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Electronic Markets

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Springer Nature

Suggested Citation: Finke, Christian; Schumann, Matthias (2025) : Is DLT the solution for current supply chain problems? Bridging the gap between EDI and DLT, Electronic Markets, ISSN 1422-8890, Springer, Berlin, Heidelberg, Vol. 35, Iss. 1, https://doi.org/10.1007/s12525-024-00750-y

This Version is available at:
https://hdl.handle.net/10419/319171

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Electronic Markets (2025) 35:15
https://doi.org/10.1007/s12525-024-00750-y

RESEARCH PAPER

Is DLT the solution for current supply chain problems? Bridging the gap between EDI and DLT

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Received: 28 February 2023 / Accepted: 10 December 2024
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Abstract

Centrally administrated systems have historically facilitated inter-organizational data exchange in supply chains (SC), relying on the message standard electronic data interchange (EDI). However, the current use of EDI fails to meet information needs, as point-to-point interfaces complicate information sharing among multiple partners and batch processing lacks real-time capabilities. This results in information asymmetries, leading to inefficiencies. Distributed ledger technology (DLT), which offers decentralized communication and data storage, presents a potential solution. In this paper, we present a systematic literature review comparing the centralized architectures utilizing EDI applications with the decentralized architecture of DLT within SCs. We identified the limitations of the current systems and assessed whether DLT offers a solution. The findings show that DLT enhances real-time data exchange, automation potential, and transparency, but also faces shortcomings. Integrating EDI with DLT offers a promising approach to leverage synergies and address the weaknesses of both technologies, e.g., lacking standards for DLT.

Keywords Electronic data interchange · Distributed ledger technology · Blockchain · Supply chain

JEL Classification O31

Introduction

Since the 1980s, companies have replaced paper-based communication with digital data exchange, traditionally managed by connected centralized information systems (Kurbel, 2013; Narayanan et al., 2009). To this end, within inter-organizational information exchange for supply chains (SC), electronic data interchange (EDI) applications were established to improve cross-company processes, reducing execution time and costs (Webster, 1995).

The increasing complexity and dynamization in SCs, due to changing relationships between companies, require interfaces aligned with business needs (Lee & Whang, 2000; Lotfi et al., 2013). By connecting centralized information systems, EDI applications pose flexibility limits due to their high degree of standardization, and point-to-point interfaces risk information asymmetries as information must be synchronized accordingly (Grabowski et al., 2002). This leads to issues that require additional effort to resolve, such as the receiving SC partner needing to verify the accuracy of the transmitted data (Schinle et al., 2017). Consumers also demand more product information due to ecological and ethical concerns (Malik et al., 2019; Masudin et al., 2021). In addition, technical hurdles exist; e.g., the introduction of Internet-of-Things (IoT) devices has increased information extraction from SC processes which can only be exchanged insufficiently or not at all (Schinle et al., 2017).

A possibility to address these information asymmetries by creating a uniform, trustworthy database could be the use of distributed ledger technology (DLT) which enables decentralized access to information for involved parties and customers (Kshetri, 2018). Furthermore, oracles can integrate data, e.g., on transportation details, like temperature levels, which is crucial for regulated areas like cold chains (Osterland & Rose, 2021). This information then serves for process automation

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Published online: 19 February 2025

through smart contracts (Koirala et al., 2019). Due to the inherent properties of DLTs and the further development of the technology around smart contracts and oracles, this SC research area has gained importance (Kshetri, 2018; Nakamoto, 2008). Here, research shows DLT's utility, e.g., IKEA's response to SC events (Sund et al., 2020) and DLT's role in freight billing (Lacity & van Hoek, 2021).

While existing research explores the potential applications of DLT in specific SC processes, it misses the consideration of the current status quo under established central information systems that rely on EDI for inter-organizational communication (Lacity & van Hoek, 2021; Sund et al., 2020). This missing point of view limits a thorough analysis of unmet needs in current SCs to assess if DLTs can provide a remedy. An analysis is also essential to assess the added values of centralized and decentralized communication approaches, explore integration possibilities, inform implementation decisions, and understand how modern technologies can enhance legacy systems. This also provides an opportunity to derive knowledge from long-established process support through EDI for DLT solutions. Therefore, a cross-sectional analysis of EDI and DLT is conducted through a structured literature review to address this research gap. Although EDI utilizes a message standard and DLT deploys a decentralized network, both technologies are enablers for the exchange of information in SCs, each within its centralized or decentralized application framework, thus making them comparable. Additionally, understanding the added value of each technology allows the study to discuss how integrating EDI and DLT can utilize an approach that addresses their respective limitations. Thus, we propose the following research questions:

RQ1: What are the benefits and problems of the current use of EDI within supply chains?
RQ2: Which problems of the current approach under EDI in supply chains can DLT solve?
RQ3: What research gaps apply to the use of DLT in problem areas of supply chains?

This paper is structured as follows: First, the concepts of "Supply chains," "Electronic data interchange," and "Distributed ledger technology" are explained. Following, the methodology and results are presented. Finally, we discuss the findings, highlight areas for further research, and draw a conclusion.

Theoretical background

To create a common understanding, we present the theoretical background of SCs as well as the communication technologies EDI, and DLT within this context. Appendix 1 provides information on the acronyms and definitions.

Supply chains

Value creation networks or SCs are complex systems managing logistical tasks and processes, in which smaller subsystems realize subtasks and subprocesses, such as procurement, production, and distribution (Branch, 2008; Hausladen, 2020; Kurbel, 2013). These processes facilitate the manufacturing of products by managing the flow of physical goods, information, and finances from raw material suppliers to end consumers. Here, tasks like ordering, production, delivery, and invoicing generate information that needs to be exchanged (Hausladen, 2020). Consequently, further SC processes are necessary to enable inter-organizational coordination and communication (Kankam et al., 2023; Nakasumi, 2017; Sundram et al., 2020). Here, communication technologies aim to optimize these SC processes, e.g., reducing inventory or improving coordination along SCs, by making them more transparent and traceable (Marshall, 2015). Examples of inter-organizational shared data are inventory-, sales-, and order information (Lee & Whang, 2000; Lotfi et al., 2013). Depending on the process, different data must be exchanged bidirectionally between the parties involved and across multiple value-generating stages according to their requirements, e.g., accurate declaration of goods in customs (Hausladen, 2020; Kankam et al., 2023).

Electronic data interchange

Data exchange in SCs is currently achieved through EDI applications. Here, data management including storage is handled by company-related systems that use the EDI message standard for inter-organizational connection (Webster, 1995). This concept of centralized data exchange, with EDI as an enabler, is defined below.

As backbone of inter-organizational communication, EDI is defined as a standardized messaging protocol that enables two partners to exchange formatted data between their internal information systems without media discontinuity or manual intervention (Choudhary et al., 2011; Kurbel, 2013; Narayanan et al., 2009). Therefore, EDI provides a standardized electronic method for inter-organizational data exchange, eliminating the need for paper-based processes and enabling faster bi-directional information exchange across company-related systems by using various communication technologies, as illustrated in Fig. 1 (Graham et al., 1995; Webster, 1995). To exchange process-relevant information between different system landscapes, companies must establish EDI interfaces with specific requirements and functions (Graham et al., 1995; Lee & Whang, 2000). Here, the parties involved must clarify

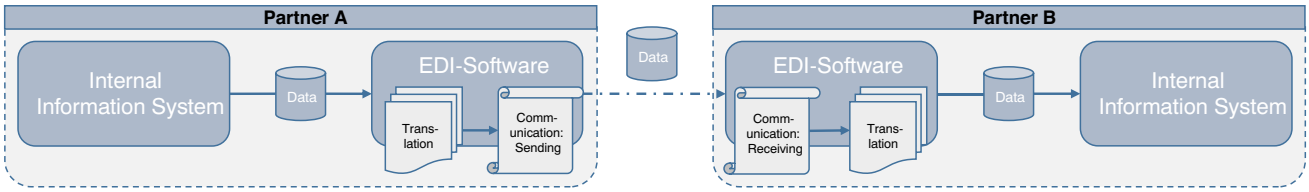

Fig. 1 Software-technical process of inter-organizational communication with EDI

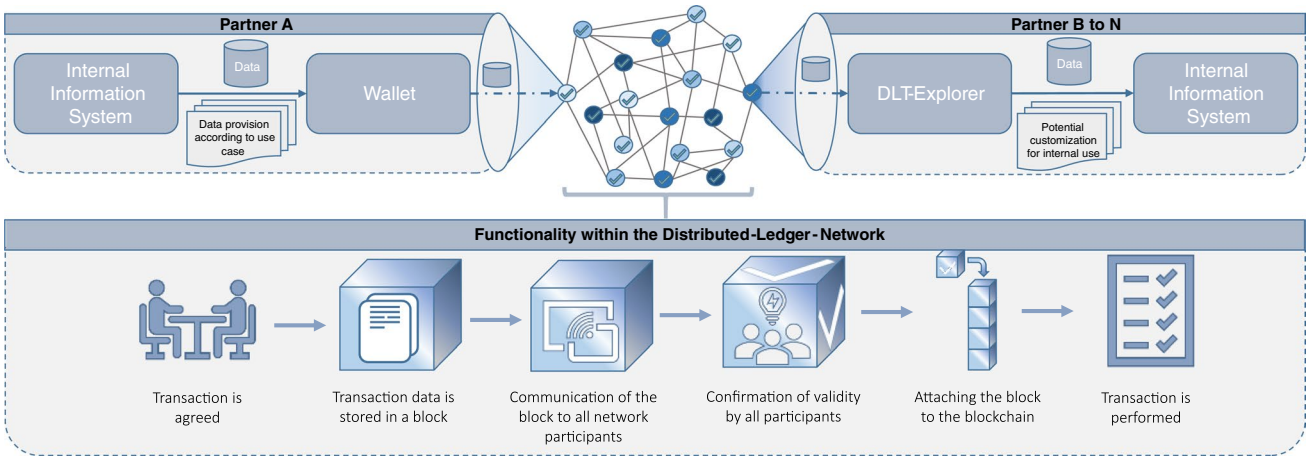

Fig. 2 Schematic representation of the functioning of a DLT

which information has to be communicated, at what time, and for what purpose, which can vary by process or industry (Lee & Whang, 2000). Therefore, the data which is stored in the sending companies information system landscape has to be translated from a company-specific format according to the EDI message standard, e.g., EDIFACT in Europe or ANSI ASC X12 in America, to transmit via the internet (Narayanan et al., 2009; Nurmilaakso, 2008). These standards define the syntax of the message by providing rules to convert, e.g., price catalogs, orders, and invoices, into an EDI format and the other way around into a company-specific format (Narayanan et al., 2009). Finally, the receiving partner translates the standardized EDI data records back into a format their internal system can process (Branch, 2008). Companies can implement these interfaces themselves or rely on third-party clearing centers if they lack the know-how (Ratnasingham, 1998). If a clearing center is used, a third-party provider's infrastructure handles the receipt, conversion, and transmission of data. However, the flexibility of data communication depends on the provider's expertise and capabilities (Ratnasingham, 1998). Once the data has been translated into the format required by the receiving company, it can be stored and processed within the company's information system infrastructure (Webster, 1995).

Distributed ledger technology

An alternative is the DLT, which creates a decentralized network that contrasts with the previously described centralized approach (Ballandies et al., 2021). A DLT refers to a fully distributed system for cryptographically capturing and storing a consistent, immutable event log of transactions within blocks of data between networked actors (Ballandies et al., 2021; El Ioini & Pahl, 2018). Therefore, DLTs operate as distributed databases, consensually maintained, updated, and validated by network participants to enforce transparency (Risius & Spohrer, 2017). Furthermore, DLTs can be public, private, or designed as a hybrid in the form of restricted access and require a consensus mechanism to store transaction data consensually in real time (Ballandies et al., 2021).

Figure 2 illustrates the described functionality of DLTs as well as the processing of the data outside the DLT. A company provides data in an agreed-upon format, either from an internal system or through a user. If the data corresponds to the data structures of the use case, a corresponding transaction can be stored in the DLT using a wallet (Nakamoto, 2008). If this is validated by consensus, the information is available and can be retrieved by authorized partners via an explorer and customized for further use (Risius & Spohrer, 2017).

In SCs, the decentralized architecture for joint, consensual, and cryptographic collection of data offers a consistent, unchangeable, and synchronized event log of transactions (Agrawal et al., 2021; Berneis et al., 2021). Here, a DLT provides potential for disintermediation that goes beyond the communication of information which could lead to competition with centralized service providers (Kshetri, 2018). Nevertheless, the joint validation via a consensus mechanism involves transaction and/or energy costs (Negka et al., 2019). Thus, a DLT enables data exchange and storage, while its multifunctionality also allows to work on the data using a single technology (Banerjee, 2019; Jensen et al., 2019; Kshetri, 2018). A further advantage of DLTs is the easy access to stored information (visibility), ensuring transparency for all participants, e.g., making it easier to track and trace products or that information can be passed on to transport service providers (Tsiulin et al., 2020; Yacoub & Castillo, 2022). This improves inter-organizational communication, especially for SCs with high communication and coordination volumes as information is available to all involved parties as soon as the transaction is stored (Berneis et al., 2021; Irannezhad, 2020). Nevertheless, scalability limitations can occur, as the number of transactions to be confirmed by consensus increases according to the number of SC partners (Reddy et al., 2021). However, the DLT setup is of importance here, as public DLTs, in particular, are significantly more cost- and energy-intensive than private DLTs (Markus & Buijs, 2022; Nakamoto, 2008). Conversely, private DLTs create dependencies to an SC partner if this partner also operates the DLT, e.g., TradeLens from Maersk (Finke et al., 2023b). Users of the DLT become reliant on the operating partner for access and operation; as the DLT becomes part of their system landscape, e.g., lock-in effects can arise (Finke et al., 2023a).

Additional technologies like smart contracts and oracles, e.g., to enable work on immutable data and the integration of external information provide the aforementioned multifunctionality to the DLT (Kshetri, 2018). Smart contracts are computer programs stored on a DLT that use if–then logic to execute terms automatically without third-party intervention. The source code can be agreed upon by all parties before deployment (Eggers et al., 2021; Koirala et al., 2019; Kshetri, 2018). Furthermore, smart contracts enable data processing of decentrally stored data using programming logic as the jointly managed database of the DLT serves as a basis (Beck et al., 2020; Eggers et al., 2021; Lacity & van Hoek, 2021). This enhances DLT's versatility, especially in the SC sector, by enabling real-time status updates and tracking of goods (S. Wang et al., 2019). Smart contracts also improve inter-organizational communication and coordination, e.g., by responding to both planned and unplanned events, such as changing transport modes based on weather conditions (Sund et al., 2020). The visibility of the smart contract functionality also offers transparency as a basis for trusting cooperation (S. E. Chang et al., 2019).

Oracles transfer real-world information into DLTs, such as information from RFID tags on goods to enable traceability. Reliable external information is essential for DLTs, as smart contracts operate on this data and allow corresponding reactions (Osterland & Rose, 2021; Pasdar et al., 2021). Oracles act as external data agents or middleware, accepting data from sensors, APIs, or other sources, and then authenticating and/or certifying it against policies before transferring credible data to the DLT, e.g., sensors can record data on the delivery process or verifying the authenticity of goods which benefits consumers (Ezzat et al., 2022; Kshetri, 2018). Therefore, oracles can be integrated via software or hardware, e.g., smart contracts or sensors that can enable more flexible monitoring of cold chains (Caldarelli et al., 2020; Reddy et al., 2021). However, even oracles can be compromised by third parties to adjust data injection policies (Ezzat et al., 2022; Reddy et al., 2021).

Research design

To address the research questions, we describe the methodology and provide a workflow diagram (see Fig. 3). The research process is divided into three phases to compare EDI applications and DLT for suitability in SC processes (RQ1 & RQ2) and derive meaningful research directions for DLT in SCs (RQ3).

Phase I establishes the basis for answering the research questions by integrating literature on EDI and DLT within the context of SCs to enable a comprehensive comparison. Although EDI, as a message standard, and DLT, as a decentralized network, are fundamentally different technologies, this paper identifies both as essential components of their respective centralized and decentralized approaches to support SC processes, thus facilitating comparability (see "Theoretical background"). While EDI has traditionally connected centralized enterprise information systems, it should be mentioned that it can also serve as a message standard within a DLT. On the one hand, reviewing EDI literature in the context of existing solutions is crucial to understanding its added values and shortcomings, allowing it to investigate where DLTs provide additional value, e.g., transparency or managing IoT devices. On the other hand, analyzing both technologies helps to identify potential synergies, as their different approaches to support inter-organizational communication can complement each other. Therefore, a structured literature review according to Fettke (2006) and vom Brocke et al. (2015) (see Appendix 2) is carried out focusing on existing research results where the central topics on the use of EDI and DLT in SCs are recorded. A neutral position is taken to record the status quo in a thematic structure and the

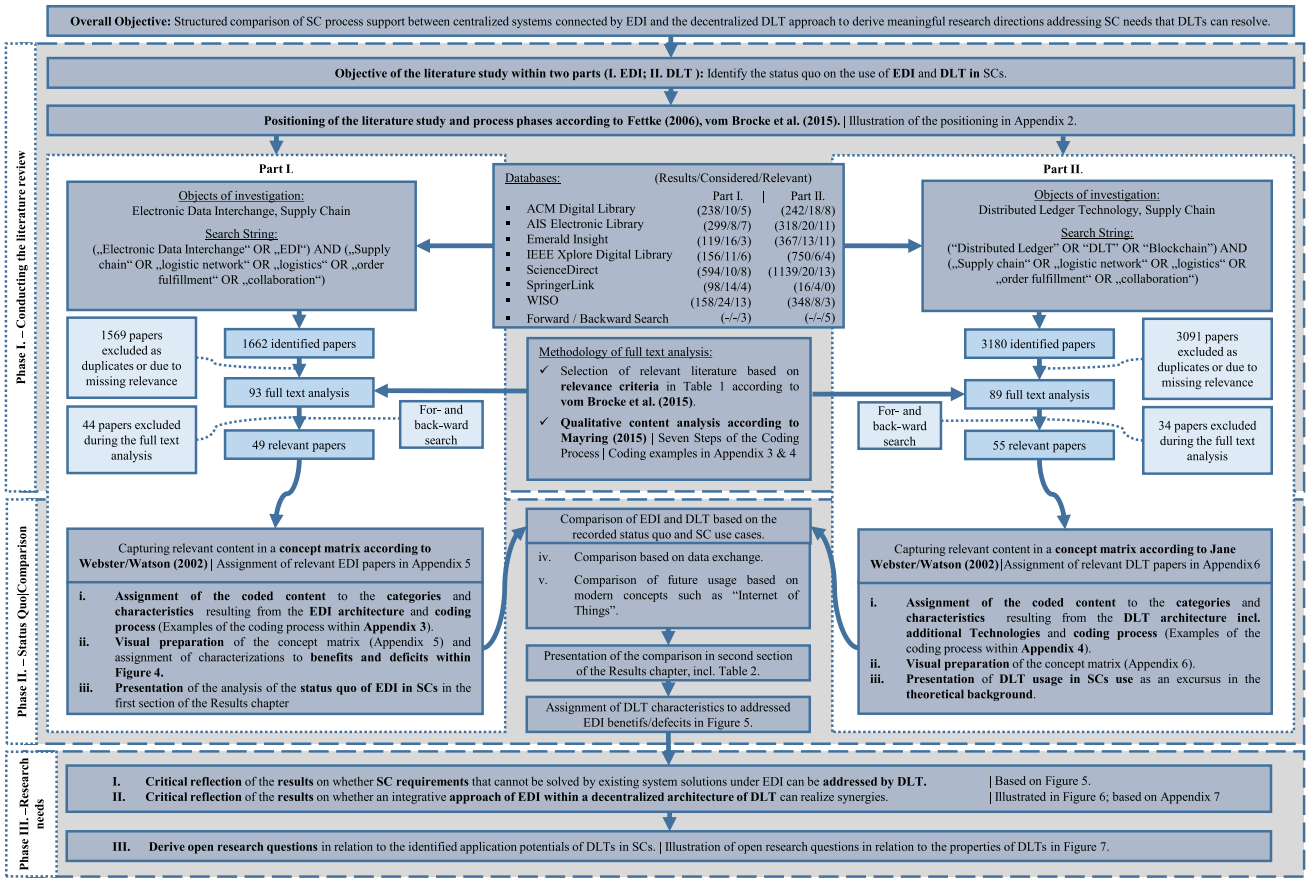

Fig. 3 Methodical procedure of the present work

Table 1 Inclusion and exclusion criteria of the literature reviews

	Scope	Criterion	Description
EDI	Revelant are papers that consider EDI or centralized solutions to support SC processes.	1	Relevant are papers that investigate data exchange with EDI.
		2	Relevant are papers that investigate centralized data storage in relation to EDI.
		3	Relevant are papers that investigate EDI in contrast to modern SC use cases.
		4	Irrelevant are papers that investigate the current and future EDI usage away from SCs.
DLT	Revelant are papers that consider DLT or decentralized solutions incl. Smart Contracts and oracles to support SC processes.	5	Relevant are papers that investigate data exchange with DLT.
		6	Relevant are papers that investigate decentralized data storage in relation to DLT.
		7	Relevant are papers that investigate DLT in contrast to modern SC use cases.
		8	Irrelevant are papers that investigate the current and future DLT usage away from SCs.

literature investigated within the databases is nearly complete. To collect information for each technology independently, we applied the search string of the literature review to the databases each in an English and a German version (see Fig. 3). This aims to provide the aforementioned comparability on the understanding that both technologies are essential for their respective centralized or decentralized communication approach in SCs. The broadly formulated search string also allows a comprehensive analysis in the SC context and was applied in scientific and practice-related databases, with papers considered relevant if they met the criteria in Table 1 (vom Brocke et al., 2015).

Using the search strings, we identified a total of 1662 papers in Part I (EDI) and 3180 papers in Part II (DLT) within the databases. Next, papers were screened by title and abstract using the inclusion/exclusion criteria outlined in Table 1. Relevant papers discuss, e.g., how DLT facilitates data sharing between SC partners, while irrelevant ones focus on, e.g., EDI applications in healthcare systems. A paper is marked for full-text analysis if it provides information on how EDI or DLT enables inter-organizational communication in SCs, highlighting the benefits or deficits of the technology. The papers marked as temporarily relevant were then analyzed in a full-text analysis to extract the relevant information. Here, 93 papers in Part I (EDI) and 89 papers in Part II (DLT) were examined using seven steps of qualitative content analysis according to Mayring (2015). Starting with the first two steps by recording the structural dimensions based on the technological structure of EDI and DLT and its characteristics, we then defined examples for

the characteristics within step three. Two tables of examples for the literature reviews conducted were included in Appendices 3 and 4. Based on the initially recorded dimensions and characteristics, the full-text analysis was carried out in step 4 and the results were extracted (step 5). As this is an iterative procedure, the previous steps were revised in step 6. Finally, the content of the literature review was edited and is presented in the "Results" section. A total of 49 relevant papers in Part I (EDI) and 55 relevant papers in Part II (DLT) were identified using this procedure. These were used for the status quo comparison in Phase II.

Within Phase II, we answer the first two research questions. It deals with the analysis of the status quo of EDI applications and DLTs within their respective communication approach in SCs, which is the basis for the structured comparison. Then, we assigned the coded contents of the papers to the identified categories and characterizations (i; see Appendices 3 and 4). Subsequently, a concept matrix according to Webster & Watson (2002) was created based on the available information for both parts of the literature review (ii; see Appendices 5 and 6) to provide an overview of the allocation of the papers. The findings of the respective status quo of EDI applications are presented in the "Results" section to answer the first research question. To this end, sub-section "Analysis of the status quo of electronic data exchange in supply chains" summarizes these results. It should be noted that identified papers can also be assigned to both parts of the literature review and, thus, a potential bias may exist (see concept matrices in Appendices 5 and 6). The DLT findings are presented as an excursus in the theoretical background (iii). To answer the second research question, the results are summarized and compared with each other. The comparison of data exchange (iv) serves as a use case, as inter-organizational communication enables SC processes. This includes the centralized data storage connected by EDI compared to decentralized data storage with DLT. The sub-section 'Comparison of the identified factors of current EDI and DLT usage in SCs' summarizes the results. In addition, the benefits and deficits of current SC communication that can be addressed by DLT are shown at the end of the sub-section.

Finally, Phase III serves to critically reflect on the results obtained and to examine when the use of DLT can address shortcomings in SCs (Phase III; I). Although EDI was originally developed for data exchange between internal company information systems, it can also function as a messaging standard in a decentralized context. Therefore, we also evaluate the results from this perspective, as potential synergies may exist, and conduct a brief literature review to substantiate the discussion (Phase III; II; see sub-section "Synergy through integration of EDI into DLT" and Appendix 7). To answer the third research question, we reflect on the implications of the work and derive further research needs for the use of DLT in SCs (Phase III; III; see sub-section "Research directions of DLT usage in SC").

Results

In the following sub-sections, the results of the literature review are presented and analyzed. First, an analysis is performed on the existing deficits and benefits of current EDI applications in SCs. Second, the identified DLT capabilities are compared with both the limiting and beneficial factors.

Analysis of the status quo of electronic data exchange in supply chains

The literature review conducted to answer the first research question revealed four benefits and 15 existing and potential future deficits from 49 papers. Figure 4 and Appendix 5 list the factors based on their characteristics within five categories. The benefits of centralized information systems connected by EDI in SCs are highlighted in green while deficits are highlighted in red. By looking at the centralized architecture, within inter-organizational SC communication, data has to be stored, communicated, and processed through an EDI application, which allows the derivation of the following categories. Data management, data transmission, and the creation of a digital value network enable the cooperation of the SC partners. In addition, the establishment of interfaces leads to corresponding resource requirements. Lastly, the category future usage resulted from the literature review and coding process, whereby this category summarizes factors that could not be assigned to an existing category but were identified through the analysis following Mayring (2015). This category also considers inter-organizational communication from the point of view of regulatory aspects and technical adaptations.

Data management

Within the first category, three factors address data management related to EDI applications in SCs. Two papers mention that EDI improves data quality, e.g., in comparison to manual and paper-based processes, as a positive value contribution (Jardini et al., 2015; Leonard & Clemons Davis, 2006). This is offset by two deficits where data redundancy or data security requirements cannot be fully met by current EDI usage (Karatas & Gultekin, 2021; Zdziarska & Marhita, 2020). First, when sharing data, companies accessing their central databases to store, retrieve, or modify data leads to intra-company data silos (Grabowski et al., 2002; Oh et al., 2019). Thus, the goal is to synchronize data on the databases of the SC partners with EDI (Grabowski et al., 2002; Shi &

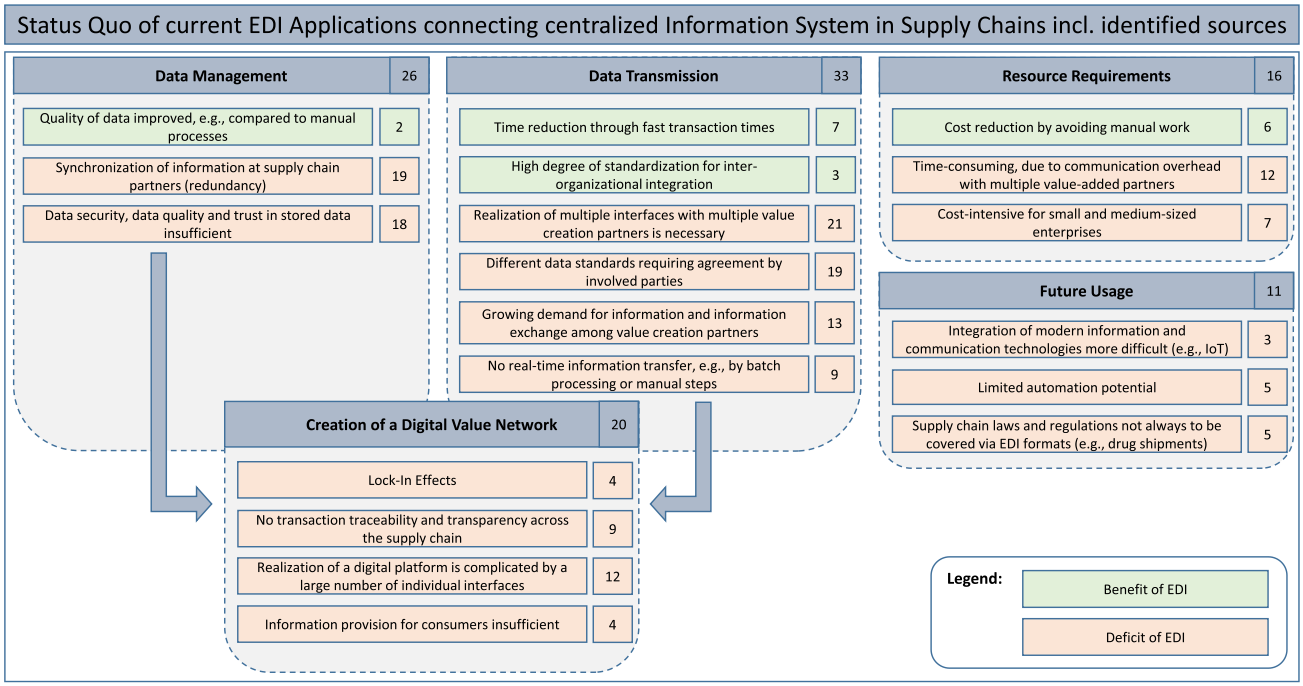

Fig. 4 Identified factors affecting supply chains by using centralized information systems connected by EDI

Wang, 2018). This results in data redundancy and the risk of unsynchronized updates, compromising data integrity across databases of the SC partners (Chang et al., 2019; Markus & Buijs, 2022; Shi & Wang, 2018). In addition, trust in the exchanged data is increasingly essential, as growing customer requirements regarding the origin of materials used in products and manufacturing conditions apply (Jensen et al., 2019). To meet these requirements and to provide reliable data, a trustworthy exchange of data and a uniform database are essential (Banerjee, 2019). As data potentially has to be communicated along the entire SC, the current use of EDI does not guarantee accurate data storage within every central database of SC partners (Hvolby et al., 2021; Markus & Buijs, 2022).

Data transmission

Further factors relate to data transmission, the application area of EDI in current communication architectures. The literature notes that faster transaction times benefit communication through the internet, compared to paper-based communication methods (Bergeron & Raymond, 1992; Webster, 1995). Furthermore, a high degree of standardized communication between companies is created through industry standards (Hausladen, 2020; Webster, 1995). However, these standardized interfaces require an agreement between the parties involved, e.g., for communicating invoices or product data (Bergeron & Raymond, 1992; Debicki & Guzman, 2020). This requires a corresponding organizational and technical effort (Bergeron & Raymond, 1992; Hausladen, 2020). In addition, if no EDI clearing center is used, a large number of EDI interfaces must be established for a corresponding number of SC partners (Singerling et al., 2015). Furthermore, these standards lack flexibility, so not all information requirements of involved SC partners are necessarily fulfilled (Schäffer & Stelzer, 2017). Corresponding customization increases the organizational and technical effort required to set up an EDI interface (Jensen et al., 2019). Finally, despite the faster communication, there is no real-time communication, as manual interventions in the event of errors or batch processing slow down the process (Global Data Point, 2019).

Creation of a digital value network

The identified factors within data management and transmission influence the creation of a digital value network. The first factor is about lock-in effects, which can be positive or negative depending on the party concerned. On the positive side, e.g., large automobile manufacturers are mentioned who bind their suppliers to them by specifying the EDI standards to be used (Bergeron & Raymond, 1992; Webster, 1995). Conversely, this factor is often a disadvantage for smaller parties, as the IT infrastructure has to be adapted to the requirements of the larger partner due to the degree of dependency (Webster, 1995). Furthermore, the literature provides particular attention to achieving transparency within SC

processes. This applies to shared master data, which represents product details, e.g., weight, quantity, and composition or origin of goods, but also event-related data. One example where the static structure of EDI interfaces poses a challenge is an unforeseen change in deliveries due to external circumstances, like changing shipping channels, the change of ownership of flow objects, or the receipt of documents (Beck et al., 2020). Creating a transparent information situation is essential to enable a fast flow of events through multi-layered SC and thus to enable production concepts such as Just-In-Time production in the first place. A further limitation applies in terms of the technical implementation of EDI (Hvolby et al., 2021; Jensen et al., 2019). EDI interfaces are implemented as point-to-point connections by default if no third-party clearing center is used where SC partners can access their information (Financial Services Monitor Worldwide, 2019; Singerling et al., 2015). However, SCs have become more complex and global, where a multitude of raw material suppliers, manufacturing sites of intermediate and end products up to final buyers have to be integrated into the information flow (Karatas & Gultekin, 2021; Schinle et al., 2017). Therefore, companies must implement a large number of EDI interfaces between all SC partners to ensure the communication of the required data (Karatas & Gultekin, 2021; Schinle et al., 2017). Nevertheless, even in this case, based on the defined standards, it is not guaranteed that each participant in the value-added network will receive the needed data (Chang et al., 2019). Finally, EDI is not designed to integrate consumers, although consumers increasingly demand information about products due to environmental and ethical considerations (Masudin et al., 2021). For example, farm and cooperative certifications such as Fairtrade are insufficient for some consumers of chocolate or coffee. This could be strengthened by trustworthy data from the manufacturing process (Martinez et al., 2019).

Resource requirements

Furthermore, 16 papers named factors regarding the resource requirements. An advantage of EDI use for data exchange between companies is the cost reduction resulting from the standardization of communication (Hill et al., 2009; Hoogeweegen et al., 1996). Nevertheless, synchronizing data across SCs requires time and communication expenditure. Oh et al. (2019) and Schäffer and Stelzer (2017) note that the implementation of the EDI interfaces is associated with initial costs for hard- and software. This applies when business processes are restructured and digitized (Hausladen, 2020). As mentioned before, depending on the number of business partners, an equal amount of interfaces if no third-party network is used has to be implemented (Jablonski et al., 2002).

Future usage

Last, the literature identifies three deficits according to the future usage of EDI in the current way. The literature mentions the integration of modern technologies, e.g., cyber-physical systems for data recording (Banerjee, 2019). Modernizing production structures to meet customer, cost, and time requirements not only affords expansion with cyber-physical systems in production environments but also in logistical processes (Banerjee, 2019). When monitoring cold chains, e.g., for food or medicines, the recording of temperature values is necessary (Banerjee, 2019). The integration of sensors confronts EDI applications with the challenge that recorded data cannot be easily shared with SC partners in real time and the sensors require a corresponding IT system landscape (Imburgia, 2006). Another challenge is the flexible integration of third parties, e.g., freight forwarders. These also require an EDI interface to participate in the data exchange, e.g., if data on the transport process is recorded via sensors and has to be shared (van Sinderen et al., 2013). Schinle et al. (2017) also note the lack of automation potential. EDI is capable of automating electronic data transmission. However, this is no reaction in real time since the distribution of the information to further SC partners is not mandatory (Hvolby et al., 2021). Especially when the data transmission fails, there are time delays (Schinle et al., 2017). Finally, some legal aspects cannot be processed using EDI, e.g., in freight transport, where the Bill of Lading is still presented as an original document in paper format due to its legally binding nature, as there is no equivalent digital solution (Stahlbock et al., 2018).

Comparison of the identified factors of current EDI and DLT usage in SCs

In this sub-section, the current centralized SC communication approach by using EDI for inter-organizational connection is compared with the decentralized architecture of DLTs. First, a comparison is made based on the use case of data exchange (Phase II; iv), which is the core of inter-organizational SC cooperation. Further applying framework conditions, like data management, or the creation of digital value networks, currently facilitated by internal information systems, is also considered (sub-sub-sections "Data management," "Data transmission," "Creation of a digital value network," and "Resource requirements"). In both approaches, for data exchange in the SC context, data management is necessary, such as a database for product, and order data. This enables the data transmission of shipping notifications, invoices, or inventory data, which is required

for inter-organizational communication and coordination. In modern SCs, data exchange between two companies is not sufficient, as a large number of (small) actors, e.g., freight forwarders, work together. Therefore, the creation of digital value networks is necessary. Finally, resources, such as finances, are required for inter-organizational communication. Therefore, the centralized and decentralized communication approach for SC support under the respective enabling technology is capable of addressing the use case of data exchange, meaning there is an underlying comparability. Following, both architectures are investigated concerning future usage (Phase II; v) (sub-sub-section "Future usage").

Table 2 shows the comparison of the identified factors of communication under the current use of EDI with the potential effect that DLTs, smart contracts, and oracles can provide on this factor. Arrows in the "Effect" column indicate if DLTs provide a good (↑), partial (↗/↘), poor (↓), or constant solution (→) compared to EDI, even if it is a beneficial factor. We derived the estimated effect by comparing the current use of EDI applications and DLTs within SCs. A good effect occurs when DLT's decentralized architecture positively affects EDI factors, such as enhanced data security, flexible databases, or real-time transaction data. A negative effect includes higher operating costs. Constant indicates no improvement, regardless of the used communication approach.

Data management

DLTs successfully provide improvement to deficits and benefits concerning data management in SCs. Both EDI and DLT can share information in an inter-organizational context to enable companies to store and process these even information (Shi & Wang, 2018; Webster, 1995). However, the technologies differ in the supported file storage, as DLT, unlike EDI, offers a decentralized option (Agrawal et al., 2021). Also, both technologies improve the data quality compared to manual processes. Here, DLT can offer further improvement due to the decentralized, shared, jointly validated, and therefore tamper-proof database (Dasaklis et al., 2019).

Furthermore, DLTs eliminate the effort to synchronize and update company-related data silos (Tan & Sundarakani, 2021; Wang et al., 2019). Small or occasional partners, such as freight forwarders, are not required to operate a node in the DLT, as the information can be provided to them on a token basis via a wallet (Finke et al., 2023b). Despite the potentially simpler integration of SC partners, there must be standardized processes and interfaces (Finke et al., 2023b). Therefore, DLTs eliminate the need for third-party intermediaries, avoiding redundant data storage with questionable integrity even though the enrichment of the data by the service provided is removed (Eggers et al., 2021). Thus, DLTs can successfully address the synchronization deficit.

DLTs can enhance data security, quality, and trust through cryptographic storage, ensuring immutable data integrity compared to centralized data silos (Sund et al., 2020). Thus, subsequent adaptations to the state of information cannot compromise data integrity (Kshetri, 2018). However, the garbage-in/garbage-out problem, where data quality depends on input applies (Markus & Buijs, 2022; Segers et al., 2019). Oracles can remedy this by validating external data, though defining them according to the process requires effort (Albizri & Appelbaum, 2021). Here, the oracle problem has to be solved, where the authentication of external data beyond doubt is required (Caldarelli et al., 2020). Despite these challenges, DLT offers the potential to address the identified deficits.

Data transmission

Factors also apply to data transmission, the main application area for inter-organizational data exchange, especially for EDI (Webster, 1995). In a positive sense, EDI speeds up communication in SCs in comparison to manual processes through highly standardized interfaces (Jardini et al., 2015), whereas DLT achieves this without relying on a large number of interfaces, as the joint data is recorded directly for all relevant parties (Agrawal et al., 2021). Nevertheless, the scalability of DLT is a potentially limiting factor here (Sigwart et al., 2019).

Furthermore, the use of EDI offers the possibility to realize data transfer based on a high degree of standardization (Webster, 1995). In contrast, DLT has no well-developed and defined standards (Helo & Hao, 2019).

Regarding deficits, a centralized communication architecture requires multiple EDI interfaces to suppliers and customers. With DLT, a single connection via a full or light node is sufficient for a copy of the data ledger and transaction validation (Beck et al., 2020; Lacity & van Hoek, 2021; Malik et al., 2019; Saurabh & Dey, 2021). Nevertheless, there may be a need for a company to become part of several DLTs, e.g., if products are relevant in several SCs. A potential solution is the cross-chain compatibility for flexible data sharing across DLTs (Ou et al., 2022). Furthermore, appropriate standards must be established to support the provision of information (Kshetri, 2018). As a simpler alternative compared to implementing an EDI interface, a wallet can be set up to communicate with the DLT and access its data. However, operating companies must set up a node, which requires knowledge (Chang et al., 2020). Although DLT provides a more flexible database, involved parties must still define data structures for underlying SC use cases. As with EDI, the data must be usable to improve processes and if data structures are insufficient, further processing is needed. Furthermore, within a DLT, it is necessary to agree to the transaction data added as part of the consensus (Li &

Table 2 Comparison of factors in current EDI usage and potential solutions through DLT

	Factors of current EDI usage in supply chains (see Figure 5)	Potential solution through DLT deployment	Effect
Data management	Quality of data improved, e.g., compared to manual processes	DLTs create a shared, consensus-driven, and tamper-proof database	→/↗
	Synchronization of information at supply chain partners (redundancy)	DLTs create a shared, consensus-driven, and tamper-proof database	↑
	Data security, data quality and trust in stored data insufficient	Provision of a consistent, immutable and synchronized event log of the stored transactions within the DLT	↑
		Solution of the Garbage-In-Garbage-Out and Oracle problem remains	↓
Data transmission	Time reduction through fast transaction times	Data is available within the DLT network for involved parties as soon as consensus is reached	↑
	High degree of standardization for inter-organizational integration	Need to coordinate the data structure used in the DLT with the partners	↓
	Realization of multiple interfaces with multiple value creation partners is necessary	Participate in the DLT network by setting up hardware and software such as Node or Wallet	↗
		Need to coordinate the data structure used in the DLT with the partners	→
		Potential further processing of the DLT data for internal use	→
	Different data standards requiring agreement by involved parties	Need to coordinate the data structure used in the DLT with the partners	→
		Smart contracts require coordination of implemented logic	↓
	Growing demand for information and information exchange among value creation partners	Data is available within the DLT network for involved parties as soon as consensus is reached	↑
		Integration possible without interface	↑
		Potential simple provision of the information via wallet or token	↑
	No real-time information transfer by batch processing	Data is available within the DLT network for involved parties as soon as consensus is reached	↑
		Potential limitation due to scalability of DLT	↘
Creation of a digital value network	Lock-In Effects	Participate in the DLT network by setting up hardware and software such as Node or Wallet	→
	No transaction traceability and transparency across the supply chain	DLTs create a shared, consensus-driven, and tamper-proof database	↑
		Data is available within the DLT network for involved parties as soon as consensus is reached	↑
	Realization of a digital platform is complicated by a large number of individual interfaces	Participate in the DLT network by setting up hardware and software such as Node or Wallet	↗
		Need to coordinate the data structure used in the DLT with the partners	→
		Potential further processing of the DLT data for internal use	→
	Information provision for consumers insufficient	Integration possible without setting up an interface	↑
		Potential simple provision of the information via wallet or token	↑
Resource requirements	Cost reduction by avoiding manual work	Data is available within the DLT network for involved parties as soon as consensus is reached	↑
		Smart contracts offer automated data processing directly on the DLT	↑
		Potential transaction and energy costs through the DLT	↓
	Time-consuming, due to communication overhead with multiple value-added partners	Data is available within the DLT network for involved parties as soon as consensus is reached	↑
		No multitude of point-to-point interfaces necessary, only the connection into the DLT network	↑
		Potential limitation due to scalability of DLT	↘
	Cost-intensive for small and medium-sized enterprises	Setting up the DLT network involves costs for hardware and software	→
		Organizational and technical integration necessary	→/↘
Future usage	Integration of modern information and communication technologies more difficult (e.g., IoT)	Decentralized management and communication with IoT devices	↑
		Potential limitation due to scalability of DLT	↘
	Limited automation potential	Smart contracts offer automated data processing directly on the DLT	↑
	Supply chain laws and regulations not always to be covered via EDI formats (e.g., drug shipments)	DLTs offer the possibility of using unique tokens to uniquely identify data records	↑
		Firmly defined structure of smart contracts and the inevitable execution of the source code pose further legal problems	↓

Zhou, 2020). For this deficit, DLT can realize easier access to information. Defining the data structure for SC use cases is necessary for both technologies.

The second deficit is the agreement on different data standards when using EDI, which is also necessary for DLTs in SC processes. Additionally, smart contracts require further

coordination to agree on the implemented logic before going live (Köhler & Pizzol, 2020; Wang et al., 2019). Even with the use of DLTs and smart contracts, the support of individual processes is restricted by the data stored (Stahlbock et al., 2018). Here, the potential coordination effort between the companies involved increases compared to EDI.

Furthermore, EDI lacks the adaptability to increasing information requirements in SCs. In contrast, DLTs benefit from oracles, which connect and validate data from various sources like APIs or sensors by using jointly defined policies (Albizri & Appelbaum, 2021; Caldarelli et al., 2020). This information is immediately available to all authorized SC partners after transaction confirmation (Asprion et al., 2019). Only the integration of the participants into the DLT is necessary, e.g., via wallet or token (Sund et al., 2020). A wallet can uniquely identify a participant, manage their relevant transactions, and grant access to the DLT platform, e.g., if it is embedded in a web application (Finke et al., 2023b). Thus, DLT addresses the EDI deficit by distributing information without a high volume of communication, e.g., multiple interfaces within the SC.

Last, batch processing of data via EDI is mentioned. Smart contracts allow immediate processing of data on the DLT, making it directly available and processable to all participants, e.g., information on unforeseen events like changes in transport routes (Reddy et al., 2021; Sund et al., 2020). However, the DLT scalability can limit this advantage in transaction-heavy processes (Kshetri, 2018). If the DLT is scalable, it provides a remedy.

Creation of a digital value network

The purpose of inter-organizational data exchange is to create digital value networks, where both approaches foster SC collaboration (Grabowski et al., 2002; Lautenschlager et al., 2023). Nevertheless, corresponding interfaces and/or networks create lock-in effects through mutual dependency (Helo & Hao, 2019; Hill et al., 2009).

Furthermore, DLT can remedy deficits concerning a transparent and traceable SC, e.g., raw materials and products moved within it. Depending on the DLT design (public, private, and consortium), it can provide information to the stakeholders (Wang et al., 2019). DLT also enables the integration of subcontractors, which selective EDI interfaces between company-related systems could not achieve (Koirala et al., 2019; Shahid et al., 2020). If smart contracts process the data, this is transparent and traceable due to the public and, if necessary, jointly validated source code (Chang et al., 2019; Eggers et al., 2021; Loebbecke et al., 2018). DLTs also ensure permanent traceability through unchangeable transaction logs. EDI, in contrast, can provide traceability between partners, but this cannot be guaranteed for up- and downstream partners if the data exchange has to go beyond the point-to-point interface. An exception is the use of a third-party clearing center (Singerling et al., 2015).

DLT can partly address the deficit for multiple individual point-to-point interfaces by enabling collaborative access to a decentralized database through a single network node (Islam & Kundu, 2019; Kshetri, 2018; Sund et al., 2020). While DLT offers the potential for disintermediation through decentralization, it can still be coordinated by a third party if necessary. A limiting factor of DLT is the so-called trilemma concerning the properties of scalability, security, and decentralization. For example, Ethereum is completely decentralized and secure but has corresponding scalability problems concerning transaction speed (Sund et al., 2020; Xue et al., 2021). Nevertheless, both solutions require coordinated data structures, which may not meet all partners' needs, necessitating further data processing (Agrawal et al., 2021; Kshetri, 2018). Again, DLT only partially addresses the deficit of a centralized approach because it requires organizational coordination among all parties involved.

Lastly, the deficit of insufficient consumer involvement within the information flow applies (Martinez et al., 2019). DLT can improve consumer involvement, as shown by market examples like Provenance and Everledger, which document and share SC steps, e.g., creation, processing, and transport of wine, with consumers (Kshetri, 2018). To provide this SC information, e.g., companies set up an application that can potentially be applied to other products and commodities to address the challenge of growing ethical and environmental concerns. Although the garbage-in/garbage-out problem for certifications such as "FairTrade" needs to be considered (Chang et al., 2020; Kshetri, 2018; Shahid et al., 2020; Wang et al., 2019). Here, the decentralized approach offers easier access to information on SCs, thus addressing this deficit positively.

Resource requirements

The last category in terms of the data exchange comparison covers the resource requirements. Both approaches aim to digitalize manual work steps, e.g., paper-based communication processes are replaced to avoid costs (Bergeron & Raymond, 1992). DLTs further automate work steps through smart contracts, allowing direct work on shared data and offering more flexibility (Chaouni Benabdellah et al., 2023; Reddy et al., 2021). However, this is offset by DLTs' potential transaction- and energy costs of the consensus mechanism (Reddy et al., 2021).

Furthermore, the literature does not address the deficit of reduced communication overhead of EDI. Li and Zhou (2020) refer to the faster data availability for the platform participants by creating the same data stock on all participating nodes of the network as soon as a consensus is reached. However, this also means that transaction data

that is irrelevant to a company is also stored on its node (Beck et al., 2020). DLT has less communication overhead by requiring only a single interface to the network, unlike multiple point-to-point EDI interfaces that are error-prone, unless a clearing center is used (Gaur & Gaiha, 2020; Kshetri, 2018). Here again, the DLTs can provide a solution when the scalability is considered (Kshetri, 2018).

The second deficit relates to the costly implementation of EDI applications for small and medium-sized enterprises (Beverungen et al., 2021; Shahid et al., 2020). Here, DLTs offer easier access to stored information, but participating in the network via a full network node and implementing smart contracts involves necessary knowledge. Furthermore, the initial implementation of a DLT also generates costs for hardware, software, and organizational restructuring of the targeted processes. While subcontractors might gain easier access, operating companies face these costs (Beverungen et al., 2021; Shahid et al., 2020). As mentioned above, a company must possibly become part of several DLTs, e.g., process industry goods that are relevant for different SCs (Ou et al., 2022). Furthermore, in public networks such as Ethereum, fluctuating transaction costs due to emerging costs via so-called gas fees have to be considered (Shahid et al., 2020). In terms of costs, DLT provides no solution, although we could not derive exact cost estimations from the sources. Due to the novelty of DLT, and the corresponding lack of expertise, there is no standardized implementation of DLTs and could therefore be subject to higher costs, e.g., within pilot and implementation projects (Stahlbock et al., 2018).

Future usage

In the following, the second comparison concerning future usage of the centralized and decentralized communication architecture is carried out. Here, an analysis according to the support of modern concepts, e.g., IoT-connected devices that trigger orders, is conducted (Hippold, 2022).

A centralized communication architecture under EDI faces limitations in integrating modern technologies like IoT, hindering their ability to address shared tasks within SCs, e.g., utilization of valuable data such as temperatures and vibrations from IoT devices (Eggers et al., 2021). This also applies to considerations of integrating IoT-connected devices that can trigger order processes independently (Hippold, 2022). Although EDI can communicate IoT data according to the definition of data conversion and normalization, this takes place, including storage, and processing, within centralized system structures (Banerjee, 2019; Imburgia, 2006). Within this context, another limitation applies, as it is necessary to communicate and process the relevant sensor data via the defined interfaces and then initiate a reaction. This is time-consuming, as the data from a large number of sensors has to be checked and then communicated if it is relevant and requires a response (Banerjee, 2019; Imburgia, 2006). Here, if sensor data is out of defined values, it needs to be communicated and stored. Centralized solutions fail to efficiently manage such devices, particularly when data is stored outside the company (van Sinderen et al., 2013). DLTs provide a solution by implementing decentralized storage of the collected, relevant data and management of IoT devices with the help of smart contracts. Here, smart contracts can react to changing sensor data, e.g., temperature levels during transportation or storage of goods, by executing a predefined reaction, e.g., generating a warning message. However, this reaction can only take place after the data has been saved onto the DLT (Sund et al., 2020; Wang et al., 2019). In addition, the direct, decentralized availability of the data can enable a correspondingly short response time. This can improve both responsiveness and forecasting based on the shared information (Sund et al., 2020; Wang et al., 2019). Nevertheless, DLT scalability is crucial due to increasing transaction volumes from the amount of IoT devices (Koirala et al., 2019). Furthermore, oracles facilitate data transfer to DLTs, offering a solution to EDI's limitations in integrating modern technologies (Caldarelli et al., 2020). Provided it is a scalable DLT, the deficits in current SC communications can be addressed.

Additionally, the automation potential that can be realized in centralized solutions for inter-organizational data exchange is limited. The provision of processed data for other companies is associated with conversion and transmission (Narayanan et al., 2009). Smart contracts address this issue by processing data from the jointly validated database and executing actions based on event-driven data (Kshetri, 2018; Li & Zhou, 2020). Added transaction data triggers smart contracts since it follows an if–then logic within the defined source code (Sund et al., 2020). This real-time data processing, triggered by transaction data, eliminates the need for batch processing and manual steps, thus realizing time advantages over current solutions, which require an additional communication process (Eggers et al., 2021; Sund et al., 2020; Wang et al., 2019). Therefore, smart contracts also can eliminate the need for manual processing steps (Eggers et al., 2021; Kshetri, 2018; Wang et al., 2019).

Finally, technically and legally unresolved aspects that limit the support for SC laws and regulations, such as Germany's Supply Chain Act and the Rotterdam Rules, apply. Under the Rotterdam Rules of 2008, electronic documents can be used as an alternative to transporting documents, provided they are unique, transferable, traceable, and have integrity (Stahlbock et al., 2018). EDI cannot guarantee fraud-proof document identification, as digital documents can be duplicated without tokenization. In contrast, DLTs use unique tokens to meet these criteria, offering secure, immutable transaction logs, e.g., transport documents, and

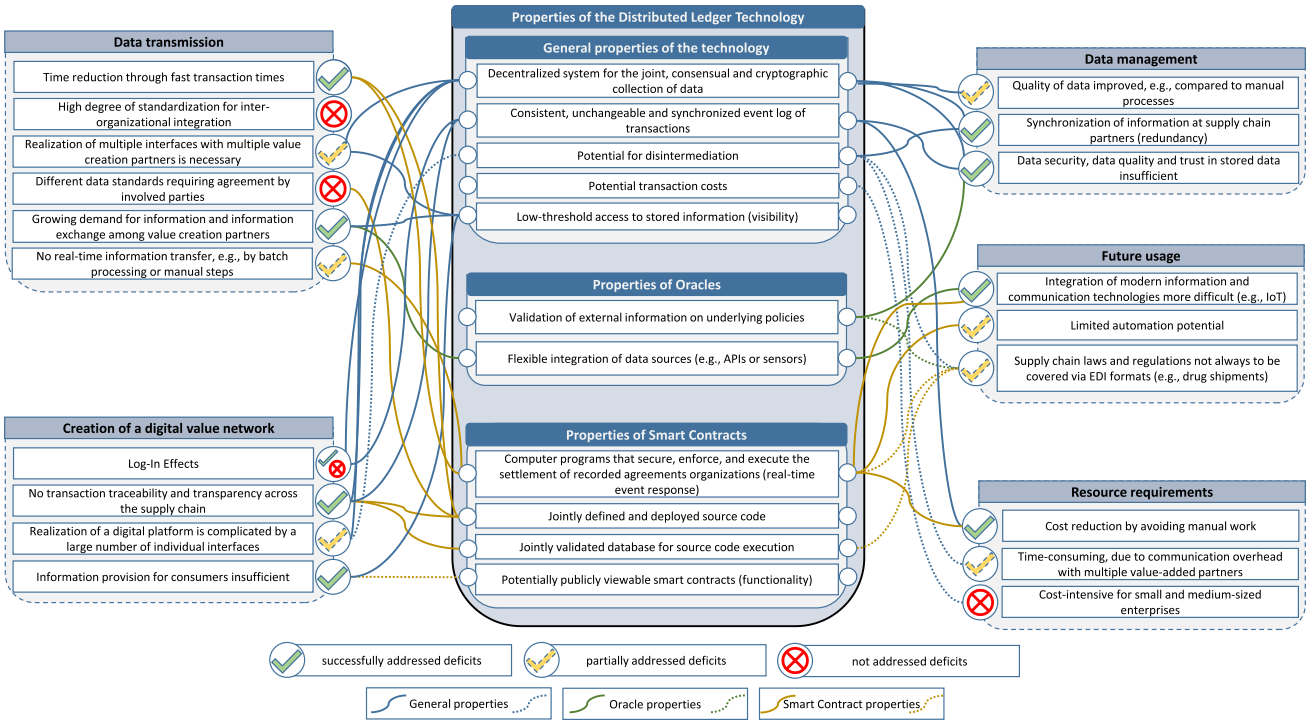

Fig. 5 Illustration of addressed factors of current EDI applications by DLT properties

thus making them transferable (Stahlbock et al., 2018). The immutable stored transaction log addresses the other requirements. However, due to legal constraints, the full disintermediation potential of DLT cannot be realized. In contexts such as medical SCs or international trade, regulatory bodies, e.g., customs authorities, must still be involved (Stahlbock et al., 2018). The firmly defined structure of smart contracts and their inevitable execution of the source code also pose legal challenges (Eggers et al., 2021). Therefore, while DLT has the potential to allow inter-organizational data exchange beyond current possibilities, unresolved technical and legal issues remain a limitation.

Figure 5 summarizes how DLT, along with complementary technologies like oracles and smart contracts, addresses identified factors in the current state of electronic data transmission in SCs. Green check marks indicate fully addressed, red crosses indicate unaddressed, and yellow check marks indicate partially addressed factors, such as where smart contracts improve automation over EDI but have limitations, like if–then logic constraints. The addressed factors are linked to their corresponding properties.

Discussion

In the conducted analysis, we identified SC communication problems within company-related information systems connected by EDI and explored whether the decentralized approach of DLT provides a remedy. In this section, we critically examine the results in two steps. First, we assess to what extent DLT improves upon the current status quo and meets open SC needs (Phase III; I.). Second, we will discuss whether integrating EDI within a DLT can create synergies for further improvement (Phase III; II.). Finally, we derive open research needs (Phase III; III.).

While current SC communication solutions connect company-related information systems through EDI, they face limitations such as inflexibility, data redundancy, and lack of real-time communication (Markus & Buijs, 2022). In contrast, DLT impacts this status quo by offering decentralized data storage, enhanced security, and real-time data processing, which can overcome these limitations by avoiding information asymmetries between SC partners and improving process automation (Beck et al., 2020). However, the lack of standards and inadequately defined use cases contributed to the failure of DLTs (Finke et al., 2023a). Here, company-related information systems connected via EDI show strengths due to their well-defined processes and standards (Hill et al., 2009). To advance research, there is a need to establish DLT standards for inter-organizational collaboration, as these are currently missing. Integration with existing EDI systems could provide established standards and expertise. Our study indicates that while DLT, smart contracts, and oracles can optimize SCs, detailed design science knowledge is lacking, particularly regarding company collaboration on DLT and added value for all stakeholders.

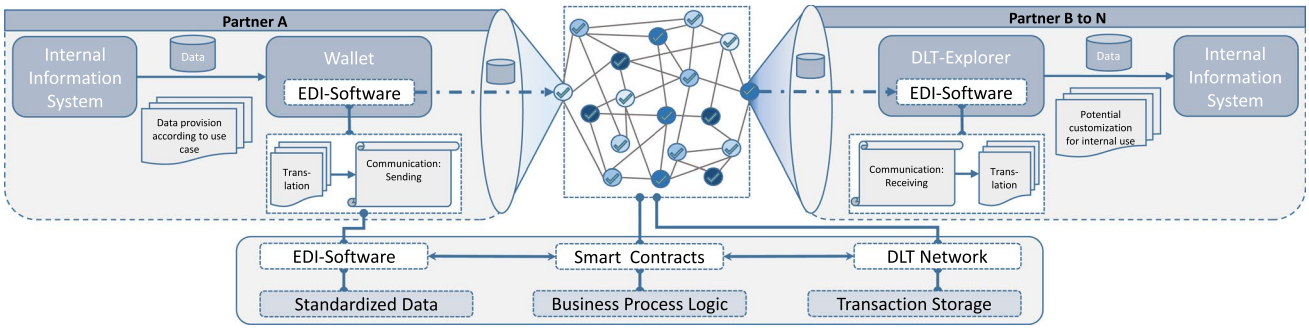

Fig. 6 Schematic representation of the potential Integration of EDI in the Context of a DLT

Here, practitioners should implement pilot projects, like IKEA's use of DLT in SC events, to test the feasibility and benefits of DLT in specific SC processes. Feasibility studies can identify appropriate use cases by ensuring support for smart contracts, IoT integration, and scalability. The integration of DLT with existing systems and processes to ensure coordination of inter-organizational with internal processes is essential. Use cases should also determine what information needs to be exchanged beyond companies by solving the garbage-in/garbage-out problem (Finke et al., 2023a).

Synergy through integration of EDI into DLT

Following these implications, we discuss the impact of DLT on EDI, building on the prior analysis (Phase II.). Additionally, we discuss data exchange formats within DLTs, particularly emphasizing the potential integration of EDI. This discussion is supported by a literature review conducted on EDI and DLT integration to strengthen the findings from our earlier analysis (Appendix 7).

Our analysis reveals that current centralized EDI applications have limitations, causing research and practice to investigate alternative solutions. Here, DLT contrasts with current solutions and is often seen as a replacement for EDI. However, since EDI and DLT address SC challenges with distinct focuses, EDI does not necessarily need to be replaced, despite discussions in the research community (Fiaidhi et al., 2018). Replacing EDI is further complicated because organizations have invested in current EDI applications, which have become essential for their inter-organizational data processing as these are embedded in internal business processes (Hill et al., 2009). This challenges the transition to new technologies like DLT, despite potential benefits. The reliability and high degree of standardization of EDI practices contribute to the difficulty of replacing them (Fiaidhi et al., 2018).

Despite its flexibility in integrating various data types, DLT's lack of communication standards seems to be a disadvantage. DLT solutions are currently developed for specific processes, e.g., tracking of products, document management, or customs, often lacking universally applicable standards, e.g., used gossip protocols (Finke et al., 2023a; Finke et al., 2022; Gao et al., 2022). The absence of uniform standards leads to missing interoperability, complicating complexity management and making integration more challenging (Helo & Hao, 2019). Although EDI was designed to connect company-related information systems, it can also be implemented in a DLT by providing a structured framework and leveraging existing expertise, ensuring continuity and reliability in existing SC processes (Jovanovic et al., 2022; Kim et al., 2023). Thus, integrating both technologies offers possible synergies that provide chances for their joint evolution beyond the technology-related capabilities (Straßengüterverkehr, 2020; van Hoek, 2020).

Figure 6 illustrates a potential architecture where EDI software is embedded in a wallet to enable communication by providing standardized data for established SC processes. The data is then stored on the DLT, where smart contracts can process it according to underlying SC business process logic. The results are then accessible to authorized SC partners (Fiaidhi et al., 2018; Helo & Shamsuzzoha, 2020). EDI automation limitations could be addressed by smart contracts that could process the standardized EDI data. Additionally, only a single interface to the DLT is needed to connect with all relevant SC partners. However, this approach could risk improving the complexity of the solution, potentially leading to increased requirements for expertise and higher costs.

Research directions of DLT usage in SC

Despite the potential benefits of DLTs for optimizing SC processes, both science and practice must address the associated open questions (see Fig. 7).

The first question addresses the design of a DLT platform, including its consensus mechanism, access types (public, private, consortium), and potential integration with EDI structures. This also involves adapting existing processes to DLT and facilitating inter-organizational collaboration on a

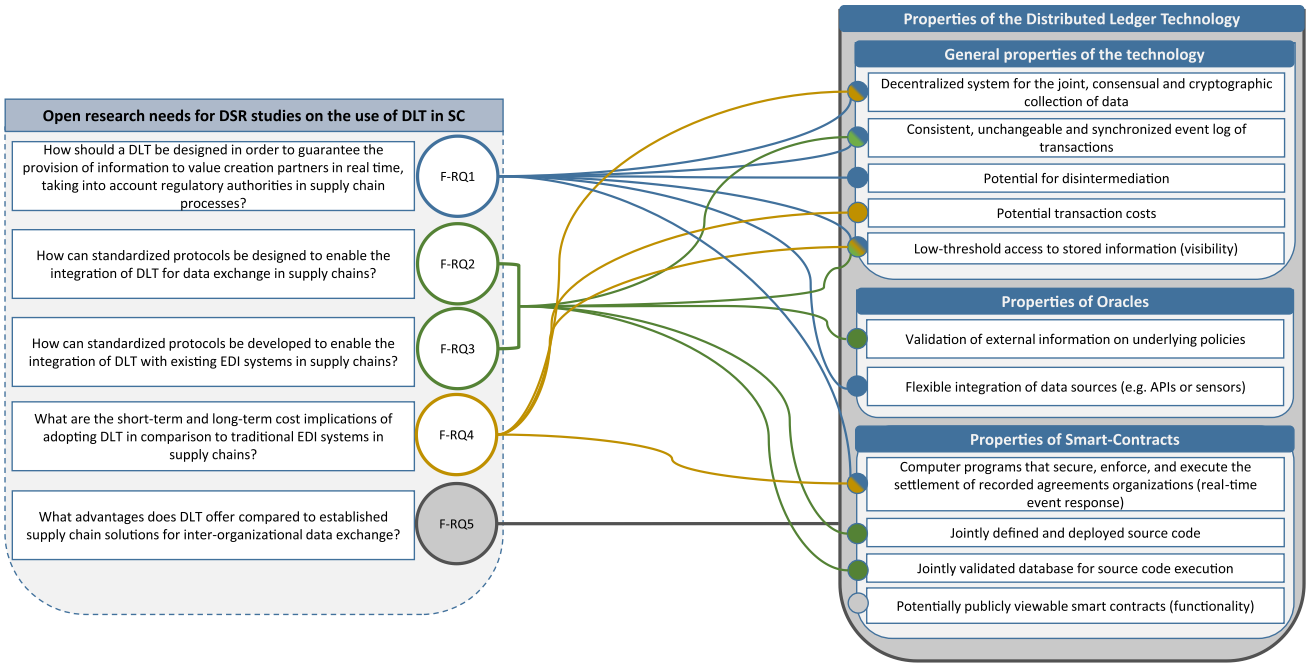

Fig. 7 Derived open research questions taking into account the analysis results

shared data platform (F-RQ1). Key issues are the development of communication standards for DLT in SCs (F-RQ2) and its integration with existing centralized systems (F—RQ3). Ensuring interoperability and defining standards are crucial for integrating DLTs into current systems. Finally, evaluating how implemented DLTs improve inter-organizational data exchange, including cost savings and efficiency gains (F-RQ4, F-RQ5), is essential for a more precise comparison against current solutions.

Conclusion

The following section contains the concluding remarks to summarize the presented results concerning the research questions. Furthermore, the limitations of the work are pointed out.

Summary of the results

We identified that implementing DLT in SCs is a subject of investigation within research due to its inherent characteristics. EDI as a connector between company-related information systems has also addressed this aspect since its introduction in the 1980s, but due to its rigid structure, it is only partially suitable for meeting growing information needs and flexibly linking business partners. Switching from a centralized architecture with EDI to a decentralized architecture with DLT could address the problems of a large number of necessary interfaces, a lack of real-time communication, and an inflexible database according to information needs. Furthermore, using smart contracts offers automation potential on a decentralized data basis, which was previously impossible via company-related data silos. However, it has become apparent through the analysis of the research papers in the context of research question two that the use of DLT can certainly resolve concretely defined problems in existing system landscapes for data exchange in SCs (e.g., IKEA or Walmart), but is subject to its limitations, e.g., trilemma, of the technology or missing standards for implementation and communication. Therefore, we have discussed integrating EDI with DLT, as this could create synergies that support existing business processes in a decentralized context and provide automation potential through smart contracts. Within research question three, we formulated open research questions from our research on the concrete design of DLTs, especially concerning the development of communication standards, as well as reviewing the cost–benefit of DLTs compared to established structures.

Limitations and future perspectives

As with any research paper, there are limitations to our work, particularly concerning the research design presented. First, methodological decisions in Phase I of the procedure meant that potential literature was not taken into account, as only English and German papers, as the languages spoken by the authors, were analyzed. Furthermore, the databases

available for the study also limit the completeness of the entire literature. Second, the qualitative methods used according to Mayring (2015) (content analysis) and Webster & Watson (2002) (concept matrix) could be affected by subjective interpretations. This may have resulted in a lack of information necessary for recording the status quo of the centralized information systems approach of current EDI applications (RQ1) and the decentralized approach of DLT as well as their comparison (RQ2). Lastly, the comparison may present a methodological limitation, as the examination of the SC literature could have been more extensive to identify further SC requirements addressable by each technology. However, the broad search strings for both EDI and DLT aim to mitigate this. A higher level of abstraction might reveal further results, yet our structured comparison offers valuable insights by identifying limitations in current SC support, analyzing DLT's potential to provide adequate solutions, and, thus, discussing implications, e.g., a feasible integration of EDI within the decentralized framework of DLT. Here, both technologies primarily enable inter-organizational collaboration and communication, and this analysis specifically highlights the SC shortcomings of current EDI usage that DLT can address. It should be noted that the decentralized architecture of DLT offers solutions that could extend beyond the data exchange capabilities of centralized systems, e.g., the management of IoT devices, which could enable a broader applicability of DLT. The comparison in Phase II is also subject to limitations, as it focuses exclusively on EDI and DLT as respective enablers of the centralized and decentralized communication approach in SCs. Other potentially relevant SC technologies that may offer further information are not considered. Moreover, while we have made EDI and DLT comparable by reviewing them as enablers of their respective approach (centralized vs. decentralized), it is important to note that, EDI, as a message standard, and DLT, as a decentralized network, provide different solutions. Furthermore, while DLTs show potential in addressing current SC problems, their ability to meet requirements is uncertain due to their technological maturity, e.g., DLT is still being piloted in SC use cases (Finke et al., 2022). Notably, many DLT solutions have failed, as seen with companies filing for insolvency in 2021 due to a lack of inter-organizational standards (Finke et al., 2023a). For instance, TradeLens was shut down in early 2023 due to insufficient participants (A.P. Moller - Maersk, 2022). Last, Phase III highlights a limitation, as a literature review revealed a lack of research on integrating EDI within DLTs, especially regarding the integration process and the added value for existing operations. Additionally, there is no information on how this integration might ease the implementation of DLT in current SC processes.

Despite these limitations, our paper provides an entry point for using DLT in SCs by analyzing specific problems in traditional inter-organizational collaboration. While both approaches facilitate collaboration, DLT's multifunctionality allows it to address additional use cases in SCs based on this. Furthermore, integrating both technologies could create synergies, addressing their respective weaknesses. For instance, EDI provides certain defined standards and use cases, leading to better integration of established EDI-based business processes into DLT. However, there are research gaps concerning design science knowledge of DLTs in SCs, especially concerning EDI integration within DLTs, which should be addressed. Also, further research could address the limitations by broadening the scope of the literature review and accessing a wider range of databases. Additionally, a quantitative procedure could be carried out to increase the robustness of the results. Nevertheless, our paper allows a targeted entry into this design science research area, practical studies with prototypes need to investigate the benefits and the challenges of DLT implementation in SCs, to examine the cost-effectiveness of DLT deployment in SCs. In particular, efforts should be made to develop inter-organizational standards for DLT, as the lack of such standards has led to the failure of initiatives such as TradeLens. Here, existing advantages of EDI should be considered, as the experience from its supported business processes could also support the implementation of DLT. Addressing these open issues could enhance our understanding of DLT deployment and its further development, effectively resolving the identified limitations in inter-organizational collaboration.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12525-024-00750-y.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data Availability All data supporting the findings of this study are available within the paper and its Supplementary Information.

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