Blockchain and the Physical Internet

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Integrating triple bottom line (TBL) goals into supply chains (SCs) is a challenging task which necessitates the careful coordination of numerous stakeholders' individual interests. Recent technological advancements can impact TBL sustainability by changing the design, structure and management of modern SCs. Blockchain technology enables immutable data records and facilitates a shared data view along the supply chain. The Physical Internet (PI) is an overarching framework that can be applied to create a layered and comprehensive view of the SC. In this conceptual paper I define and combine these technologies and derive several high-level research areas and research questions to investigate adoption, management as well as structural SC issues. I suggest a theory-based research agenda for the years to come that exploits the strengths of rigorous academic research, while remaining relevant for the industry. Furthermore, I suggest various well-established theories to tackle the respective research questions and provide specific directions for future research.

Keywords: Blockchain ; Distributed Ledger Technology ; Physical Internet ; Supply Chain Management ; Research Framework ; Innovation ; Information Technology ; Triple Bottom Line ; Sustainability

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1. The PI and the Blockchain

Figure 1 presents a layered framework that integrates the PI with the Blockchain. The seven layers of the model are based on Treiblmaier et al. [1]. The lowest layer, modular containers, deals with the creation of modular, ecologically sound, robust, lightweight and scalable containers. The next layer is about vehicle usage and optimization, which includes sharing of transportation means, ensuring full loading, energy efficiency and the use of relays. The following layer deals with the creation of modern and open transit centers that offer a fully functional design and provide effective and efficient cargo handling. Seamless, secure and confidential data exchange can be achieved by open, shared and secure protocols as well as mechanisms to regulate data access. A legal framework is needed to ensure legal security, which is especially important in cross-border transport. Cooperation models deal with the equitable sharing of revenues and, finally, specialized business models can be built that fully capitalize on the strengths of the PI resulting from previous layers.

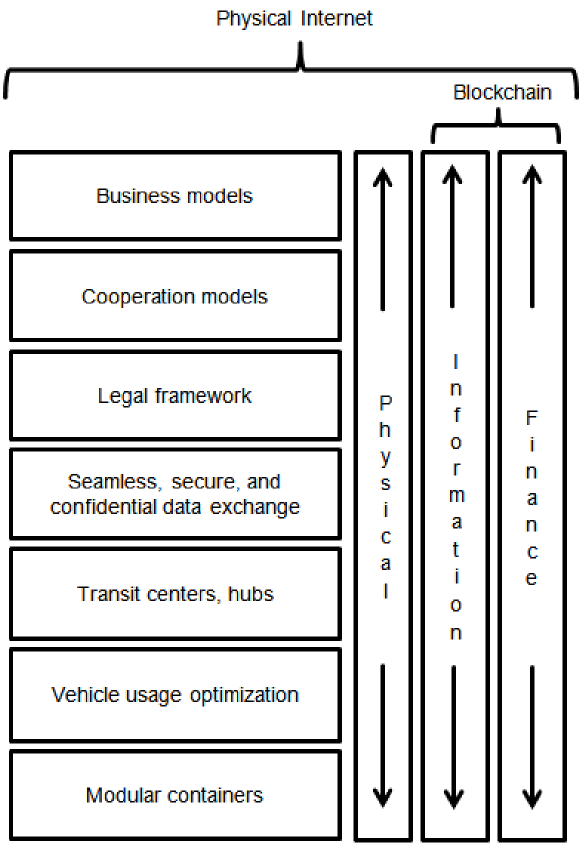

Figure 1. A Layered Logistics and SCM Research Framework

On the right side of Figure 1 the physical as well as informational and financial flows are shown. The physical supply chain is made up of the flow of products, while information and finance flows play key supporting roles. The flow channels span all PI layers and play an important role on each respective layer, as well as in connecting different layers. The Blockchain affects both non-physical layers, namely the flow of non-financial information as well as financial information in the form of payments. Figure 1 thus presents a framework that integrates different perspectives on logistics and SCM as well as the accompanying flows. It is noteworthy that, similar to the Internet protocol TCP/IP, improvements in each layer can be made without any need to consider adjacent layers, as long as the respective interfaces are taken into consideration.

1.1. Research Areas and Research Questions

In the following sections I briefly outline core research areas and corresponding research questions to provide guidance for future studies. All questions are presented at a relatively high level of abstraction and it is up to individual researchers to further specify and operationalize them. In other words, many interesting ideas can be found between the lines and the respective research questions can and should be refined as the technologies improve and new research results emerge, on which further research can be built. Similarly, the suggested theories can be modified as needed and, at times, even the application of a single theoretical approach might suffice [2]. The research questions are clustered in blocks, starting with explanation/prediction and followed by prescription, the latter of which I have labeled as action research in order to highlight the fact that these activities are directed toward practical outcomes and characterized by interactions between researchers, subjects and the context. I will start with research into adoption, followed by structural and managerial topics.

1.1.1. Diffusion of Innovation and Technology Adoption Research

Systematic research on the diffusion of innovation (DoI) started in the 1960s with the synthesis of a multitude of diffusion studies by Everett Rogers and the identification of key elements (innovation, adopters, communication channels, time, social system), innovation characteristics (relative advantage, compatibility, complexity, trialability, observability), stages of the adoption process (knowledge, persuasion, decision, implementation, confirmation) and adopter categories (innovators, early adopters, early majority, late majority, laggards) [3]. Many concepts from DoI research were later combined with behavioral research (e.g., Theory of Reasoned Action (TRA), Theory of Planned Behavior (TPB)) and resulted in a multitude of parsimonious (e.g., Technology Acceptance Model (TAM)) or rather complex models (Unified Theory of Acceptance and Use of Technology (UTAUT)), which investigate technology adoption (TA) from various angles, considering a wide variety of antecedents as well as numerous mediating and moderating variables. The theoretical underpinnings of these models are extensively discussed in the academic literature across several domains and shall not be reiterated here. Accordingly, previous research has already suggested the application of concepts from DoI or TAM to investigate Blockchain [4] and PI adoption [5]. Care has to be taken, however, not to blindly apply the TAM or one of its many derivations without taking into account the idiosyncrasies of the Blockchain or the PI. I therefore suggest the differentiation of two different adoption research streams, the first one focusing on the characteristics of the respective technologies and the second one on the characteristics of the adopting organizations.

The main characteristics of the Blockchain are immutability, transparency, programmability, decentralization, consensus, and distributed trust. Introducing such a technology into a company not only poses a major challenge during the implementation phase, but frequently also requires significant structural and procedural changes. Similarly, the characteristics of the PI can be directly derived from Figure 1 and comprise modular containers, universal interconnectivity, container handling and storage systems, smart networked containers embedding smart objects, distributed multi-segment intermodal transport, a unified multi-tier conceptual framework, an open global supply web, product design for containerization, product materialization near to point of use, open performance monitoring and capability certification, reliable and resilient networks, business model innovation and open infrastructural innovation [6]. The PI is an integrative concept, rather than a single technology, which spans the boundaries between companies and therefore also necessitates substantial changes within and between organizations. Accordingly, the respective characteristics have to be taken into account as a starting point for adoption research:

- **RQ- TA 1a.** How do Blockchain characteristics affect organizational adoption?
- **RQ- TA 1b.** How do PI characteristics affect organizational adoption?

Innovation adoption regularly happens within a context that is shaped by a wide variety of organizational characteristics. These can be defined as "features originating both from the management model adopted by the organization, through its structure or strategy, and from the company culture embodied in the nature of its membership and relationships" [7]. Additionally, existing inter-organizational relationships might impact the decision-making scope of an organization. It is therefore intra- and inter-organizational characteristics that influence the successful adoption of the PI as an overarching concept and the Blockchain as a novel paradigm for the exchange and storage of financial and non-financial information. Future research needs to identify those characteristics that play a major role in the adoption decision process as well as their level of impact:

- **RQ- TA 2a.** How do organizational characteristics affect Blockchain adoption?
- **RQ- TA 2b.** How do organizational characteristics affect PI adoption?

TBL sustainability presents a comprehensive goal system that comprises economic, environmental and social aspects. All three aspects contain a wide selection of subgoals that depend on the respective organization and its context. Organizational logic can be used to prioritize between the different elements of TBL and to create a goal system that follows a clear structure and potentially even an hierarchical order. For example, in their four case studies on sustainable supply chain use among social businesses in Haiti, Bals and Tate identified the following outcomes: financial support for customers, monetary flows back to the community (economic), closed-loop waste management (environmental), better educational outcomes, jobs for disadvantaged groups, funding of social projects, and community pride/commitment (social) [8]. Both the PI as well as the Blockchain have already been scrutinized regarding their potential to achieve high-level goals in all three dimensions of TBL. The PI was designed such as to increase the overall sustainability of SCs and inherently contains many economic, environmental and societal goals. The Blockchain is not only one of the major enablers of the PI, but also has the potential to realize benefits such as economic inclusion or a more sustainable economy. An application of a TBL-based sustainability approach therefore implies (a) the identification and operationalization of a goal system with relevant subgoals, and (b) the identification of suitable measures. Two broad research questions emerge:

- **RQ-TA 3a.** How does Blockchain adoption impact TBL sustainability?
- **RQ-TA 3b.** How does PI adoption impact TBL sustainability?

Action research, which was developed and described by MIT professor Kurt Lewin and the Tavistock institute, advocates research activities with practical impact. By following an action research approach, the practical implications of the research project are taken into account and success or failure represents an important part of the project. Given that the PI as well as the Blockchain are currently in a nascent stage of development, and that both of them strive to achieve goals of improving the quality of human lives, an action research approach is therefore frequently justified. The theoretical background can be provided, for example, by the design science research paradigm, which frequently contains prescriptive elements that outline how to best create a specific artifact. Given that the PI is the current framework for EU research funding activities, it is not surprising that the practical relevance of numerous research activities plays an important role and that the majority of PI-related research projects is conducted in close cooperation with the industry. Many research studies therefore describe or design practical solutions ranging from the development of modular containers to novel business models that foster inter-organizational cooperation and help to avoid unnecessary transportation.

Similarly, many academics investigate the design and implementation of Blockchain-based systems that help to solve pending logistics and SCM problems. Examples include the application of Blockchain technology to build secure and trusted environments for intelligent vehicle communication [9] or the provision of secure key management between heterogeneous networks to enable intelligent transportation systems [10]. Using the Blockchain as a core element within the general PI framework was previously suggested by Galvez and Dallari [11], who developed a shipment use case using Hyperledger Fabric. In this use case, the Blockchain supports three transactions that are embedded into the general PI-framework: auctions, exports & payouts, and custody. The authors conclude that a Blockchain-based PI infrastructure helps to address economic, environmental and social sustainability challenges in scalable, modular, and autonomous ways. Following an action research perspective that aims at TBL sustainability, two major research questions can be derived:

- **RQ-TA 4a.** How can the Blockchain be implemented to foster TBL sustainability?

- **RQ-TA 4b.** How can the PI be implemented to foster TBL sustainability?

1.1.2. Structural Research

Halldórsson et al. [12] suggested a new institutional economic perspective to investigate topics such as third party logistics and new product development within SCM. Their framework has previously been adapted to Blockchain-related questions [13]. Transaction cost economics (TCE) and principal agent theory (PAT) can be used to answer questions pertaining to the structure of SCs and to investigate them from different angles. TCE especially helps to answer the fundamental question of why firms exist and provides guidance regarding appropriate governance structures. The Blockchain is expected to significantly alter intra-organizational structures (e.g., by removing levels of middle management) and inter-organizational structures (e.g., by removing market intermediaries). The PI provides the general framework by specifying layered instances and a communication model between them, called an open logistics interconnection (OLI) model. Following the ISO/OSI reference model for open systems interconnection, the OLI has seven layers (i.e., physical layer, link layer, network layer, routing layer, shipping layer, encapsulation layer, logistics web layer), which receive services from their lower layers and provide services to their upper layers. All changes in the flow of goods and information induce a change in transaction costs that can be investigated using TCE.

PAT focuses on the relationship between a principal and an agent, both of which act in self-interest, but only the latter possesses all the relevant information. The transparency and immutability of the Blockchain alters information access and therefore reduces information asymmetry. For example, integrated supply chain ledgers in permissioned Blockchains allow trading partners to post on each other's ledgers. Again, the PI provides the broader framework and allows for an assessment of how SC innovations trigger intra- and inter-organizational structural changes. Related previous research has investigated the structural impact of the PI in numerous areas ranging from the design of vendor-managed inventories based on shared facilities and means of transport to PI networks that span 26 European cities in 9 countries [14].

A third option to investigate intra- and inter-organizational structural changes, which goes beyond the framework of new institutional economics, is Structuration Theory (ST). ST helps to understand how social systems are produced through social interactions. Based on the work of Giddens [15], it was later developed into Adaptive Structuration Theory (AST) by DeSanctis and Poole [16], who studied the interaction of groups and organizations with information technology. ST has already been recognized as a valuable framework for logistics and SCM research [17]. In that study, the authors used ST to discuss the adoption of the global transportation network by the US Department of Defense. AST provides new insights into SC research at the firm level especially when it comes to investigating the difficulties of using IT systems to drive systemic change [18]. Since the Blockchain and the PI presuppose the introduction of novel technology, the application of (A)ST might therefore lead to novel perspectives that especially consider social aspects of IT usage.

Given the three-fold sustainability goal structure of the proposed research framework, all structural changes also need to be assessed with regard to their economic, environmental and social implications. This brings forth the following two research questions:

- **RQ-ST1a.** How does Blockchain implementation impact the structure of the SC?

- **RQ-ST1b.** How does PI implementation impact the structure of the SC?

Action research strives to design and implement intra- and inter-organizational structures that help to create value chains which are TBL sustainable. For example, one of the outstanding features of the Blockchain is the possibility to allow shared databases access. This enables the creation of structures in which mutual interpersonal trust is replaced by trust in the system. Consequently, various layers of intermediaries whose main tasks are to compile and process information might be replaced or reorganized, which not only lowers total costs, but also optimizes delivery thus reducing emissions and improving quality of life in various ways. More generally, Blockchain-enabled solutions, namely improved auditability, immutability, disintermediation and smart contracts, can help to solve salient SC pain points: traceability, compliance, accountability and enforcement [19]. Similarly, simulations of PI implementation have illustrated its potential to improve value networks thus leading to decreased traffic and emissions and hence cost and energy savings [20]. Again, the overall goal is to create structural changes which explicitly consider economic, environmental and social implications. This leads to the following research questions:

- **RQ-ST2a.** How can Blockchain implementation create SC structures that are TBL sustainable?
- **RQ-ST2b.** How can PI implementation create SC structures that are TBL sustainable?

1.1.3. Management Research

Within the comprehensive new institutional economics framework, network theory (NT) and the resource-based view (RBV) can be applied to answer questions pertaining to the management of organizational structures [12]. Every comprehensive investigation of the Blockchain and the PI needs to also include managerial issues, since changes in the organizational structure or inter-organizational relationships are likely to impact management. The focus of NT is on the nature and quality of business relationships, which will presumably be altered by technological advances. The Blockchain can be seen as an enabler for increased transparency of information and trust (e.g., through the use of smart contracts) and the PI demands an improved information flow between different entities in the SC as a crucial prerequisite of value chain efficiency. RBV investigates the importance of organizational resources and how they can be used to stay competitive. The Blockchain constitutes a technology that can help to save costs and increase informational transparency by streamlining processes and removing intermediaries, while the PI provides the broad framework to scrutinize all SC-related technologies and processes. Both of them are likely to impact managerial issues and lead to the following questions which need to be investigated under consideration of TBL sustainability:

- **RQ-MA1a.** How does Blockchain implementation impact SC management?
- **RQ-MA1b.** How does PI implementation impact SC management?

The hype around the Blockchain has created a significant amount of interest especially among C-level executives. To a lesser extent this is also true for the PI, not least because the latter is propagated by the EU and several PI research projects have already been carried out jointly by academia and the industry. The Blockchain is mainly about the flow of information, while the PI also includes the flow of goods. In combination, Blockchain and PI strive to increase the speed and the transparency of these flows. The goal of design-oriented research from a managerial perspective is the design of systems that ensure data security and privacy while simultaneously providing management with the needed information in an aggregated manner. Further implications might include a shift in responsibilities as well as the emergence of completely new skill sets. Research is needed on how management can cope with the challenges of these new technologies:

- **RQ-MA2a.** How can Blockchain implementation support SC management?
- **RQ-MA2b.** How can PI implementation support SC management?

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