Chapter 10
Blockchain Technology and International Data Spaces

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Abstract The core objective of the concept of International Data Spaces (IDS) is to enable controlled exchange and sharing of data between organizations, regardless of the type of data. Sharing of data will generate services that become an asset while data providers maintain their sovereignty. IDS furnish a technology enabler for implementing data economies to exchange data and knowledge, which are according to usage policies. Thus, data turns into an economic asset. However, once data have been provided toward IDS, sovereignty of data owners is of pivotal importance, as well as the question of its use and the transfer of incentives to providers. At this point, blockchain technology enters the ballpark. It is instrumental for the implementation and operation of clearing houses as trading platform for data provision and knowledge utilization. The aim of this chapter is to examine and discuss the role of blockchain for IDS. Next to general blockchain foundations and potentials, blockchain's specific potential for IDS is discussed and its application is demonstrated by four compelling use cases.

10.1 Introduction

The International Data Spaces (IDS) concept is a virtual data space leveraging accepted standards, technologies, and governance models of the data economy to facilitate secure and standardized data exchange and data linkage in a trusted business ecosystem. It provides the foundation for creating smart-service scenarios

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and enabling innovative cross-organizational business processes, while at the same time guaranteeing sovereignty for data providers [1]. Hence, IDS is the technology enabler for the monetization of data [2].

The core purpose of IDS is to enable controlled exchange and sharing of data between organizations, regardless of the type of data (e.g., structured data, streaming data). In IDS use cases, two basic data sharing patterns can be identified. First, data is shared to feed new, data-driven services, such as apps, smart algorithms, and other digital services. Second, data is shared for some form of business process synchronization such as using the data to execute transactions, enable production, or synchronize processes [1]. The generation of knowledge is one specific type of service that also builds upon a shared data space. This knowledge can be utilized to improve production processes once generated. PigFarm illustrates a vital life cycle of knowledge for the optimization of pork production processes [3]. Information does become the currency of the digital age as pointed out earlier by Carly Fiorina.[1] In many of these cases, sharing of data enables transactions with data as services, which become shared assets with responsibility for the participating organizations [1]. Data analysis for the generation of knowledge is one specific instance of this case. The question arises on how the generation and trade of such data-driven assets are monitored and how incentives toward knowledge producers as well as invoice users are rewarded. Thus, accounting methods come up as one particular use dimension of blockchain for IDS.

Methods for an accounting and clearing of data and knowledge utilization would complement the already existing capabilities of the IDS architecture to share (potentially large) datasets with the help of IDS connectors. Blockchain has the potential to ensure data consistency and transparency in combination with the general IDS approach for data sovereignty as well as secure data exchange and sharing owners [4] in order to turn data into business assets [2, 5].

The aim of this chapter is to examine and discuss the role of blockchain technology for IDS. Therefore, we introduce the general foundations of the blockchain technology, describe the different design parameters for setting up blockchain implementations, explain the concept of smart contracts, and outline the general potential of blockchain. On this basis, we discuss the potential role that blockchain can play for IDS. We then illustrate the application potentials of blockchain for IDS by referring to four compelling use cases. Emphasizing the important role that blockchain can play to fully leverage the potentials of many IDS use cases.

Throughout the course of this chapter, we use the term *blockchain technology* consistently. Yet, blockchain is just a specific instance of *distributed ledger technology (DLT)*, which spans a wider spectrum of implementation technologies such as data structure for the ledger. The term DLT also expresses the nature of the distribution of ledgers across stakeholders to be more tangible and intrinsically

[1] Carly Fiorina, former CEO of Hewlett-Packard, Oracle Open World, San Francisco, 2004 http://www.hp.com/hpinfo/execteam/speeches/fiorina/04openworld.html

includes smart contracts as means for process automation. Basically, both terms can be used interchangeably in the context of this chapter.

10.2 Blockchain Technology

This section addresses the core concepts of blockchain technology and exposes specific characteristics that distinguish it from common data management methods.

10.2.1 Basic Concept

A blockchain is a distributed data structure that manages transactions transparently, chronologically, and immutably in a computer network. The core concept of databases with its centralized governance of transaction management in terms of ACID (atomicity, consistency, integrity, and durability) is replaced by maintaining data distribution [6].

A blockchain is a chronologically ordered chain of blocks, in which each block contains information about valid network activity since the addition of the previous block. The individual blocks are connected to each other by cryptographic hashes, creating a data structure that cannot be changed afterward. Each block contains a block header in addition to transactions within the network. The block header contains a reference to the previous block in the block chain, a timestamp, an arbitrary string (nonce), and the root of a Merkle tree, which represents a data structure that efficiently aggregates all transactions contained in the block via hashes [7, 8].

The blockchain together with the associated peer-to-peer network can be described as a blockchain system. Such systems use cryptography and peer-to-peer principles instead of a central authority to achieve a network-wide verification of the system's status by consensus [9]. The general transaction processing of a blockchain system can be illustrated by the example of the Bitcoin system. Here, a network node first sends a message combined with a digital signature including transaction details to the entire network. Network nodes that receive the message then check for duplicate use of the Bitcoins and then propagate the transaction and the evaluation result further in the network [10]. To coordinate the consensus, i.e., the common status of the current blockchain, the network nodes use a so-called proof of work mechanism [11]. In general, the proof of work (PoW) is intended to prevent excessive or improper use of a service [12]. The provision of a PoW requires a certain amount of effort; in the case of Bitcoin, a computationally intensive problem must be solved. A hash value must be changed until it matches a certain pattern [10, 13].

10.2.2 Design Parameters

Blockchain systems can be distinguished regarding several design parameters [14]. First, blockchain systems can be classified according to whether they are private or public [15]. The decisive factor here is by whom the systems can be used, i.e., who has access to the data or can propose new data inputs (e.g., transactions)? If this use is permitted to anyone, it is a public system. However, if it is restricted to a specific user group—e.g., an organization or consortium—the blockchain system is considered private [15]. Another possible distinction between different system types is whether permission is required to participate in the administrative process of the blockchain. In the permissionless Bitcoin system, this process is basically allowed to anyone without approval. However, if the network nodes that perform the corresponding validation are pre-selected by a consortium or a central authority, the system is a permissioned blockchain system [15]. Finally, blockchain systems can be distinguished by the way in which a consensus on the system status is reached. In addition to the PoW mechanism employed by Bitcoin, a number of alternative consensus mechanisms exist. An alternative approach is the use of a proof of stake. The basic idea here is that the blockchain is updated primarily by network nodes that hold a large share of the currency or other values in the blockchain, which creates an incentive for correct maintenance of the system [16]. Further alternatives are the use of a proof of activity [17], a proof of publication [18], or a proof of storage [16]

10.2.3 Smart Contracts

A blockchain is not just a distributed transaction manager, but a special form of database management system [6]. It can also be utilized for the automation of processes and in particular an automation of cooperation logics in terms of scripting languages. Such scripts coined smart contracts can be programmed to run arbitrary application logics on the nodes of the P2P network [19]. As early as 1997, the concept of Smart Contracts was introduced by Nick Szabo [20] and defined as a computer-based transaction protocol that implements the terms of a contract [21]. Blockchain technology for the first time offers suitable means for implementing such contracts. Smart contracts can be understood as computer programs that conduct computations once certain conditions are met [22]. To this end, the smart contract can use external information as input, which then causes a certain action to be taken via the rules defined in the contract. The corresponding scripts with the contract details are stored in a specific address of the blockchain for this purpose. If the specified external event occurs, a transaction is sent to the address as trigger, whereupon the terms of the contract are executed accordingly [8]. Therefore, smart contracts are instrumental for maintaining dependencies between data and processes consistently.

Smart contracts are therefore an effective means for the automation of interactions among systems, agents, and the environment. Contracts can be executed, enforced, verified, and inhibited by means of algorithms without any interventions and control by intermediaries. The range of possible applications is therefore very broad. For example, properties such as cars, bicycles, or apartments could be rented out via a smart lock and blockchain system without physical key transfer. To do this, the owner sets the deposit and rent in the smart contract. Therefore, the correctness of smart contracts, i.e., how to automize the cooperation's logic, is essential [23]. The smart contract also contains rules for access and usage authorization (e.g., the user can only open the lock after paying the deposit and rent). All interactions with the blockchain system, such as making payments, exchanging the digital key, or opening and closing the smart lock, can be performed by the tenant and user via smartphone. Incoming payments, authorization distribution and management, as well as deposit repayments are carried out transparently, securely, and unalterably via the blockchain [8]. Moreover, any type of information logistics and digital ecosystems can be maintained consistently due to process automation by smart contracts.

10.2.4 Opportunities of Blockchain Systems

Blockchain potentially offers at least a revolutionary element of change for the development of the Internet as a digital infrastructure. The first step was the Internet in its well-established understanding as "Internet of information." Recently, the "Internet of things" has emerged through the increasing networking of intelligent devices. However, transfer of assets is limited to those that are available in digital format such as data about container transports on inland waterways. A transfer of values—such as contract transaction for the transfer of physical premises—was only possible by involving a trustworthy third party and the use of common ledger technologies in public administrations. With the introduction of blockchain, value transactions without dependence on or trust in a third party have now become possible, the so-called the Internet of values and trust. Hence, knowledge about processes and their improvements can also become a valuable business asset with governance for its management and control of transactions.

In principle, blockchain technology can be used in the form of three generic roles: firstly, as an enhancer for optimizing existing processes that are already being handled digitally or non-digitally without intermediaries via bilateral (peer-to-peer) interfaces, *optimization of operational businesses*; secondly, as a transformer to streamline processes that were previously carried out with the involvement of traditional intermediaries, *change governance of partner networks*; and thirdly, as an enabler to foster collaborations that were previously not feasible due to the lack of an intermediary for organizational and technical integration, *innovate business partnerships to generate new markets*.

Possibilities for implementing new and innovative services and different application solutions are manifold, but certain patterns can be identified as landmarks: “neutral platform for business collaboration,” “tamper-proof documentation,” “payment transactions,” “management of cross-organizational processes,” “digital identity,” “digital documents,” “services without service providers,” and “economically autonomous machines” [14, 24].

The use of a blockchain technology for a particular use case is often justified economically and organizationally. The identification of technological evidence is often rather sparse from an application [25] as well as a governance perspective [26]. Moreover, performance and scalability of blockchain-based solutions are, at least up to now, technically inferior to a centrally organized system with well-known database technology for the management of operational data that show up in production environments with high frequencies. Established database technology is certainly the asset for efficient data management, while blockchain technology can maintain audit records for the correctness of processes, i.e., *database technologies allow an efficient management of production data while blockchain technology offers auditing services for the correctness of business processes*. Moreover, blockchain technology offers the possibility to digitally implement processes that could previously only be realized by involving a trustworthy third party.

10.3 Blockchain in International Data Spaces

So far, potentials of blockchain technology from an application- and process-oriented point of view have been identified previously. Moreover, a distribution of concerns between an efficient management of operational data by DB (database) technology and an auditing of business processes by BC (blockchain) technology has been clarified. The following technical properties of a blockchain are relevant for the identification of its potential for accompanying an IDS:

- Information and transactions stored in a blockchain are irreversible and cannot be deleted or modified. Immutability of collaborations conducted is granted.
- Consensus about the information to be agreed upon is achieved within a public or permissioned network. Hence, partners and potential stakeholders can team up in an open fashion and they are no longer limited to organizational frameworks agreed upon in advance.
- Smart contracts promote the automation of cooperation logics in terms of (business) processes and elements in a trusted way. Trustworthiness of interaction is granted, and cooperation of partners can be based in more open networks in which trust is based on algorithms and organizational positions.
- Assets can be represented on a blockchain using tokens of various kinds. As such, tokenization can be applied to a multitude of business assets starting with raw data of production processes via data-driven knowledge about the optimization of

processes toward auditing machine data amid production processes and certificates for vocational training.

In light of these opportunities, we also have to consider limitations with regard to information governance:

- A blockchain is not suitable to store large amounts of data that are typical for operational and production environments. Therefore, a blockchain application often requires the combination and linkage of blockchain transactions with data managed in an off-chain information space.
- Transaction throughput of blockchain infrastructures is also limited compared to established database technology. Thus, applications with high-frequency transaction workload require special solutions with regard to data governance.

Consequently, blockchain applications require an integration with high-performance data management services such as the IDS. A separation of concerns between efficiency of data crunching and immutability of process auditing is an effective solution.

The IDS Reference Architecture Model already identifies the application of blockchain for data consistency and data transparency [1]. However, we believe that beyond these aspects, a number of additional integration and combination possibilities exist [4].

IDS themselves aim at meeting several strategic requirements of which the following are very much related to the basic blockchain concepts. The first is the requirement of trust which is satisfied by an evaluation and certification of each participant before granting access to the system. Identification management and certificate management form one of the primary application areas for blockchain technology. Several solutions are already available [27, 28]. In combination with the recently published W3C standards on Decentralized Identifiers [29] and Verifiable Credentials, the blockchain technology can provide an ideal solution for the decentralized and trusted management as well as fully automated verification of identities and credentials. A solution for the identification and the authentication of stakeholders for inland waterway transport has been developed for project Sinlog [30]. The core idea is that a written confirmation in terms of personally signed documents—perhaps scanned and forwarded as PDF by email for the sake of digitalization—can be replaced by certified signatures of humans as well as technical agents, e.g., the load of a barge has to be assessed, be it by a human with a yardstick or a technical sensor on board.

A blockchain network can provide the functionality of the certification authority identified in the IDS Reference Architecture Model. [1], which would also be in line with the architecture proposed by the W3C [29].

The aspect of security and data sovereignty as proposed is also very much in line with blockchain principles. The IDS apply the concept of usage contracts and usage policies to determine the permissions and obligations of a resource. The implementation of these policies can be defined as a smart contract in a blockchain that is directly attached to the information itself or a token that represents the information or

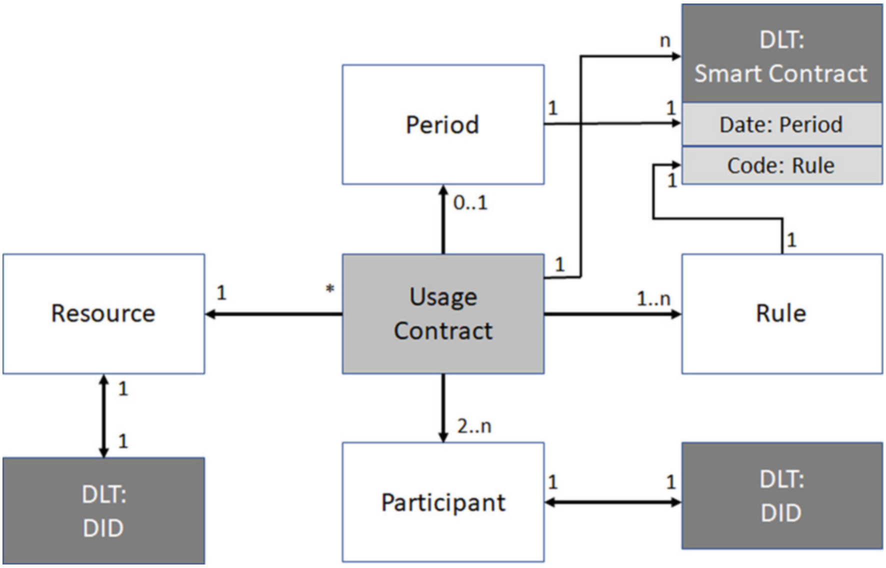

Fig. 10.1 Usage Contract concept from [1] extended with DLT concepts

any other asset. Furthermore, standardized smart contracts can provide means for trusted exchange and distribution of access keys to information as demonstrated in Weber and Prinz [31]. In combination with payment tokens or a planned digital euro, it can also support an integrated payment process.

Figure 10.1 illustrates the current data model of the usage concept. This can be mapped to a blockchain concept in the following way:

- The *Resource* is represented as an asset token.
- The *Participant* is identified by a DID.
- *Period* and *Rule* are stored as data in a smart contract.
- The *Usage Contract* is implemented as a smart contract.

With this approach, the usage contract can be implemented either as a generic smart contract that is able to interpret and execute the rules or as a smart contract that actually implements the rules. The former allows more flexibility as rules can be adopted but will require the implementation of a smart contract as a sophisticated rule engine. Rules that two partners have agreed upon will then be stored in a blockchain as the payload of a transaction or within a specific rule smart contract. This allows for more flexibility as rules can be changed during a cooperation process if both parties agree, which is similar to process modeling in smart contracts [32].

Vice versa the usage policy language proposed for the IDS provides a very good basis for the specification and automatic generation or configuration of smart contracts. In such a scenario smart contracts are being automatically generated from a usage policy and deployed in a blockchain. Thus, the smart contract can be used to enforce a usage policy on data that is either stored in a blockchain or guarded by a blockchain through the provision of access rights or keys.

Another application of the IDS concepts is the use of the usage policies in the context of programmable money. Programmable money goes beyond digital money or a cryptocurrency not by just providing a tokenized asset but by adding rules and programmable capabilities to money. This enables the combination of a budget with a specific purpose. Examples for such rules are:

- These 50 euros can only be used to pay for food, but no alcohol.
- Only 20% of my donation shall be used to pay for administrative purposes.
- 10.000 euro of my heritage shall be transferred to my granddaughter.

These few examples show that this concept can have a strong impact on services such as auditing but also general trustees' services and they enable a whole new range of blockchain applications. However, they do also require a semantic modeling of services outside the blockchain environment to enable the validation of services in the context of the execution of programmable money rules. Obviously other alternatives for the description of these rules exist [33]. However, once the blockchain community would adopt the IDS specification, then the world of data and production would speak the same language as the world of finance.

The considerations of this section show that a combination of the blockchain and IDS technologies has more opportunities and potential than just using the blockchain as trust service for data consistency and data transparency. In the following section, we will illustrate these with application examples.

10.4 Application Examples: Industrial Use Cases

The previous section unveiled opportunities of the IDS to capitalize on blockchain technology. Usage policies are one instance, i.e., an automation of provenance governance. On the other hand, information use calls for rewards. Hence, usage policies can be seen in both directions between IDS and blockchain technology. This section highlights some projects that exemplify the advantages of blockchain for governing integrated data spaces and capitalize on data-driven services:

- *TrackChain*—Initial focus has been provenance of processes in the logistic domain. Integration of devices via Internet of Things (IoT) has allowed for several automation patterns in terms of smart contracts, while role-based access control supports flexibility of information visibility.
- *Silke*—Safety and traceability of food chains is of vital importance for all kinds of wholesalers and retailers in the food production industry. Silke illustrates the use of blockchain technology for secure process provenance. Although such tracing is mostly required upstream, i.e., from the retailer toward the producer, a reverse approach might also be beneficial when automating product handling by smart contracts.

- *Sinlog*—German inland waterway transport is the most environmentally sound means for transport, be it for container transports or bulky loads such as grain or coal. Digitalization across the transport routes is rather sparse and merely in place for local terminals or single operators. Cross-organizational exchange is sparse, and the question arises on how blockchain technology can impact the efficiency of transportation processes. Moreover, audit certificates for information are required when no more physical documents with handwritten signatures for authentication are in place.
- *BC for Production*—In production environments, i.e., sequencing of machinery for the fine-blanking of body parts for a car, fusion of information sources is essential for the optimization of production lines. Since sources can come from different operators, questions about a trustworthy information fusion arise, i.e., how to certify the correctness of information transmitted without unveiling raw data.
- *Blockchain for Education*—Many people intend to transfer the management of educational and vocational certificates to electronic deposit boxes for reasons of comfort. Hence, digitalization of certificates and a transfer to content management system are offered for such reasons. Moreover, such certificates are a constant source of fraud. Blockchain technology can be employed to assure the correctness of certificates issued by training institutions.

All projects share some conceptual features.

- *Fusion of heterogeneous data*—All applications are founded in the fusion of data originating from different data sources. Hence, sovereignty of data providers is a vital concern by nature.
- *Data governance*—Operational data such as university certificates or sensor data from machinery are maintained by database-oriented systems. Blockchain is merely used for auditing purposes with regard to data transferred or processes conducted.
- *Flexibility of process cooperation*—Due to advanced availability of digital information, some process optimizations can be implemented. Yet, blockchain technology has to assure the correctness of information transferred before official authentication arrives.
- *New governance structures*—Typical intermediaries are replaced by ledgers controlled by blockchain technology. In addition, new cooperation patterns among partners can be established.
- *Sensors for data capture*—Some of the systems built depend on sensor data. Once these sensing devices are certified with proven identities, then processes can be fully automatized without human certification.

10.4.1 TrackChain

TrackChain strives to improve the tracking of transports. Products are going to be shipped from manufacturers toward consumer sites. Goods are moved by haulers and each transport is insured. Thus, four stakeholders are involved in the process. Although they relate to the same objective of delivering a product, they certainly have different business objectives on their agenda. However, all parties share the interest to have an immutable documentation of the transport process. In addition, sensors inside transport containers are used to monitor each transport with regard to violations of temperature or concussions, which are both potential risks to the goods.

Parties certainly ought to have different views on the data of the process, which is provided by role-based access control. Yet, proper provision of data access has to be traced by a blockchain.

TrackChain illustrates the advantages of utilizing blockchain technology in several dimensions:

- A collaborative information flow about transport devices with goods from a production facility to customers including transport agencies and insurance companies is maintained by a blockchain.
- As such, the clearing of service use can directly be triggered by smart contracts.
- Transport procedures are automatically controlled by sensors. In case of violations of transport conditions, measures can directly be triggered. If goods arrive with damages at their final destination without any sensor alarms, then damages might originate from the sender. Hence, sensors are used to monitor the transport in an immutable fashion. If violations occur, measures can be initiated.

10.4.2 Silke

Silke addresses the safety of transport chains in food production processes. Food products are very sensitive and vulnerable against environmental conditions. During the transportation of meat, certain temperature constraints have to be assured and monitored for safety and liability reasons. Hence, transport monitoring is similar to TrackChain. In addition to TrackChain more processing agents are involved in the entire process. Thus, a number of agents and sensing devices increase. Yet, automation and control opportunities are pretty similar.

One difference revolves around the tracing of the transport chain. Typically, there is an upstream interest in the provenance of the process: the destination is interested in the correctness of the process starting from the source. As such, proper execution of transportation orders can be monitored. In a downstream scenario the source would strive for governing proper transport conditions in order to assure an outstanding quality of the product produced and delivered, e.g., certain handling conditions might be required. Again, smart contracts can be utilized to enforce such constraints, e.g., temperature conditions or packaging instructions, down the supply chain.

10.4.3 Sinlog

Sinlog strives for the digitalization of documents in German inland waterway transportation. As of now, information logistic in this ecosystem of transportation services is characterized by the processing of PDF documents. Digital information, e.g., specific attributes of containers, is only available inside organizations such as terminals but not across organizations. An exchange of information is only possible when the full account of information for a processing step is available in terms of PDF documents as proof of activities. Imagine how overall process performance can be improved when pieces of information can be forwarded in advance. Simple examples include the improvement of planning processes for container placement in terminals.

By splitting information typically represented by one document into pieces of information, many process optimizations are possible due to an earlier availability of information as advocated by manifestos for re-engineering. In addition, process collaborations can be tracked, and proper process compliance can be proven. Hence, cooperation patterns can become more flexible. Planning of follow-up transportation is a grassroots example.

In addition, merely handling digital assets requires an authentication of data, processes, and tools, i.e., having 1000 tons of grain be loaded according to what meter. Thus, identity management of process participants is necessary [14], be they human or technical agents in terms of sensors such the ones for insertion depth as meter for the tonnage loaded.

When all documents revolving around the transport are available as electronic freight transport information (eFTI) according to European bylaws, then questions about correctness of information arise in general. Thus, information exchanged requires certification in terms of content as well as origin. Hence, digitalization of processes generates new requirements for identity management since the trustworthiness of exchanges via certified documents diminishes.

10.4.4 BC for Production

Data security and traceability while at the same time maintaining the sovereignty of data providers are becoming decisive factors for production processes in light of digitalization and globalization for manufacturing companies (manufacturing, factoring, supplier, etc.). Methods for an immutable and controllable documentation of production-related data are necessary. At the same time, access to information sources has to be supported with a revision-safe documentation of any kind of utilization.

Intelligent management approaches for production data are required that offer related information in process-aware contexts. The IDS again serve as a concept for data fusion, while blockchain supports the clearing of data utilization and auditing of transactions.

In production industries several machines contribute to the manufacturing of goods. Along this production process data about production parameters are exchanged and integrated. A part passing different processing stations and perhaps also crosses enterprises can turn from a kind of raw material toward a product. Along this process of formation several information transfers from suppliers to manufacturers happen. However, suppliers do not intend to unveil their production parameters in detail but merely confirm the compliance of production constraints.

A similar pattern occurs for the transportation of bulk material in Sinlog. A delivery of grain has to guarantee certain levels of nutrition and moisture. Since the delivery will be a combination of several contributions, the trader has to guarantee quality indicators, but is certainly not willed to unveil details [34]. Hence, raw data will not be provided but the compound is supposed to meet the requirements. The trader merely encodes the aggregation of the data such that proper delivery can be proven. Such pattern of information exchange is a role model for many business collaborations. Our approach furnishes the technical means for such business collaboration and the tracking of its provenance.

10.5 Conclusion

We started with the challenge of marrying the concept of the IDS with the potential of blockchain technology. Data monetization and information economies accompanied by machine-to-machine collaboration appeared as full-fledged candidates to capitalize on the potentials of both lines of research and development, i.e.,

- Generating knowledge for process improvements on the basis of aggregated datasets and knowledge derived due to econometric analytics.
- Capitalizing on this knowledge by utilization policies and their economic clearing, i.e., monitor and bill the use of this knowledge while analysts and data providers ought to be awarded with incentives.

On the one hand, *data space concepts* are required to reconcile data stemming from a multitude of information spheres each perhaps representing a different view of related activities on a shared core process such as the fine-blanking of body parts for automotive vehicles or the optimization of food production processes.

Any knowledge economy is contingent upon insights derived from an analysis of data originating from different but comprehending data sources.

On the other hand, application of this knowledge generates a significant economic advantage as demonstrated by statistical models for improving farming efficiency and animal welfare as shown by PigConomy [5]. Since management and use of this kind of knowledge cannot be controlled by intermediaries for economic reasons due its rather low market capitalization for each single transaction, automized procedures with an algorithmically controlled governance are necessary, i.e., DLT for the clearance of knowledge use. Knowledge users will be charged on a use case basis, while data providers and analysts will receive fair incentives.

Hence, both lines of research and development for data space management and transaction control of knowledge management are essential ingredients to foster data economies. The chapter has firstly shown a conceptual marriage of both lines as a complement. Moreover, it has shown an array of outstanding examples for capitalizing on knowledge due to the digitalization of processes ranging from the tracking of the transportation of sensible goods, via the integration of process data from different machinery parcs in the production domain and process automation for the operation of container shipments toward a trustworthy management of educational and vocational certificates. Furthermore, we identified how the blockchain community can adopt IDS concepts of usage policies to implement smart contracts in the context of programmable money.

To reiterate, the IDS provides a trusted operational basis for the integration of data sources, while DLT empowers knowledge transactions with trust across business partners.

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