Towards the conception of a multi-chain to meet users' future needs: A design science research approach to digital servitization in the automotive industry

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Abstract

Recent literature claims that blockchain technology (BCT) has the potential to enhance interorganizational data sharing. Yet, in practice, BCT's implementation faces challenges which partly explain companies' reluctance to adopt BCT in their existing interorganizational environment. This is particularly striking in some economic sectors, such as the automotive industry transformed by the current digital servitization (DS) of the connected vehicle ecosystem; where traditional automotive businesses are being urged to collaborate with new ecosystem actors (e.g. insurance companies). With the perspective to tackle these challenges and promote the use of BCT at the interorganizational level, this article designs a BCT-based architecture based on Polkadot. Based on a Design Science Research (DSR) approach, we ensure alignment between the technological, interorganizational, and organizational dimensions of DS. Results are drawn from a dialogue with the connected vehicle ecosystem's actors as well as a literature review at the intersection of BCT design, DS, and data sharing. Overall, results contribute to the existing literature on BCT design, as they emphasize the potential of multi-chain BCT to structure interorganizational settings. Additionally, the study provides design principles for integrating BCT into data-sharing contexts like the one observed in the connected vehicle ecosystem. More specifically, this research emphasizes the suitability of multi-chain architecture in allowing a balance between the decentralization of public blockchains and the control of private blockchains.

Keywords: Blockchain technology, Design science, Digital servitization, interorganizational data-sharing, Polkadot.

Managerial relevance statement

This paper provides a detailed description of a multi-chain BCT prototype, presenting key insights into its development, and implications for replicability and adaptation in various interorganizational contexts. Specifically, this research develops a BCT-based architecture based on Polkadot for the connected vehicle ecosystem. This architecture enables secure and decentralized data sharing across a diverse range of actors, even beyond the actual consortium blockchains. The presented BCT-based architecture serves as a proof-of-concept for new interorganizational relationships, demonstrating how multi-chain BCT can facilitate interorganizational relationships while preserving autonomy in decision-making at the IT and strategic levels. The evaluation provided in the article aims at providing better-informed decision-making to companies regarding the adoption of multi-chain technology for digital service development and data sharing. Furthermore, the paper addresses current challenges in BCT use, offering four design principles to overcome the existing barriers to the practical implementation of BCT in interorganizational settings. Consistently, the paper sheds light on existing challenges in BCT implementation and collaboration and provides four design principles to address these issues effectively.

I. INTRODUCTION

In the actual digital servitization context [1], organizations must collaborate in their data management activities and practices where there is a shift from a product-centric to a service-oriented approach. Digital Servitization (DS) refers to the convergence between two trends, namely servitization and digitalization [1]. Specifically, it involves the use of technology to associate digital services to physical products. Data becomes a critical resource, and new partnerships for data-sharing are emerging with the help of advanced technologies. A significant example of this is the BlockChain Technology (BCT).

BCT-enabled systems can leverage enterprise data using secure transactions among third parties [2]. In this context, scholars and industrial experts raise new questions concerned with the economic value of such systems [3], depending in turn on the adoption of these new governance mechanisms for data sharing. To facilitate these mechanisms, recent insights focus on the design of BCT-based architectures, enabling the development of technical requirements to support and evaluate BCT integration for data quality and security (e.g., [4], [5], [6]). In addition, design science research on BCT has introduced user-centric requirements, such as understandability and usability (e.g., [7], [8]). This contributes to the conception of socio-technical devices that consider users' cognition, knowledge, and skills. Despite this emergent literature on BCT design, few BCT applications in data sharing are already available and used [7], especially in DS contexts. There is therefore an urgent need to transform the *"hype around blockchain technology into viable sharing economy applications"* [9]. This limited BCT adoption is hindered by the lack of BCT adaptability to current organizational and interorganizational landscapes, which frequently refers to a resistance to change in ecosystem design and behavior. This refers to the distinction between the famous bitcoin example and current BCT for DS project, as the latter is required to be more adapted to traditional organizational systems. Although existing beliefs that BCT can lead to a disruptive revolution, there is still a strong need for adherence to the current characteristics of application contexts, especially in these early stages of BCT exploration in interorganizational landscapes. Moreover, the structure of interorganizational relationships has to be studied in the context. For instance, DS differs drastically from supply-chain, which is characterized by established and rigid relationships between actors, with a manufacturing company typically taking on a pivotal role. By contrast, DS involves new relationships between actors, each of whom plays a pivotal role in their own respective sector (e.g. car manufacturers, insurers, banks). Because of this complexity, adherence is more difficult, and centralization with private and consortium BCTs seems not suitable. To fill this gap, this article seeks to ensure an alignment between three main dimensions characterizing DS ([10], [11]) : (i) technological, (ii) interorganizational, and (iii) organizational. Hence, this paper aims at replying to the two following research questions:

1) How can a BCT-based interorganizational system be aligned to established structure and processes?
2) What are nascent design principles of BCT-based data-sharing in DS?

In line with its main objectives, this paper follows a design science research (henceforth, DSR) approach (see, [12], [13], [14]) with the aim to provide both practical and conceptual solutions. Overall, it builds a BCT system applied to connected vehicles. In the connected vehicle ecosystem, economic actors are looking for the most appropriate BCT system to improve connected vehicles' data-sharing, considering the value of the given data in creating digital services.

Based on a multidisciplinary design science approach combining electronics and information systems management, this article collects qualitative data (produced mainly by a series of interviews with BCT experts) to inform prerequisites and organizational/interorganizational constraints perceived by industrial actors. This integrative approach enables us to not only examine the technical challenges of operational implementation but also to involve the ecosystem actors in the process of conception. Findings from interviews are also combined with a literature review and technical tests.

The originality of the paper lies in its theoretical and empirical ability to identify the technical specifications required for BCT-based data-sharing. Our proposed design objectives [15] concern both organizational and interorganizational contexts. To meet such objectives, a BCT-based architecture containing multiple individual blockchain implementations is provided. Accordingly, this article formulates four design principles [15], and contributes to the current literature in engineering management. More precisely, this paper scrutinizes the suitability of new types of BCT ledgers, design approaches, and in particular Polkadot [16], in satisfying current needs from businesses in terms of data sharing

The paper falls in seven parts: A state of the art is first introduced (Section II) before presenting the methodological framework (Section III). In line with the DSR perspective and as a result of collected data during semi-directive interviews, Section IV introduces the problem identification, while Section V outlines the needed requirements expressed by potential users. Accordingly, Section VI provides the architecture of a BCT system based on realistic requirements, and Section VII outlines its evaluation. Finally, Section VIII discusses the findings and highlights design principles.

II. FOUNDATIONS

A. *Digital servitization: the value of interorganizational data sharing*

Servitization involves a strategic transformation from a product-centric to a service-centric business model [17]. Digitalization refers to a change of mindset involving the use of technologies to support strategic shifts in creating competitive advantage [18]. Consistently, DS mainly implies the use of technological means (e.g., algorithms, sensors, smart devices) to develop or improve services around traditional physical goods (e.g., vehicles, fridges) [19].

The current trend of data-driven services perfectly illustrates how digitization and servitization are tightly linked [11]. As data is becoming the new gold for organizations in several sectors [20], current DS is mainly driven by the deployment of emerging technologies such as the Internet of Things (henceforth, IoT), and cloud computing. Emerging technologies enable more efficient data collection, processing, and application, thereby reducing transaction costs [21]. Consistently, interorganizational collaborations and partnerships appear as suitable solutions to foster data gathering, and analytic capabilities in more complex and dynamic environments. As a result, uncertainty in value capturing for traditional organizations can be reduced.

However, the integration of such technologies requires drastic and disrupting changes not only at the product architecture level, but also at the organizational structure level, regarding how the organization collaborates and makes decisions ([1], [22]). While technologies foster data sharing at the interorganizational level, new challenges appear in developing and maintaining collaborative environments. Such challenges relate not only to technical difficulties in integrating the technologies, but are also concerned with strategic and organizational resistance in developing a new way of coordinating and cooperating at the interorganizational level ([23], [24]). More precisely, to create value from emerging technologies, organizations undergo profound changes at the internal level ([25], [26], [27], [28]). Hence, DS requires a multi-dimensional transformation based on three main levels, i.e., technological, organizational, and interorganizational ([11], [10]).

B. Blockchain Technology: unlocking servitization around connected vehicles

Beyond their potential to facilitate the proliferation of data, emerging technologies also offer new ways to cooperate and collaborate, especially at the interorganizational level. BCT is one prominent example as it is defined as a decentralized, distributed database in which all maintainers of the blockchain possess identical data [29]. Storing data in such a network is more secured than in centralized “traditional" ones. Data set on the blockchain cannot be deleted or even modified. More precisely, blockchain is a specific type of decentralized ledger technology (DLT) which can be defined as a peer-to-peer system that implements an immutable distributed ledger of transactions. The blockchain consensus is a mechanism (i.e. commun agreement based on an algorithm) that ensures all copies of the distributed ledger contains the same data, contributing to the security and reliability of the blockchain network. This is achieved through protocols such as Proof-of-Work or Proof-of-Stake, which allow network participants to agree on the validity of transactions. The primary goal of blockchain consensus is to uphold the integrity and trustlessness of the blockchain, deterring malicious activities like double-spending, and facilitating secure, decentralized transactions.

The role of BCT in developing a disruptive trajectory for organizations toward servitization and new business models has already been highlighted in recent literature [30]. First, BCT supports all phases of collaboration by promoting coordination and reducing vulnerability between counterparts. It primarily provides a trusted environment in which uncertainty about partner’s behavior, and information asymmetry are removed or reduced through transparency, immutability, and automation [31]. Moreover, BCT ensures security to data by reducing vulnerability to hackers’ attacks. Second, while BCT can deliver cost reduction and transparency [32] to offer innovating services, its potential also refers to a new foundation for trust that lies in the characteristics of the technology instead of the quality of the service of a third trusted party [33]. Hence, the potential of BCT in shaping data sharing also refers to its integration with Internet of Things (IoTs). Today, the integration of IoT into BCT for DS is a central scientific and industrial challenge. IoTs are everyday objects capable of sensing, collecting information, processing data, and communicating with their environment [34]. With the explosion of these devices, standards and mandatory security features have become the priority for organizations. With newer BCT developments, the ledger also provides a layer of secure custom logic execution called "smart contracts" [35] (also called modules, pallets or transaction processors [16][36]). By contrast with a traditional paper contract, a smart contract is a digital program that can be used between two parties without trusting any third party.

There is a lot of BCT-based IoT systems applications as for example finance, healthcare [37], supply-chain systems [38] and also vehicle infrastructure [39]. This latter is a relevant comprehensive case study on how BCT can shape interorganizational data sharing. The automotive sector provides a viable empirical context to study the role of digital technologies in the implementation of intermediate and advanced digital services [40]. Various interorganizational collaborations are emerging around the potential of BCT for connected vehicles ecosystem. Thanks to immutability, decentralization and traceability, BCT creates a suitable data sharing environment for personalized services on the entire life cycle of a vehicle (e.g. maintenance, car-sharing, pay-as-you-drive insurance, second-hand car sales). A noteworthy example of the potential of BCT in the automotive industry concerns the automation of insurance processes in the case of an accident [41]. First, we have immutable time-stamped records of every accident data (e.g. driving behavior, vehicle condition, infrastructure status) on the chain. Second, smart contracts can activate the automatic execution of the insurance contract.

III. RESEARCH METHOD

A DSR paradigm is used to answer each research question ([14], [12]). This approach is suitable for solving current organizational and interorganizational issues related to the adoption of BCT technology in data sharing. It allows to design an innovative artifact ([13], [14]). As a result, this article is based on Peffers et al. [15] approach. They identify 6 steps to approach design issues in a "systematic" way: (i) *problem identification and motivation*, (ii) *definition of solution objectives*, (iii) *design and development;*, (iv) *demonstration*, (v) *evaluation* (vi) *communication*. More precisely, this paper is concerned with the second phase (②) of a larger DSR process (depicted in figure 1).

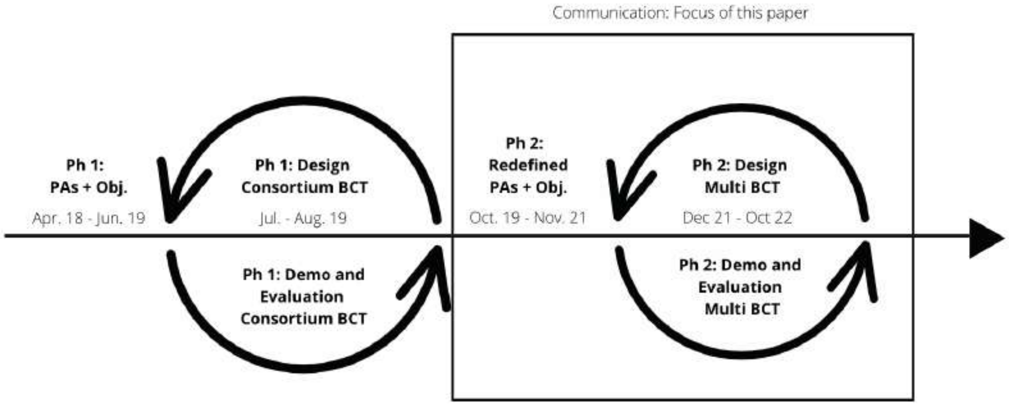

Fig. 1. Design science research process based on [15]. PA : Problem Area

This paper builds upon a prior DSR phase (phase ①) that examined data quality and security issues related to connected vehicles. Hence, both phases consider the same interorganizational data-sharing but phase ② enriches the problem areas [15] with new issues on the adaptability between BCT potential and current contextual characteristics. More precisely, in phase ①, a private BCT design was created ([41], [42]). The evaluation of the first design with experts made us realize that our problem areas were evolving. While being confronted with the features of this particular BCT, the experts were pointing out important issues that our first objectives were not addressing, leading us to phase ②. This phase refers to a second systematic process from step i to vi of Peffers et al. [15]' approach. Consistently, this paper outlines a completely different BCT architecture (based on Polkadot), showing its potential in solving BCT's adaptability problems.

In phase ②, we integrated recent expert opinions and experience for problem definition (step i). This phase results from individual semi-structured interviews with 19 experts [43] from October 2019 to February 2023. We interviewed the same experts of phase ① and complement these data with other experts' perception/opinion. Each interview lasted between 30 and 100 minutes and was recorded and transcribed. Table I provides an overview of IT and business experts participating to interviews in steps (i), (ii), (iv), (v) of Peffers et al. [15].

TABLE I

EXPERTS PARTICIPATING TO THE DSR PROCESS

Interviewed Experts	Expertise	Sector	PAs & Obj. identif.	Demo & Eval.
Interviewee 1	Business	OEM1	X	
Interviewee 2	IT	OEM1	X	
Interviewee 3	Business	Bank1	X	X
Interviewee 4	IT	Bank1	X	
Interviewee 5	IT	OEM1	X	X
Interviewee 6	IT	OEM1	X	X
Interviewee 7	Business	OEM2	X	
Interviewee 8	Business	Insurance1	X	
Interviewee 9	Business	OEM1	X	X
Interviewee 10	Business	OEM3	X	
Interviewee 11	IT	Fleet1	X	
Interviewee 12	Business	OEM4	X	
Interviewee 13	Business	Law1	X	
Interviewee 14	IT	Service1	X	
Interviewee 15	IT	Component1	X	
Interviewee 16	Business	Service2	X	
Interviewee 17	Business	Component2	X	
Interviewee 18	IT	Bank1	X	X
Interviewee 19	IT	Service2		X

We interviewed experts from different organizations specialized in connected vehicles, from component providers to new service providers (e.g., charging stations, peer to peer applications). All respondents actually work on BCT projects or have regular contacts with projects' members to discuss corporate needs. They all work in organizations that participate in at least one BCT project for sharing connected vehicle data. Moreover, we collected secondary data on project steering committees and regular reports. Complementary data also came from secondary data collection based on public releases from stakeholders. Finally, empirical data were strengthened by a literature review on BCT, DS, the automotive industry, and other interorganizational data-sharing contexts. This literature review has been crucial to identify, redefine objectives and address them.

The use case of a one-sided vehicle accident serves as the foundation for our prototype development. In accordance with experts' opinion, we use this specific use case to identify the necessary actors and transactions between them to create a higher level of realism during the prototyping phase. As a result, our prototype is designed with this use case in mind (see section VI) to ensure that the necessary tests can be conducted.

The use case includes not only a direct relationship between the insurance company and its insured, but also an interorganizational collaboration with Original Equipment Manufacturers (OEMs). OEMs are responsible for collecting and storing the data, which insurance companies then request in real-time in order to combine it with information pertaining to their insurance policies. Additionally, certain OEM branches are responsible for producing and delivering the connected vehicle. Consistently, this use case covers all problem areas and objectives, and ensures the itinerary between objectives and evaluation.

During the development process (step (iii) of phase ②), we based our choices and development on interviews and meetings with experts, but also on white papers, grey literature and conversations with developers specialized in the BCT (e.g. on GitHub, StackExchange). Furthermore, discussions with other computer scientists and IT scholars ensured a correct interpretation of BCT typologies and related prototype development. This process and its objectives are detailed in section VI. Accordingly, step (iii) of phase ② started with investigating different stabilized frameworks and BCTs. This investigation concluded with the selection of Polkadot and Substrate Framework. Consequently, the prototype was developed with a multi-chain (i.e. multiple blockchain technology) perspective (1 private blockchain for each organization (parachain), 1 public blockchain (relay-chain) for transactions).

Throughout evaluation interviews, we explain the prototype based on the use case of one-sided vehicle accident. We also extend the use case as we questioned the interviewees on the potential services around connected vehicles as a whole. A continual evaluation was put into place during the development process, and all feedbacks were assessed to validate the prototype, evaluate it, and enhance the solution. Consistently, the itinerary between definition of objectives and evaluation has been sustained even after the begging of Phase ②. In our evaluation section, we link the derived objectives to the prototype and evaluate the fulfillment based on empirical observation and theory-driven reasoning [44]. Moreover, through interviews, we assess the complex interaction between technology, interorganizational, and organizational dimensions [13] and verify the technological feasibility of applying the proposed design. Additionally, we contrast our BCT-based solution with the existing systems and BCT typologies. Subsequently, abstracting from the DS context-specific findings, we discuss our results and propose a multi-chain model, thereby expanding the current literature on BCT for interorganizational relationships, especially data-sharing.

IV. PROBLEM IDENTIFICATION

As described in the methodology section, the evaluation of the initial prototype (BCT consortium), pointed out the evolving nature of our problem areas (phase ①). While facing with the features of this particular BCT features, the experts underlined important issues that our first objective designs were not addressing, especially the adaptability to current interorganizational and organizational processes and structures. Therefore, this section provides a more comprehensive overview of the issues. It refers to the second wave of problem identification (Phase ②).

The lack of adaptability is also emphasized by recent literature on DS. For instance, Toth et al. [23] underline a constant emergence of pressures and tensions when DS requires significant organizational and interorganizational changes. Accordingly, our respondents outline how BCT reduces traditional blurred industry boundaries, and intensifies the complexity and dynamics of interorganizational environments. As a result, stakeholders need to find the best degree of decentralization, hybridization, interoperability to be easily deployable and reliable at the interorganizational level without congestion or high costs. They face adaptability issues in finding a suitable BCT application for current interorganizational data-sharing around connected vehicles.

In phase ①, we identified problem areas (PAs) similar to [5], and [6]. Consistently, PA1 in table II summarizes the generic issues that make BCT a suitable system to ensure cooperation among organizations (e.g., data availability, data quality, reducing information asymmetry).

TABLE II

Identified problem areas of BCT integration in connected vehicles-based servitization

PA1	***Cooperation*** in DS, shared responsibility	Possible high cooperation with distributed leadership, reduction of opportunistic behavior challenged by current structure and processes
PA2	***Autonomy at the IT level*** for using current technology and integrate IT evaluation	Coexistance and complexity of information systems. Stakeholders have different information systems.
PA3	***Autonomy at the strategy level*** in selecting partners, data strategy	Low acceptance of dependence on other players' approval, resulting in the need for an individual strategy for openness to transactions. This concern also refers to a resistance to change in strategic positioning.
PA4	***Monetization*** for value partitioning	Need for automatic data monetization based on a transparent agreement between counterparties. Automatization needs to deal with complexity regarding intellectual properties and business models.
PA5	***Clients integration***: personalization , demand volume, and IT compatibility	Need for high level of flexibility in service offerings to ensure personalization. Clients' integration also requires adaptability to changes in demand volume, and communication between different typologies of devices (compatibility to clients' IoT systems).

Table II also suggests 4 other problem areas (from PA2 to PA5) that contribute to the literature by decomposing the present lack of BCT integration in a DS interorganizational environment. Our experts still struggle to find an appropriate BCT architecture, resulting in a lack of BCT integration. This latter mainly refers to recent changes due to the constant evolution of DS.

While problem areas PA2 and PA3 mainly concern issues at the organizational level, the other two (PA4 and PA5) rely on both interorganizational and ecosystem perspectives. The first two issues (PA2, PA3) concern the increased multiplicity of organizations around connected vehicles for DS (OEMs, banks, insurance companies, etc.). On the one hand, each organization's information system structure is distinct and the implementation of DS necessitates tailored modifications based on the type of actor. Therefore, as *"little by little the fact of being connected (DS) will lead to changes, and these changes should always be valid for BCT"* (I6), organizations require a BCT-based system that ensures *autonomy at the IT level* to employ their existing technological system and to integrate specific IT evolutions, while still allowing changes in the ledger (**PA2**). On the other hand, even though the DS calls for strong interdependence among organizations, they persistently prioritize autonomy in their strategic decision-making (Autonomy at the strategy level, **PA3**). For example, organizations require autonomy in data-sharing - *"some data is better not shared with others, and some data is better shared with others"* (I7). This issue is related to a low acceptance of potential dependency on other organizations' approval in a BCT-based setting. **PA4** refers to the value distribution issue among the organizations concerned with data-sharing. This issue is related to **PA3**, as automatic value sharing would address the complexity of intellectual properties and business models. In this sense, "*the objective is to bring the partners to communicate in an automatic way for which how to say the sharing, by regulating the remuneration which is a sticking point.*" (I6). Consistently, organizations do not only face the challenge of adaptability to the specificity of each actor but also the nature of their relationship. Finally, **PA5** refers to the high level of flexibility required in service offerings to ensure personalization. From this perspective, DS around connected vehicles requires customer integration from an interorganizational perspective [28]. First, the technology structure at the interorganizational level must adapt to changes in the volume of demand. Second, with respect to customer needs, relationships must evolve and also be different (with respect to rules, actor typology, etc.). Therefore, organizations require means to create and manage interorganizational relationships in a flexible manner. Put differently, I15 argues *"the business model of these services is really something tricky that we have to be as flexible as possible"*. In addition, such a PA also addresses the issue of IT compatibility between a potential interorganizational system and client devices. To sum up, **PA5** refers to the central role of clients (drivers and vehicle owner) in data sharing. The interorganizational relationship "*depends on the choice of the customer. It will be to each user to adhere to a dedicated network*" (I6).

V. DESIGN OBJECTIVES

The formulation of design objectives results from the combination of two sources of information, related to the literature (connected vehicles, interorganizational collaborations, BCT-based IoT, DS), and interviews' data collection. The literature review ensures the generalizability of empirical insights [5].

At the design level, the literature already provides technical objectives to support and evaluate BCT integration for data quality, and security ([4], [45], [5], [6], [46], [41], [47]). This strand of research identifies design-level goals for solving problems in a specific case. Additionally, current design research on BCT includes a set of requirements covering user-centric needs, such as understandability and usability (e.g., [7], [8]). In this case, findings introduce design objectives to conceive a socio-technical device, taking into account users' cognition, knowledge and skills. However, this literature lacks requirements for BCT adaptability to current organizational and interorganizational landscapes (e.g., IT modularity, traditional coordination), especially for the automotive sector. This set of requirements emerges from the interviews with experts and current literature on DS ([1], [10], [48]).

We identified a total of 20 design objectives and classified them into 3 typologies considering the type of information sources [5], namely *information sharing*, *information auditability and security*, and *industry-specific requirements*. We also reported for each design objective whether it aims at creating an appropriate shared information system across organizations (interorganizational level) or ensure organizational involvement (organizational level). Each typology is composed of interorganizational and organizational design objectives.

The first typology, *Information sharing* concerns the use of BCT features to mainly improve data and information sharing between companies [49]. The latter relies on the BCT adaptability to both interorganizational and organizational environments. Consistently, on the one hand, five design objectives have been identified to support data sharing for DS. On the other hand, we derived two design objectives, consistent with the need for IT flexibility and strategic autonomy at the organizational level. We also identified an interdependence between organizational and interorganizational goals. As an example, the *heterogeneous data handling* implies the *channel adaptation*, because in order to achieve a highly *heterogeneous data handling*, first, a *channel adaptation* is needed. The *channel adaptation* can be considered as technical implementation in the IT infrastructure and the choice of communication protocols, which can lead to achieve optimal interoperability in both organizational and interorganizational levels.

Regarding *auditability and information security* (typology 2), we identified two objectives for the interorganizational level, and two for the organizational one. In addition, three design objectives emerged across the two levels.

Finally, we derived 6 objectives *industry specific* by considering the specificities of DS around connected vehicles (explained in the next subsection). 2 of the 6 objectives concern the interorganizational level, 3 relate to organizational requirements, and the last one refers to both levels. Table III describes each objective and highlights the addressed problem areas.

TABLE III
OBJECTIVES

Level	Typology	Objective	Description	PAs
INTERORG.	Information sharing	Two-way Communication	Based on Guggenberger et al. [5], the system should promote transparency in service provision by enabling two-way information exchange between both B2B and B2C stakeholders (E. 4, 18)	PA3, PA5
		Timeliness of information	Consistent with Guggenberger et al. [5], Rapid information dissemination (time threshold) between organizations, as determined by the use case (E. 6, 18) [41]	PA3
		Channel adaptability	A generic data flow must be established to ensure consistent interorganizational communication and data processing, taking into account the heterogeneity of IT systems across organizations (E. 15, 18)	PA3
		Intellectual properties valorization	Valorize intellectual property in exchanges (E. 6)	PA4
		Low cost data exchange	Operation costs (exchange) have to be as low as possible [5] (E. 6, 16)	
	Information auditability and security	Integrity in data exchange	Prevent corrupted or malicious behavior in data exchange [4] (E. 6, 11, 16, 18)	PA3
		Confidentiality	Treat private data in a confidential way [5] (E. 17)	
	Industry specific	Adaptability to interorganizational changes	Support future changes at the interorganizational level (e.g., ecosystem dynamics) (E. 5, 6, 15, 16) [5]	PA5
		Predefined autonomous data processing	Enable trust between organizations and protect against malicious actors, a system of autonomous contract execution and data processing is needed. (e.g., vehicle accident reporting [41], [42]) (E. 6, 14)	PA3
INTERORG. & ORG.	Information auditability & security	Data Availability	Guarantee continuous availability of data [5]	PA3
		Data consistency	Ensure data quality by enabling accurate data entry by also guaranteeing the autonomy of data providers in terms of strategy and business (E. 8, 15, 16, 18)	PA3, PA2
	Industry specific	Audit logs	Provide traceability and audit logs for conflicts and legal issues. [5] (E. 4, 7, 13)	PA3
		Graphical user interface	User-friendly interface providing valuable information to organizations [5] (E. 6)	PA3, PA5
ORG.	Information sharing	Heterogeneous data handling	Enable a high degree of IT agility in producing and delivering data to organizations [4] (E. 1, 2, 6, 14, 18)	PA1
		Intellectual properties management	Allow intellectual property management at the organizational level (E. 6, 15)	PA2
	Information auditability and security	Integrity in data storage	Avoid data storage corruption or individual modification by actors (E. 6, 15) [45]	PA3
		Personalized confidentiality and access control	Support different levels of confidentiality and access control to meet the needs of organizations' strategies and offerings [45] [28] (E. 6, 9)	PA2, PA5
		Adaptability to organizatonal changes (IT, business)	Adaptation to organizational changes at the IT, business and strategic levels (E. 5, 6, 12, 15,16) [28] [50] [27]	PA1, PA2, PA5
		Personalized business logic automation	Provide customized automation based on organizations' business and processes (E. 4, 6, 8, 15)	PA1, PA2
	Industry specific	Low cost implementation	The cost of the system to the organization should be as low as possible (direct and indirect costs) [5] (E. 16)	

VI. DESIGN AND ARCHITECTURE OF A MULTI-CHAIN SYSTEM PROTOTYPE

This section focuses on the development of a prototype, that meets the design objectives reported in Table III.

As stated by Guggenberg et al. [5] and Lock et al. [6], current literature shows that intrinsic blockchain characteristics can provide a shared ledger, data immutability, transparency, and on-chain custom business logic execution by the use of smart contracts. However, the use of

BCT in interorganizational contexts, particularly in the automotive industry, remains limited. Traditional BCT (public and private) do not meet several essential objectives described in Table III, such as multi-chain two-way communication, channel adaptability, heterogeneous data handling, intellectual properties management, or adaptability to organizational changes.

The emergence of new approaches is leading to a shift from existing closed-network BCTs to more open interoperable BCTs, enabling interaction and cooperation among blockchains, users, and devices across numerous blockchain networks.

TABLE IV
COMPARISON OF DIFFERENT MULTI-CHAIN INTEROPERABLE BLOCKCHAINS

Technology	**Initial apparition date**	**EVM compatibility**	**Specific blockchain development**	**Interoperability solution**	**Architecture Topology**
Polkadot	2017	Possible	Substrate Framework	XCM	Relay-chain, parachains
Cosmos	2016	Yes	Comos-SDK	IBC	Zones, hubs, blockchains
Avalanche	2020	Yes	Avalanche-cli	AWM	Three blockchains and Subnets

Cosmos BCT is a network of multiple blockchains interconnected by the Cosmos hubs. The Cosmos hubs contain different "zones" that maintain a zone state. IBC (Inter-blockchain Communication) is the communication protocol used to exchange messages between blockchains. Blockchain bridges can provide interoperability for cryptocurrencies by using two one-way communications (one for each BCT).

Avalanche is a blockchain platform that operates on a Proof-of-Stake consensus protocol and is designed with a unique architecture consisting of three chains: the Platform Chain (P-Chain) for network coordination, the Exchange Chain (X-Chain) for asset transfers, and the Contract Chain (C-Chain) for Ethereum-compatible smart contracts. The communication between the connected blockchains or "subnets" is performed by the so called Avalanche Wrap Messaging (AWM).

Polkadot is built using the Substrate blockchain framework and its purpose is to relay messages (Polkadot is a relay-chain) between multiple Substrate-based blockchains (parachains). The Cross-Consensus Message (XCM) is a message format for its associated protocol, the cross-chain communication protocol of Polkadot. The Polkadot ecosystem has standardized this XCM communication format. This format allows parachains to exchange messages between the relay-chain and parachains and between parachain themselves through the relay-chain. The resulting implemented interoperability protocol is called XCMP.

We propose and implement a prototype based on the novel multi-chain technology Polkadot along with the Substrate framework [51]. Put differently, we implement an interconnected multi-chain environment.

The choice of Polkadot to be applied in our use case over the technologies shown in Table IV, is due to the fact that at the time of the start of our development Avalanche network was not yet stable, and Cosmos platform had not provided a fully functional inter-blockchain communication. Moreover, Polkadot had already proven early potential for similar use cases with multiple active parachain development (e.g., involving blockchain interoperability).

Our prototype relies on two typologies of BCT, i.e., relay-chain, and parachain. The relay-chain, i.e., Polkadot [16][1], is a public relay-chain that allows communications between any other

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[1] Polkadot was founded by Gavin Wood (a co-founder of Ethereum) alongside by co-founders Peter Czaban and Robert Habermeier in 2016.

blockchain becoming a parachain thanks to a process called *parachain slot auction*. It is called a *slot* auction because each auction chooses a period which the parachain is authorized to be connected to the relay-chain and benefits from this latter's features. The parachain slot auction is executed on the Polkadot relay-chain, making the process friction-less, decentralized, and acting as a DAO (Decentralized Autonomous Organization). The organization that reflects the whole community behind Polkadot decides which Substrate-based blockchain is to become a parachain.

Parachains, short for parallel chains, is a type of blockchain that can operate in parallel with other chains by handling transactions and smart contracts. The block production, consensus, and smart contract are specific to each parachains. A shared consensus mechanism (GHOST-based Recursive Ancestor Deriving Prefix Agreement, **GRANDPA**) between relay-chain and parachain provides finality (i.e. make blocks and transactions immutable and permanent).

Based on the use case of one-sided accidents, we now detail hereafter the design and development of our prototype. We therefore, focus on a specific digital service around connected vehicles to demonstrate that the prototype can answer the challenges raised in this article. We have two main organizations involved, the OEM (Original Equipment Manufacturer) and the insurance company. The driver has a key role in allowing data-sharing between organizations. interorganizational data-sharing refers to the accident report. Figure 2 therefore outlines the use case implementation with parachains and relay-chain.

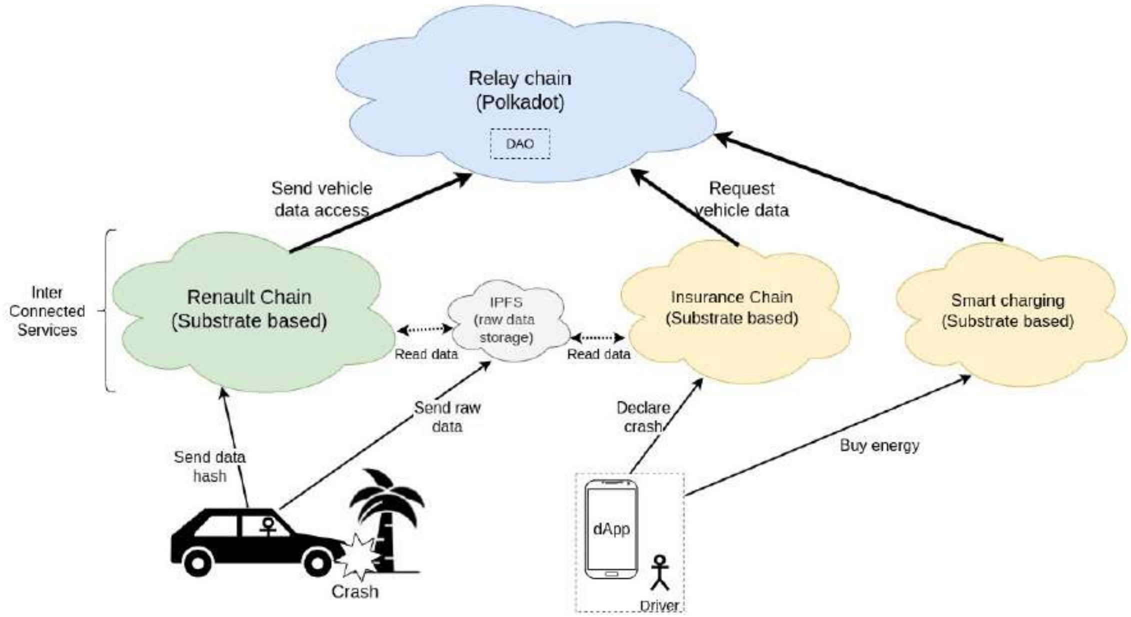

Fig. 2. One sided vehicle accident use-case based on Polkadot ecosystem

The design is as follows:

- Two specific parachains with the Substrate Framework. One parachain that represents the OEM, and another parachain for the insurance company.
- One relay-chain interconnecting and securing all BCT parachains. It validates transactions (data-sharing about the accident report), and finalizes blocks.
- Smart contracts are coded in Rust language, i.e., substrate module, and executed in the parachains.
- The prototype front end application is coded in React.Js (User-Interface framework for web applications). The front end application will connect to the parachains WebSocket API and

interact with the smart contrats.

Detailed interactions between all actors of the use case are depicted in Figure 3. With a total of four different smart contracts, we grouped the interactions smart contract actions (in yellow). In the OEM parachain, an OEM administrator first registers an OEM branch identity (step 1.a.). The OEM branch then registers vehicles in the parachain (step 1.b.). For a vehicle to be able to send accident reports, it must first declare itself to the OEM parachain (step 1.c.). This declaration serves as a basic check process to ensure the vehicle can access and write only after verification. After declaration, vehicles can send crash reports in the case of an accident (step 1.d.).

In the Insurance parachain, drivers can subscribe to an insurance company (step 2.a.) and report an accident to their company (step 2.b.). A driver reporting an accident to its insurance company initiates a cross-chain request towards the driver vehicle OEM to request vehicle data (in purple, the interactions using the relay-chain). The OEM processes the data request (step 2.c.) and if authorized, the OEM sends a cross-chain message back to the insurance company with the data location (step 2.d).

We can notice that the interactions between the OEM and the insurance company are automated, encoded and predefined by the parachains smart contracts; the relay-chain is the secure trusted third party between these two BCT.

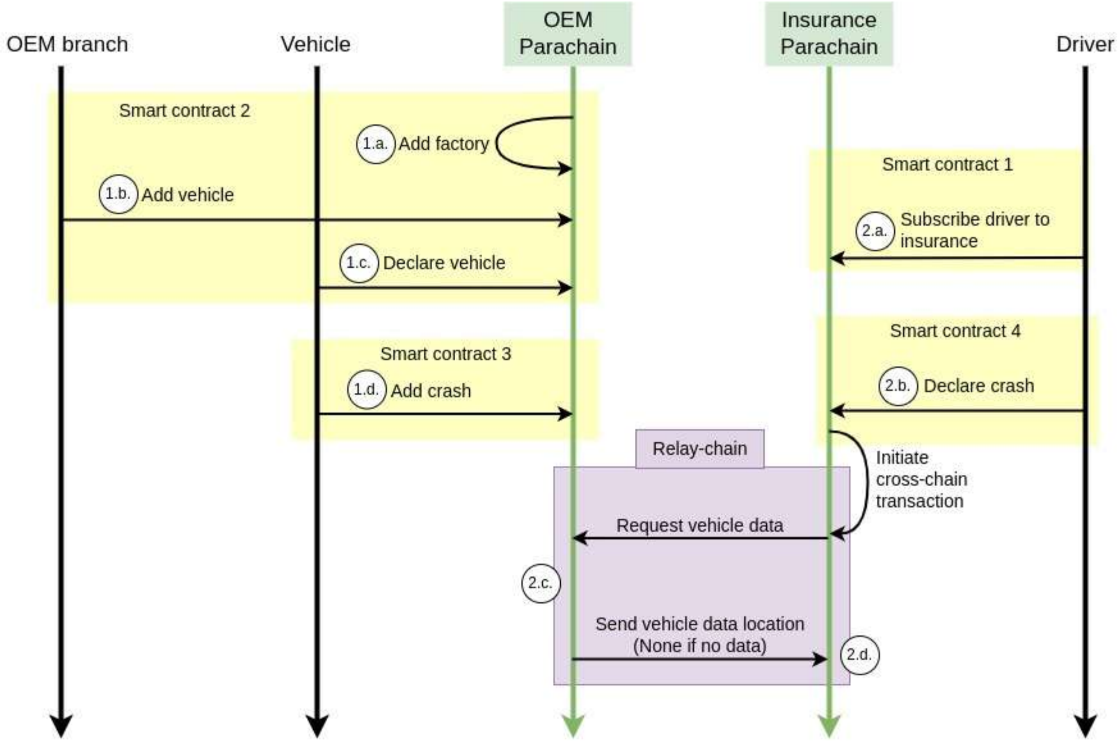

Fig. 3. One sided vehicle accident use-case interaction flow

The prototype OEM's parachain has two smart contracts (i.e. custom modules in Substrate) that provide the necessary business logic: one to manage vehicles and the other one to report accidents. The reported accident data is: i) a unique identifier (ID) generated from the raw data (i.e. *sha256* data hash); ii) an accident ID that is a composite key using the vehicle ID and the accident index. Similarly, the prototype insurance's parachain has also two smart contracts which: i) allows to manage drivers subscriptions, ii) allows to report accidents to the insurance, and automatically request accident data to the OEM, if necessary.

It is important to notice that the prototype is composed of three different BCT (two parachains, one relay-chain) and that a vehicle sends data only to its manufacturer and not directly to the insurance. Each organization has its own chain, smart contract, data, and state. With this shared consensus, the state of the entire ecosystem is evolving at the same rate.

The prototype is setup and tested using Kubernetes container orchestration system and multiple benchmark scripts. The Kubernetes cluster is configured with 3 worker hosts, totaling in 192 reserved vCPUs and 283 GiB reserve memory, all hosted in a cloud service. The use case configuration is as follows: the relay-chain comprises six validator blockchain nodes (Polkadot version: *polkadot-v0.9.24*), while the OEM and insurance company parachains (based on *substrate-parachain-template*) consists of one to three collators. Both the validators and collators are configured with 20 GB of RAM and 8 virtual CPUs. The relay-chain and parachain RPC endpoints are implemented as Kubernetes ingress endpoints, which distribute (round-robin style) requests to the validator and collator services, respectively.

In our prototype, we take advantage of a relay-chain derived from the Polkadot Rococo testnet [52]. It is not required to setup a private relay-chain. However, if we intend to transition this prototype to a production environment, certain necessary modifications will need to be implemented within the parachains to align with the standards of Polkadot's production-ready relay-chain. Throughout the prototype's development phase, economic aspects, including coins or tokens, were not considered, as they fall outside the defined scope of our technical-focused research. In this early stage, parachains were manually integrated into the relay-chain by an administrator (using Rococo *sudo* module). To put a parachain into production and be connected to Polkadot relay-chain, it has to follow a distinct procedure (i.e., *parachain slot auction*).

VII. EVALUATION

We presented the prototype in detail to the experts and asked them to reflect on the fulfillment of the design objectives. We also asked them to assess the prototype's suitability in shaping data sharing. Thus, we discussed the strengths and issues of the prototype generally and with respect to a unique BCT consortium. To do so, we focus on a one-sided accident, and other potential digital services. This evaluation is supplemented with tests and measurements to provide a comprehensive assessment. We evaluated the performance of our prototype implementation by considering the one-sided accident use case, and exploring its limits and capabilities. The benchmark of the prototype involves setting up a new relay-chain and parachain network and initializing it by sending transactions to register an OEM branch, vehicles, and drivers.

Overall, experts emphasize that our prototype could enable collaborations. The interconnected multi-chain environment of our prototype, which is necessary for achieving the desired objectives of *channel adaptability* and *heterogeneous data handling*, can be technically referred to as "*blockchain interoperability*". Several strategies exist to enable the interoperability between different BCTs, each providing a different solution with varying levels of success and performance. In addition to Polkadot, other specific blockchain technologies or bridges are available such as Cosmos BCT [53] and Avalanche platform[54].

We chose Polkadot technology as the best suited for DS thanks to its shared security (multi-level consensus rule), blockchain core development modularity, and reliable cross-chain communication (design objective: *data consistency*). Furthermore, the Polkadot and Substrate Framework projects have progressed to a point where their stable software versions can be used to test transactions per second and develop a client program. The interorganizational objectives in Table III are also satisfied with the governance of a Polkadot multi-chain model, compared to Cosmos. Similarly, blockchain bridges work mostly for cryptocurrencies, but not for generic smart contracts. This makes them unsuitable for our vehicular use case, as it requires interorganizational information exchanges, i.e. *two-way communication*.

More precisely, the prototype considers differences in devices and IT structures around connected vehicles. On the one hand, the prototype fosters collaborations because, depending on the case study, different parachains can be deployed. *"There are different blockchains and one or more different blockchains can be exploited depending on the use case"* (I3). On the other hand, this prototype may facilitate a step-by-step integration of use cases, enabling the automotive and mobility sectors to join a unique relay-chain and thus increase cooperation and coordination at the ecosystem level. It might be noted, that each organization will have its parachain that can be connected to the previously mentioned unique relay-chain. According to I5, the parachain allows to "*avoid the problem of hegemony*", a crucial challenge preventing the adoption of current BCT consortiums.

Regarding data-sharing, we then explore the accident use case to evaluate it. First of all, insurance companies (or more generally service providers) can access data on driving behavior and claim history to offer personalized policies and reduce costs for drivers. The prototype meets the objectives: *data availability*, and *timeliness of information*. Second, Transactions per second measurements (TPS) were performed in order to determine the prototype's performance. The TPS of a blockchain network is an essential performance factor for organizations considering the implementation of a blockchain-based system. It helps determine whether the network can handle the anticipated transaction volume without congestion or slowdowns, maintain low transaction costs, enhance user experience, and potentially confer a competitive advantage.

The analysis demonstrates the accident use case, which consists of sending transactions to the OEM's parachain for reporting accidents, followed by transactions sent to the insurance company's parachain. Finally, results are obtained by extracting all blocks from the start until all transactions have been processed and there are no pending transactions in the network.

The rate of transactions that are finalized within a parachain per second is referred to as the *output TPS*, while the *input TPS* refers to the number of transactions sent to the parachain. It is worth noting that the prototype utilizes specific smart contracts, the use case interactions are encoded into these smart contracts code. The code can be written and optimized in different ways. It is important to consider that the performance results are strongly dependent on the interpretation and optimization of the implementation. The TPS metric aims to describe the interaction throughput limitation of the prototype, and the observation of the average output TPS histogram (Figure 4) shows that the OEM's parachain can handle up to 1500 input TPS without any transaction rejections. However, the OEM's parachain is limited to an average maximum of 45 Output TPS, thus the transactions are stored in a temporary queue and then executed and processed at a maximum rate of 45 TPS. The insurance company's parachain shows an average maximum Output TPS of 35, thus its parachain can handle less interactions per second. The blocktime indicates the latency for a block to be created and added in the blockchain. Figure 5 shows that the the average blocktime fluctuates around 15 seconds for either the OEM and insurance parachains. The block production is constant, the Input TPS doesn't impact significantly blocktime. The standard deviation shows that we sometimes can have occurrences of a higher blocktime: maximum 24 seconds for OEM and 26 seconds for insurance.

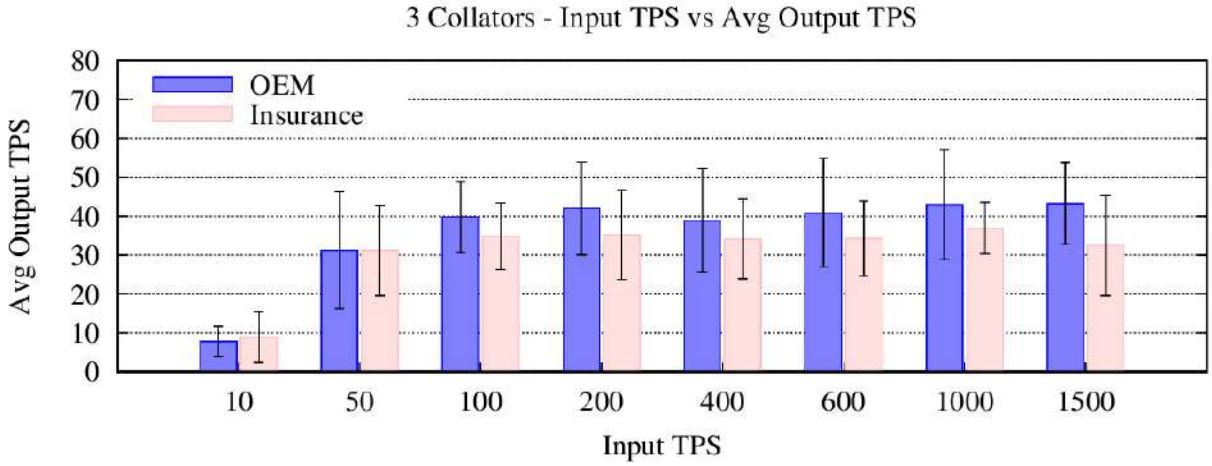

Fig. 4. Input TPS vs average Output TPS

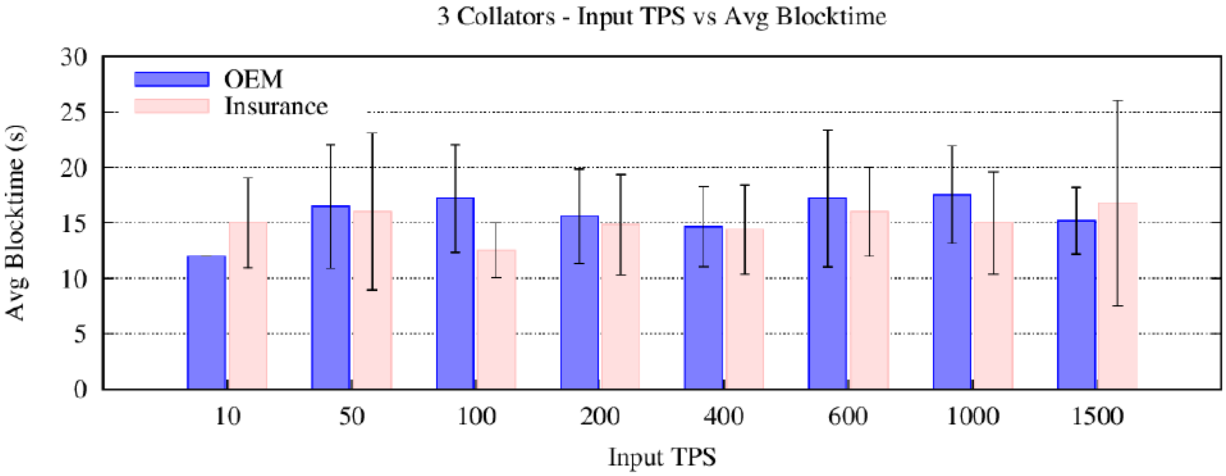

Fig. 5. Input TPS vs average blocktime

We evaluated these results with our experts who underlined the feasibility of our prototype for the specific case of accidents. However, experts also highlighted some issues in satisfying the objective of *timeliness of information* in other use cases. In other words, these issues depend on the characteristics of the digital services (use case) proposed. *"The problem that will appear, in my opinion, will be in the real-time part because, being a public blockchain, it could be slow. With accidents is ok for example, there will be a lot of data coming back, but well, it won't be every 4 seconds, but for certain types of other use cases, there will be a lot more feedback, and there I think we won't get there in terms of performance"* (I5).

The challenge of *timeliness of information* mainly refers to the fact of having a public blockchain instead of a consortium blockchain as relay-chain. This design choice may limit the number of digital services and the nature of the DS in the ecosystem, but it ensures decentralization, the "key potential" of the BCT. In particular experts stressed this important point: *"we need to go for the potential of the BCT, not just adjust the BCT to our traditional way of doing things, for example, with a private or consortium BCT with only control from traditional stakeholders"* (I19).

Continuing with the accident use case, we performed another test on the exchange of cross-chain messages. When a driver reports an accident to the insurance company, the insurance company will initiate a cross-chain transaction using XCMP to request vehicle accident data from the OEM. The time it takes for the insurance company to retrieve the data is the result of two XCMP messages exchanged through the relay-chain, which constitutes the delay in the exchange of the cross-chain message between the insurance and OEM parachains. Based on experimental results, the average delay for processing the insurance company's accident report transaction and retrieving OEM data is 1 minute and 20 seconds. The interorganizational *channel adaptability* is achieved by the generic cross-chain data XCM format and the prototype test shows that *two-way communication* is possible within a relatively small delay.

Moreover, the prototype ensures clients integration (PA5) by meeting these design objectives *"confidentiality"*, *"personalized confidentiality and access control"*, and *"two-way communication"* (I3, I5, I19). Specifically, the prototype applies different levels of confidentiality and access control in the parachains according to the clients' preferences.

Confidentiality, though not present in the prototype, can be implemented through the use of cryptographic techniques according to the organization strategy. In this vein, OEMs can use those data to monitor the performance of their vehicles, identify potential issues, and provide proactive maintenance on an individual basis thanks to the parachain. The prototype replies to the objectives: *"adaptability to organizational changes"*, *"personalized business logic automation"*. The prototype ensures a high level of flexibility in data management (from production to delivery), and allows a selection of data and partnerships, depending on the use case and nature of the data. For instance, I5 underlines that *"It's better to use multiple blockchains than a single blockchain consortium, which constrains everyone and allows for less data sorting, rather than, for example, we have data on the replacement of (vehicle) tires, and we send it directly to tire suppliers, who store the tires, but the insurance company doesn't know that he had a flat tire, so we're not necessarily going to share it with everyone"*. As a result, the "centralized data management" is one of the most appreciated feature of multi-chain. Consistently, the prototype offers greater autonomy at the strategic and IT level, compared to a single consortium blockchain, by keeping a high level of integrity and data quality (I3, I5, I18).

The prototype follows a certain logic to realize the use case. However, the logic can be updated thanks to the on-chain runtime features. Consistently, experts highlight reduced "impositions" between partners compared to a consortium blockchain based architecture. The same is outlined when evaluating the parachains' flexibility in intellectual properties management. Hence, the prototype satisfies the requirement of *flexibility in intellectual properties management* by also replying to the objectives of integrity at both organizational and interorganizational levels.

Regarding integrity, the fact of having both para and relay-chains ensures higher integrity in both data storage, and data sharing compared to an unique consortium blockchain. The parachain does not only ensure flexibilty at the strategy and IT level but also ensures traceability of organizations' data management. *"(With parachains) changes would not be possible, the hash would be modified and would be immediately apparent"* (I5). This advantage is also underlined while evaluating transactions' integrity in the relay-chain. For instance, experts highlight the importance of security of relay-chain *"because it is the one that acts as the "real BCT", not the other (relay-chain), that we will extract the real benefits"* (I5). These features meet to the objectives: *integrity in data exchange*, *integrity in data storage*.

Moreover, the relay-chain is a trusted intermediary for the organizations, and in the prototype, the relay-chain is locally deployed (operated by the researchers). However, in a production environment (real case scenario), the relay-chain validator nodes have to be operated by actors others than the parachain organization to prevent trust biasing. One possible solution is to create a decentralized autonomous organization (DAO) regrouping all parachains participants controlling the operation of the relay-chain network. This DAO would encode relay-chain rules, thus maximizing transparency and automation of the network (design objective: *predefined autonomous data processing*).

Last, it is worth assessing the cost to determine the prototype's practicality (objective: *low cost implementation*). Our prototype offers a compromise between private and public blockchains in terms of cost. Costs associated with our prototype can be divided into two categories: parachain costs and relay-chain costs. Parachain costs are required to operate and manage the servers hosting the parachain blockchain nodes. These costs can be removed completely by taking advantage of the parachain's modularity and adaptability. Relay-chain costs, however, are dependent on the implementation and refer to the costs of connecting and adding a parachain to the relay-chain's parachain list. Consistently, unlike public blockchains, where costs are fixed, our prototype is subjected to more volatility in terms of cost (relay-chain cost).

VIII. DISCUSSION OF THE FINDINGS

Our prototype demonstrates how a recently-developed multi-chain BCT can effectively propose a balance between the potential of BCT and the existing structures and processes at both intra- and interorganizational levels. Hence, the potential of BCT is guaranteed by also fulfilling current challenges in BCT integration for interorganizational data-sharing purposes [7].

Specifically, as it focuses on DS phenomena around connected vehicles, our prototype answers our first research question (RQ1). Compared to common case studies, such as the supply chain, DS refers to a greater diversity of actors, services, data, and relationships. This implies that we face a greater complexity in terms of established processes, practices at both strategic and IT level. As an alternative, our prototype offers a new institutional environment for data sharing [55] by also considering the established IT modularity, coordination and governance on which actors currently rely to provide digital services (it provides a solution to PA1, PA2, PA3 and PA4).

Polkadot ensures the disruptive potential of BCT (decentralization) by the relay-chain and by also taking into account the need for flexibility at both strategic and IT level. This means that we achieve adherence between technological, inter-organizaitonal and organizational dimensions of DS [10]. Compared to a consortium or private BCT, we still have decentralization and we propose data sharing in a peer-to-peer format instead of having an ecosystem actor or a group of actors dictating the rules. At the same time, the prototype includes the end-users (the driver) in the interorganizational relationships (PA5).

The design of our BCT prototype shares the GRANDPA common consensus mechanism (between relay-chain and parachains), which builds interorganizational trust. In addition, the GRANDPA consensus mechanism allows the parachains to work together and agree on the same state. By using this shared mechanism, all organizations involved in the DS can trust that the state of the entire ecosystem is evolving fairly and transparently, without any one organization having undue control or influence. With the previously mentioned "shared" consensus, the state of the entire ecosystem can evolve at the same rate, even if each organization has its own chain, smart contract, data, and state (I3, I4, I19).

Thanks to the DSR process followed in this research, we also formulated four design principles (DP). This replies to RQ2. These design principles refer to blockchain-based data sharing in an interorganizational setting :

1) **DP1**: Provide a high degree of adaptability at the IT level
   When BCT is integrated into existing intra- and interorganizational levels, a collaborative adjustment between existing IT systems and BCT is key. This requires the BCT archi-

tecture to optimize current operations while allowing participants to benefit from their current IT systems. Furthermore, with digital transformation being an ongoing process, participants need the flexibility to modify their offerings or processes at the IT level. Compared to private and consortium blockchain, a multi-chain technology provides higher IT adaptability since the given organization does not have to modify its infrastructure to be compatible with the existing private or consortium blockchain connecting the different organizations. The organization is therefore free to choose the IT infrastructure that meets its own requirements. With a multi-chain architecture, the organization can also more easily change its IT structure to accommodate future innovations at all levels of the organization.

2) **DP2**: Ensure a trade-off between decentralization and centralization
   This second principle refers to the challenge of balancing decentralization with traditional ways of operating. BCTs improve interorganizational relationships (e.g., it increases transparency and data security, and smart contracts can automatically execute transactions). Yet, their integration requires significant changes in organizations, not only at the operational level, but also at the strategic level. In this phase, where blockchain-based innovation is still in its infancy, a multi-chain prototype offers a valuable way to leverage the potential of BCT, while maintaining a high level of centralized data management (e.g. storage, selection of data to share). This design principle mainly refers to how our prototype addresses both PA2 (autonomy at the strategy level) and PA3 (cooperation).
3) **DP3**: Ensure flexibility to face uncertainty around data sharing
   Data analysis for improving offerings is still in its early stages, especially in the automotive industry, where organizations are uncertain of the value of data in modifying services or products. Compared to a private or consortium blockchain, our prototype offers a lower degree of inter-dependency between its members, reducing the need for approval of other members for the partnership's evolution and decisions. This design principle directly addresses PA5, favoring direct and flexible B2C relationships and facilitating the personalization of offerings.
4) **DP4**: Manage data valorization between different actors
   Today, data valorization is key and requires interorganizational cooperation. However, experts pointed out an information asymmetry regarding data value in interorganizational contexts. For instance, while car manufactures would be the main collectors of data, service providers are the ones knowing how to use such data to improve driving experience. Consistently, OEMs are reluctant in sharing data mainly because no systems allow them to ensure the right compensation for their activities in providing data. A relay-chain offers data monetization, compliance, and intellectual property management to ensure an interorganizational form of data valorization. For instance, smart contracts could trigger greater balanced compensation to companies based on the value produced by the service provider. This design principle mainly refers to PA4.

These design principles are intended to supplement, rather than replace, the existing design principles of other DSR on BCT in interorganizational data-sharing (e.g., [5], [6]), thus enriching them.

IX. CONCLUSION

The evaluation of our prototype showed that it was able to meet the objectives outlined by BCT experts and the literature. This article provides a blockchain-based architecture that enables secure and decentralized data sharing across a diverse range of actors, even beyond the actual consortium blockchains. The multi-chain architecture allows for a balance between the decentralization of public blockchains and the control of private blockchains. We believe this type of architecture can contribute to a shift in mindset among established organizations, which is a primary challenge to the adoption of BCT.

However, there are some limitations to our research. The performance benchmark of the system was based on a single digital service, with only two organizations and a limited number of nodes. This does not account for real-time communication between organizations needed for other types of digital services (e.g., car sharing) and thus limits the insights into actual system performance. Additionally, the use case was designed for a single sector, the automotive, which may not be applicable to other sectors and could produce different results. Therefore, we invite further research to explore designs that utilize other interoperable blockchains, and challenge and extend the current design principles.

Through our research, we have made several theoretical contributions. First, this research contributes to the current literature on BCT solutions for interorganizational environments or IoT ecosystems ([5], [6]), by proposing a more socio-technical perspective based on an attentive assessment of current processes, structures and dynamics. This paper focuses on novel typologies of BCT, namely multi-chain technology, which, to the best of our knowledge, the literature is still lacking a comprehensive overview and systematic understanding. Moreover, it provides empirical insights to the emergent literature on DS implementation ([10], [27], [28]). The article also empirically contributes to the existing body of literature on BCT and DS due to its focus on the automotive sector and digital services for connected vehicles [33]. This empirical context provides an in-depth understanding of more intricate relationships (compared to supply chain ones), leading to the development of new design objectives and principles.

This paper provides a detailed description of the prototype, including key insights of the development, and their implications for replicability and adaptation for other interorganizational contexts. In addition, it serves as a proof-of-concept for new interorganizational relationships, demonstrating how multi-chain technology can facilitate interorganizational relationships while preserving the autonomy in decision-making at the IT and strategic level. Overall, the paper's evaluation should enable companies to make better-informed decisions on the use of multi-chain technology for developing digital services or data-sharing.

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