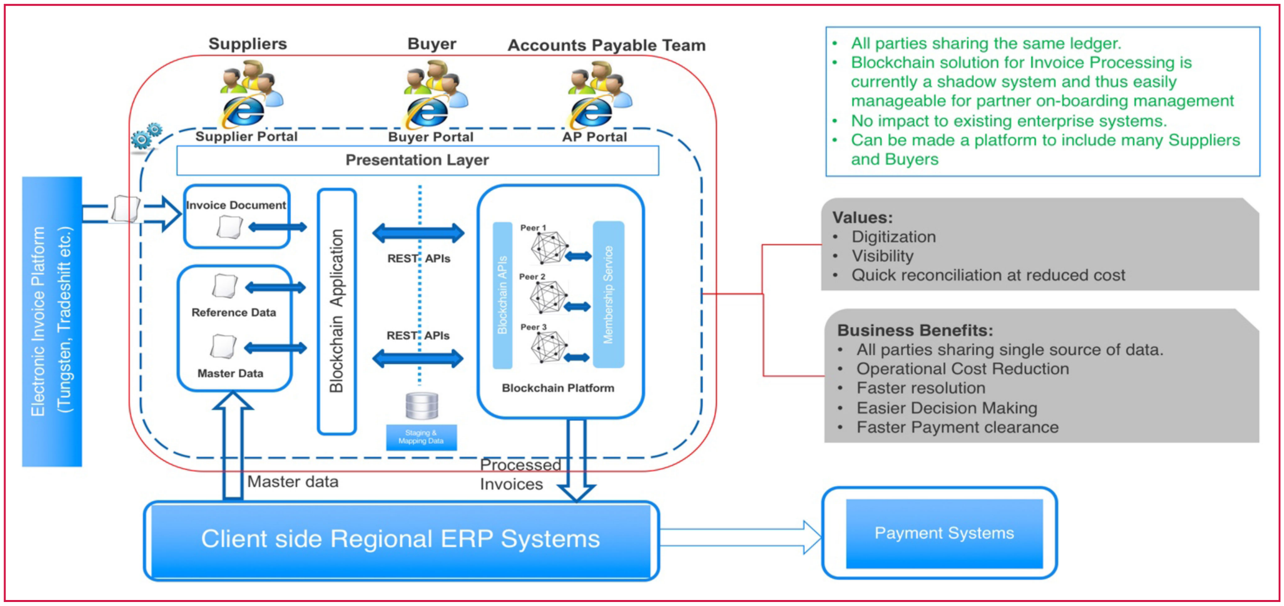

Figure 3

IBM blockchain anchored invoice reconciliation and settlement.

Invoice reconciliation and settlement management

Invoice reconciliation is when an invoice is matched against a purchase order (PO) and other reference data to release payment. This process is time-consuming and laborious for the buying and supplying organizations due to fragmented access to necessary data. This gap can be bridged by providing a trusted blockchain platform for all participants to resolve such disputes.

Figure 3 illustrates a web-browser-based multiparty blockchain solution with integration of SoR systems that is compliant with defined smart contracts. This solution is being implemented in a global CPG company currently processing 5 million invoices/year across 80 countries. The estimated savings through automation are more than 60% reduction in invoice processing costs.

The SC reference architecture is leveraged as follows.

S01) Infra services are provided by the IBM Cloud service and IBM Blockchain Platform (IBP) as a blockchain service on IBM Cloud.

S02) Data store services: The invoice data and reference data, such as Purchase Order, Goods Received Notices (GRN), Company Code, Tax Code, etc., are persisted on the on-chain data store of the blockchain ledger in CouchDB. These are all key data elements used in business validations against the asset called Invoice and hence kept on the on-chain data-store (Ledger) for smart contracts to operate on the data safely and easily. In addition, DB2 is used for storing the off-chain data. Anything personal/private is not stored on the on-chain data store (Ledger), but instead it is stored off-chain, and a hash of the data is used to link it with the on-chain for references. Also, data used for analysis are stored on off-chain data-store for efficient data access and manipulation.

S03) Out-of-the-box services for this solution include IBP as a readily available blockchain platform on the IBM cloud. Managed services such as IBM Kubernetes Service, DB2, etc., are also used.

S04) Application services are defined in the form of Smart Contracts for implementing business process validations, such as valid PO, Company Code selection, Bill To Name validation, Single PO versus Multiple PO, Vendor Name Authentication, Remit to ID, Duplicate Check, Post Facto PO, Currency Validation, Determine PO Unit Price, Line Aggregation, Common Unit of Measurement, Budget Validation, GRN selection, Tax Handling, Price and Additional Cost Variance, etc., deployed on the chain code container of IBP. Workflow management is configured in the IBP and a Java-based custom component used for data processing and loading.

S05) Interaction services: Role-based web applications for buyer, vendor, and accounts payable teams from different organizations are provided and developed using angular framework (https://angular.io) and Node services (https://nodejs.org).

S06) Integration layer: The secure shel (SSH) file transfer protocol (SFTP) is used to transport the files between the SoR systems and the Blockchain (BC) solution and store them in cloud object storage. Node REST APIs are created and exposed to share the functions between services. Also, the

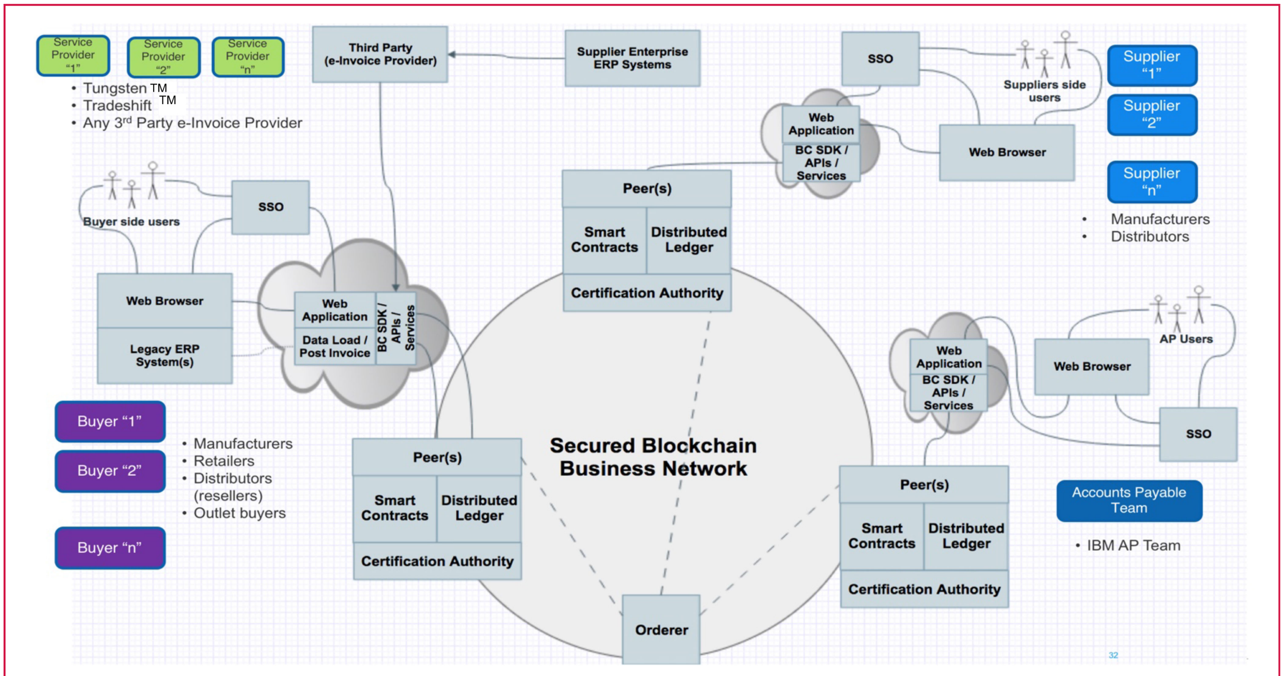

Figure 4

IBM blockchain-enabled automated invoice processing business network.

Fabric SDK is the main integration service to connect the application components with the blockchain functions.

S07) Access control and security are implemented using the IBM cloud security service AppID (https://www.ibm.com/cloud/app-id). The Enterprise Single Sign On (SSO) of the on-boarding organizations are integrated using the AppID. It is possible to have multiple AppID instances to connect with multiple enterprises SSOs across globe. Also, role-based access has been defined, and certificates are created, registered, and enrolled on the CA server of IBP to have certificate-based access control.

S08) The DevOps and governance are implemented using the IBM's blockchain innovation method (https://www.ibm.com/blockchain/services).

S09) The SoR systems are ERP systems of the buyer organization that include the PO management system, vendor master, GRN system, buyer data store, payment systems, etc.

S10) As shown in Figures 3 and **4**, the Buyer(s) provides all supporting data for invoice processing, such as POs, vendor master, GRN, tax code, etc., through back-office integration. The invoices are supplied by the e-invoice provider network(s) such as Tungsten, Tradeshift, etc. The suppliers are on-boarded through a web-based application to view the real-time status of their invoices on the blockchain solution. Using a web-based portal, the buyer's accounts payable team addresses any exceptions related to GRN, POs, etc., raised during invoice processing. For example, when a mismatch between the PO and the GRN occurs, the resulting price variance will need the buyer to resolve the exception.

This use case demonstrates the flexibility of the reference architecture to automate a high-transaction-volume multiparty supply chain operation. Further improvements are possible with application of AI technologies to understand the structure of invoices through automated document processing. We are in the process of applying the reference architecture for the remaining use cases in Figure 2.

Conclusion

Mushrooming business networks and affiliated participants desirous of effecting "friction-free" secure valid transactions in a high clock-speed "as a service marketplace" will drive demand for blockchain-based supply chains that are automated and self-correcting. This implies the need for IoT and AI, which in turn relies on availability and access to trusted data and is the prime reason as to why blockchain must be at the forefront and not an afterthought to transforming supply chain management. While we have discussed supply chains in depth, the usage patterns identified are applicable to other inter-enterprise processes such as finance and accounting, employee training, and data and records management. Furthermore, the applicability also extends to provisioning, usage, and payment settlements for digital assets such as media, designs, etc.

This said, it is often asked, "Is blockchain technology really needed, or are traditional shared ledgers/databases adequate?" If it is possible to establish a central trusted party, a centralized database would be adequate. In some cases where this is possible, businesses can use centralized databases. In general, establishing a central trusted party is hard, however, since a single entity is very unlikely to be trusted on all aspects of the supply chain, unless granular access controls on data elements and transactions are provided to all members. Even so, trust levels can change over time, and businesses may not want to get locked in on that front. On the other hand, blockchain technology provides immutability, provenance, and trust via consensus with out-of-the-box key components being available as open-source. Consequently, building the same function from first principles or by enhancing centralized databases will be time-consuming and not cost-effective. Additionally, existing blockchain networks would have defined data standards and protocols that become established and, hence, prudent to leverage.

To accelerate the adoption of blockchain in supply chain business, management, operational, and technical challenges will need to be addressed. On the business front, clear incentive mechanisms have to be designed to encourage participation in the blockchain network. Operationally, since blockchains are about increasing trust, and protecting data once it is placed in the chain, it is important to ensure that their authenticity is certified at data entry. It is analogous to the issuance of a birth certificate to a citizen based on a trusted record of birth at a hospital, which then is the credential that is used to issue other forms of identification. A related paper on crypto anchors or "BlockTags" in the current issue addresses this topic in depth, where small embeddable electronic tags with optional sensors can be attached to physical objects to establish authenticity and provenance [26]. Note that this only addresses the provenance of data. The data could still be erroneous and standard statistical, and AI-based techniques would still be needed to detect anomalies, correct for outliers, interpolate and project for missing data, etc. Habitually erroneous sensors could potentially be tracked down and isolated using the data Blockchain.

Several challenges on the technical front also need to be addressed to make blockchain technology a success. The first is scaling it to handle multi-enterprise loads and networks where several hundreds of transactions may be occurring per minute. The second is hardware accelerators for encryption kernels since all data submitted into the blockchain is encrypted. This becomes critical as the transaction throughput increases. Another issue that arises is the growing length of the chains in the blockchain as data is appended over time, which can increase the time to verify and retrieve data from the blockchain. This may call for truncation of some chains for efficient access and building associated logging and indexes to enable faster access. Also, as the number of parties in the blockchain network increases, more attention has to be paid to the algorithms that establish consensus before data is written into the blockchain. How consensus is defined and how it changes as members join and leave the blockchain networks are of critical importance.

As blockchain networks evolve, interoperability among networks will be necessary. Members in one network need to be able to send and receive data to another network. Standards around representation for supply chain elements and processes, such as orders, shipments, cold chain contracts, etc., would need to be established and adopted. Member credentials in one network have to be accepted in another, just like a driver's license from one state is accepted in another state. Similarly, tools that are used to create assets on the blockchain have to interoperate and provide mechanisms to do necessary data format translations, any real-time brokering that is necessary, etc. Another paper in this issue treats these topics in greater detail.

We are indeed at an exciting point in time where the confluence of AI technologies that is driven by data from various sources, including IoT devices, which is backed and protected by blockchain technology, is making the proposition of automated self-correcting supply chains a reality.

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