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RAMI 4.0 and Smart Contracts: Sustainable Product Lifecycle Management in Knowledge-intensive Manufacturing Organizations

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Manufacturing organizations can be assumed to be knowledge repositories due to the excessive exchange of knowledge and information between humans, machines, and products. Activities are the building blocks of processes in any manufacturing organization, and knowledge is assumed to be an essential resource for any process to exchange value. Therefore, communication and exchanging the right information at the right time to the right process in a product life cycle are the key elements to running a smart manufacturing organization. In the current regime of big data and Industry 4.0, smart factories can work as knowledge repositories using smart contracts of blockchain technology. This paper represents the mapping of Reference Architectural Model Industries (RAMI) 4.0 and the hierarchical structure of the knowledge repository by addressing two agendas: 1) knowledge-related functions can be linked with the outer world within the RAMI 4.0 framework, and 2) blockchain technology via smart contracts can be used to link various processes within smart manufacturing factory.

Keywords: *knowledge repository, knowledge-related functions, blockchain technology, RAMI 4.0, smart contracts.*

Introduction

Organizations can be considered as knowledge repositories, which have been defined by Mustafa and Werthner (2008) as "…a site (physical or virtual, e.g., a domain on the world wide web), location (knowledge store like library, document storage room), computer, an entity or an organization to store, reside or locate knowledge for its reuse or redistribution over a network of actors (involved in an exchange of knowledge) through different channels". This definition uses knowledge repositories from both micro and macro perspectives. From a micro perspective,

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knowledge repositories can be visualized as a site, location, computer, human being, or entity, whereas, from a macro perspective, knowledge repositories can be visualized as an organization. The knowledge repositories retain tacit and explicit knowledge in different databases, including documents, tables, pictures, signals, etc. With computer science, engineering, and technology advancements, new technological paradigms have surfaced in the first two decades of the 21st century. Smart manufacturing and the Internet of Things are noticeable and radically innovative paradigms. Smart manufacturing relates to the Industry 4.0 regime, whereas the Internet of Things relates to Big Data. Recent research and development trends bring these under one roof, and now scientists are moving towards smart manufacturing in the wake of big data.

On the other hand, the fiat currency market has also been challenged by the latest hype of bitcoin cryptocurrency. Bitcoin, the first digital financial asset, was created by a programmer under the pseudonym of Satoshi Nakamoto. Bitcoin has been developed on top of blockchain technology. With every bit-coin transaction among participants, the record of past transactions is saved and locked in an immutable and scalable block. The essence of blockchain technology is to conduct transactions in a trustworthy manner in a trustless environment. The immutability, scalability, and trustfulness features make this technology a promising tool in the current scenario of Industry 4.0 and the Big Data regime.

The current paper aims to enhance discussion on two agendas: 1) The knowledge-related function of an organization can be linked with the outer world within the Reference Architectural Model Industries (RAMI) 4.0 framework, and 2) blockchain technology via smart contract can be used to auto-execute various processes within an organization. The current paper reflects an effort to provide an overview of how organizations acting as knowledge repositories can benefit from the developing technologies in the regime of Industry 4.0 and Big Data in the context of blockchain technology.

This paper is an extension of the work of Mustafa and Werthner (2008), proposing the idea of organizations as knowledge repositories and discussing the notion of knowledge-related functions in knowledge repositories and the role of knowledge-related functions in defining the business model of an organization. In this latest paper, it has been postulated that "How" knowledge-related function can be linked with the "functional and business" layer of RAMI 4.0 framework and what the potential use of blockchain technology can be. The major objective of this paper is to discuss the integration of RAMI 4.0 and blockchain through smart contracts in knowledge-intensive manufacturing originations. The paper also discusses whether the machines can communicate and self-execute the processes without human intervention.

The first part of the paper consists of a literature review of several concepts used in this paper. The second part consists of mapping RAMI 4.0 and the hierarchical structure of knowledge repositories (Mustafa & Werthner, 2008). The last part consists of the implications of this proposed mapping for industrial concerns and the final concluding words.

Theoretical Background

This section describes the earlier work (Mustafa & Werthner, 2008) on knowledge-based business models and the ongoing research in Industry 4.0 and blockchain technology. This section aims to build an argument that using blockchain technology within knowledge-intensive manufacturing organizations by using smart contracts helps to auto-execute various activities and processes. Since these processes and activities are the loci of creating value through creating and utilizing knowledge, the use of relevant information, which is stored as knowledge within the manufacturing organization in the form of databases, can be used to further design various codes and programs for self-automation of various activities in a knowledge-intensive manufacturing organization.

Knowledge-Related Functions and Knowledge Repository

Mustafa and Werthner (2008) proposed the concept of knowledge-related functions and knowledge repositories. The knowledge-related function comprises value-creating processes, and knowledge is the primary source of value creation. The knowledge repositories have been defined by (Mustafa & Werthner, 2008) in a micro- as well as macro-perspective as a physical, location, computer, entity, or organization to store reside or location knowledge for its reuse or redistribution over a network of actors through different channels. The knowledge repositories have been proposed to have a hierarchical structure with three layers: strategic, business model, and business process layer. The firm's knowledge-based view can be used to view the firm in terms of integrated processes for superior firm performance (Emery, 2002). Organizations can be decomposed into levels of functions, which can be further decomposed at the level of processes. The processes then can further be decomposed into atomic levels of activities; this virtual decomposition of the organization into functions, processes, and activities helps to identify the locus of the source of value creation within organizations.

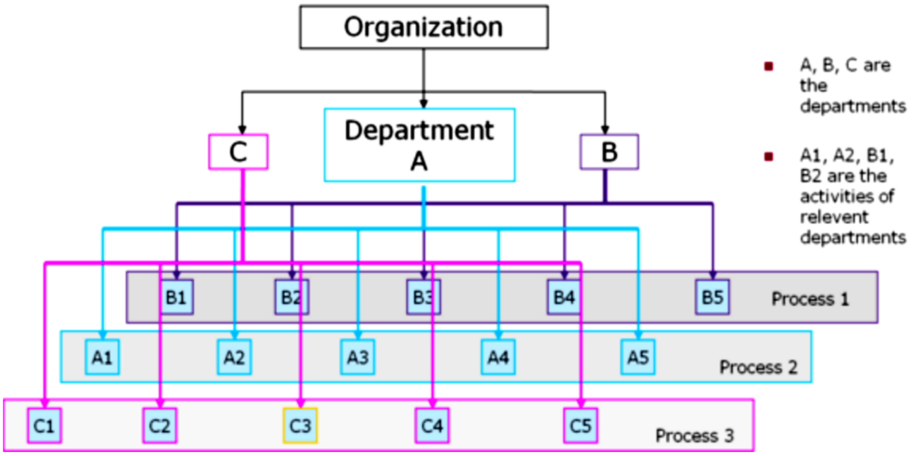

Figure 1: Decomposition of processes and functions in an organization

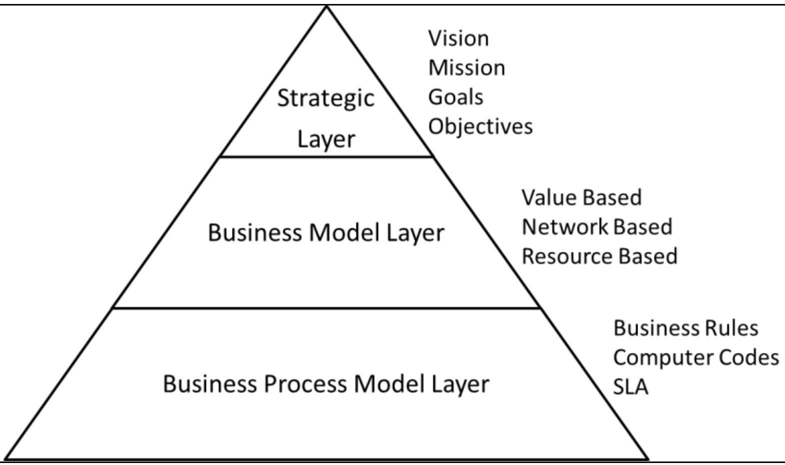

Figure 2: Hierarchical structure of knowledge repository

Since organizations are based on different functional groups and each functional group is composed of various processes, knowledge can be assumed to be a key source of value creation among these functional units. Therefore, it can be assumed that each organization performs various knowledge-related functions. This discussion concludes that knowledge repositories are composed of various knowledge-related functions. Figures 1 and 2 show the diagrammatic representation of knowledge-related functions and repositories.

Blockchain

Blockchain has been at the forefront for a couple of decades after Bitcoin gained popularity because of its underlying technology. Blockchain is a general-purpose technology based on distributed ledger technology. The technology supports smart contracts that validate whether terms are met by each party (Bagchi, 2017)—the higher cost of using blockchain results from the massive volume and frequency of data generation. However, blockchain technology can be made viable and less costly by optimizing the number of contract creations, code size, data amount, and data writing frequency (García-Bañuelos et al., 2017).

Smart Contracts

Smart contracts are the additional concept of blockchain technology that is important for automating processes and transactions among collaborating organizations or end-to-end process nodes (Mendling et al., 2018). A smart contract is, in fact, a computer code that can be deployed in a specific transaction. Untrusted parties can establish a trusting connection by deploying a smart contract. The smart contract of a particular transaction can be exemplified as a legal contract that contains the terms and conditions of a transaction (Debabrata & Albert, 2018). The process or transaction can be executed if both parties agree to execute the specified terms and conditions in the smart contract. The latest research efforts have been in progress to establish smart contracts for linking various business processes through encoding business processes on the blockchain (García-Bañuelos et al., 2017).

RAMI 4.0

Industry 4.0 refers to cyber-physical systems that combine the Internet of Things with an information and communication network. Figure 3 represents the RAMI 4.0 reference architecture proposed by ZVEI (Hankel, 2015). RAMI 4.0 and the Industry 4.0 component are the first versions of the reference architecture for Industry 4.0, released in 2015. Reference architecture model 4.0 comprises six layers and seven hierarchical stages integrated within the product lifecycle value chain.

The hierarchical levels are extracted from IEC62264 (international standard for enterprise-control system integration, based upon ANSI/ISA95). These levels represent different functionalities within factories or facilities. These functionalities are expanded from product to connected world. The concept is that the product is connected throughout its lifecycle with the manufacturer and consumers through the Internet of Things and network services.

According to Figure 3, each stage of RAMI 4.0 is interlinked through different layers. For example, product and field devices are connected through the asset layer. Assets include physical, financial, and human resources, which can be used to develop and produce a product. The connection between product and field devices can be established within the asset layer, which means that at the product development phase, specific field devices or gadgets are implanted or associated with the products, which transmit information at different PLC (Product Life Cycle) stages. Similarly, the development of product ideas, prototyping, and testing can also be linked with the control devices that regularly monitor different stages of product development. The integration link is between the real world and the IT world. Different devices, e.g., RFID tags, QR codes, sensors, or barcodes, are typical devices that can be used for integration links.

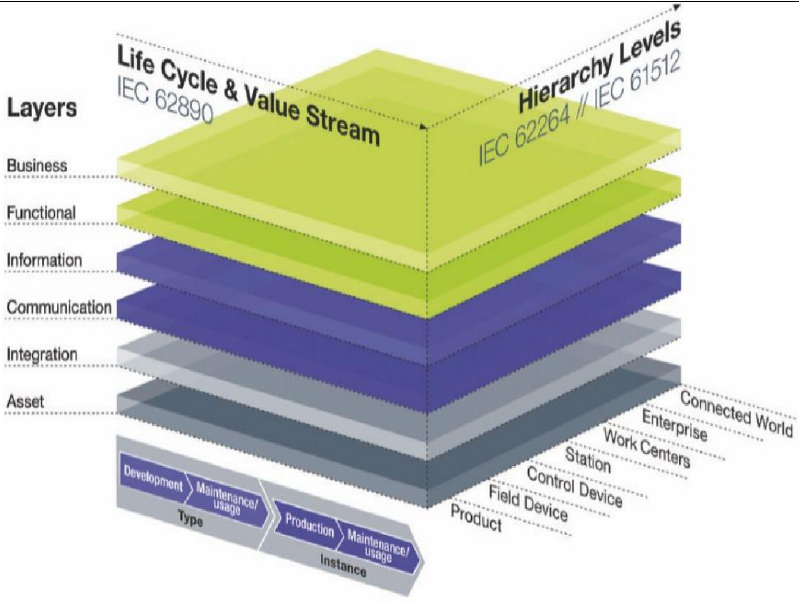

Figure 3: Different levels and layers of RAMI 4.0 architecture showing relatedness and interaction among different layers and hierarchies (Source: [9])

The communication layer establishes a link between the control device and the station where users (human beings) see the incoming information and prepare to take preventive, corrective, or proactive actions to continue the production process. This information is highly structured and can be viewed in graphs, charts, tables, or any other readable format. Different stations are further connected to work centers through this information layer. The work centers are part of the enterprise and integrated through the functional layer. The functional layer is responsible for the "action to be taken" based on the information received from different functional units or work centers. It represents a runtime environment for application systems. Enterprise is linked with the rest of the world through the business layer. The business layer describes the business model regulation and underlying business processes, which can be adjusted based on inputs from the functional layer and legal and framework conditions. Post-sale product usage and maintenance are done through Internet of Things devices. The central concept behind Industry 4.0 is to optimize production and reduce rework and cost of the entire value chain. The layers and hierarchical levels are built upon the product lifecycle management.

Product Life Cycle Management

From product development to its recycling after usage, a product has been passed through various stages and steps. All these stages and steps are linked in one way or another. Under the regime of Industry 3.0, production processes are already automated and interlinked, and products can be traced within a factory or outside factor during logistics. However, the link between the manufacturer or producer and product performance is either discontinued or weakened once the product comes into the hands of the end consumer. Industry 4.0 has been suggested to establish this link and emphasize intensively linking manufacturers with products from the raw material stage to final consumption by end consumers or even beyond. There are many real-world examples where the product is linked with the manufacturer when it is in the hands of the end consumers, thanks to the Internet of Things concept (Hofmann & Ruesch, 2017).

Product lifecycle management (PLCM) consists of stages from product conceptualization to maintenance and support. It includes production conceptualization, architecture design and prototype, development and testing, deployment and maintenance, and support. Close-looped or sustainable PLCM also includes product consumption, disposal, and recycling. Discrete production units allow companies to cut costs and effectively utilize available resources. This discrete production mechanism requires the management of location-based information. Various tools and technologies have collected, processed, and disseminated location-based information from discrete production units (Vadoudi et al., 2014). Thus, the use of the latest technologies can help manufacturing organizations to develop sustainable product life cycles for sustainable business models not only for geographically distributed production units but also in a factory.

Industry 4.0 Component

Industry 4.0 consists of an administrative shell and the "thing," which could be a product, a machine, or even software. All relevant hardware or software data in a production environment is stored in the administrative shell (Figure 4). This data is critically essential for value creation processes because it contains a complete history of the thing's entire lifecycle. This administrative shell provides immense benefits to all participating enterprises, e.g., data availability, integrity, and security, support functions like planning, configuration, operation, maintenance, etc., and horizontal and vertical integration among various enterprises throughout the lifecycle value chain – thus creating new business models, seamless information flow between processes, workstations, participating enterprises, and the connected world, and the last but not least the modularity, i.e., general and specific information storage.

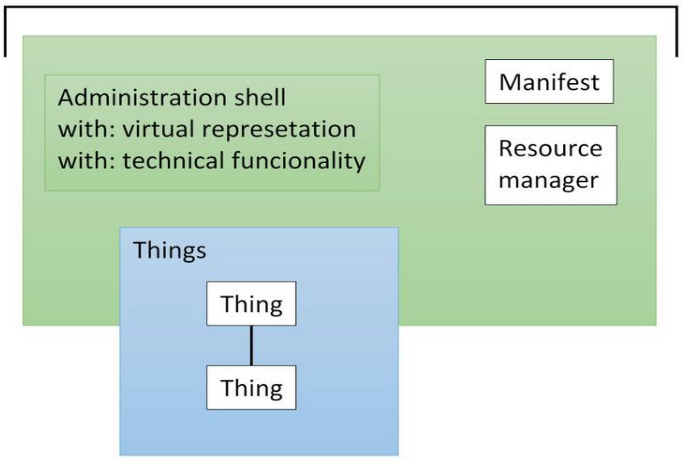

Figure 4: I4.0 Component

Mapping Rami 4.0 and Knowledge Repositories

Within the reference architecture model RAM4.0, the communication and information layers provide real-time information to different functionalities, participating enterprises, and end-consumers. This information is critical to developing new business models, rules and regulations, and other product economic and technical aspects. The communication between different machines, processes, and products at different levels of the product lifecycle value chain and hierarchies shall be swift, seamless, instant, secure, and reliable. So far, the i4.0 communication is based on existing industrial protocols. However, it has been recommended that the suitability of Industry 4.0 communication must be examined (Hankel, 2015). Therefore, based on this open call for future research, the communication layer is proposed to be built upon blockchain technology.

Based on Mustafa and Werthner (2008), the hierarchical structure of a knowledge repository consists of three different layers, namely, the strategic layer, the business model layer, and the business process layer. The strategic layer consists of goals and objectives set both at the organization and department levels. The business process layer constitutes business processes that deal with generic value creation processes, including technical, human, and technological processes. The business model layer is conjoint, integrating the strategic and business process layers. "A business model layer provides a framework for business processes with organizational vision, mission, and strategies. The business model framework, as described in general, is a "translation of strategies into actions to achieve specific objectives and goals" (Mustafa & Werthner, 2008).

Knowledge transfer and sharing is the key to PLCM. Based on this knowledge sharing and exchange, the abstract decomposition of an organization can be done into "functions" and "activities" (Mustafa & Werthner, 2008). This virtual breakdown identifies the locus of creating value for economic exchange. A function can be part of different processes or sub-processes (when activities of different organizational departments are connected) to achieve the objective. Since the main objective of an organization is value creation, the function can be assumed as part of the value creation process. As knowledge is the primary resource underlying the value creation process, we can assume that knowledge directly relates to function (Felin & Herstely, 2007). The processes are composed of value-creating activities, either performed by man, machine, or both. These activities are building blocks of a process that incorporates specific information about that process. This information is further extended into knowledge by a combination of framed experiences of human beings, values, contextual information (of specific process), and expert insight, providing a framework for evaluating and incorporating new experiences and information (Samaddar & Priestley, 2005). The knowledge created through interaction within different processes of the different departments is vital not only for the knowledge-intensive manufacturing company itself but also for its vendors and customers.

Figure 5 represents the pictorial of a smart factory decomposed into various processes and functions, as suggested by Mustafa and Werthner (2008), and its link to the outer world within the framework of RAMI 4.0 reference architecture (Hankel, 2015). The dotted lines represent the information and communication network within smart factories and across its boundaries with the outside world. Solid lines represent the functional hierarchy of the organization. The critical knowledge created, utilized, and disseminated within each process and its subsequent activity is supposed to be stored within the product throughout the product lifecycle, and this (critical) knowledge is also shared with the external world when the product is in the hands of the customers. The knowledge created during its consumption and disposal is also communicated to the manufacturing organization via the same communication channels.

Thus, the knowledge created within and across the process and function can be shared within and across the organizational borders. After passing through the production floors and warehouses and onto the retail stores, products become organizational assets in the hands of their customers. Therefore, the information and knowledge contained within and attached to the product shall also be accessible to the customer in the same manner as the product itself. RAMI 4.0 explains how the production floor and the customers are interlinked in the pre-and post-production stages through the product.

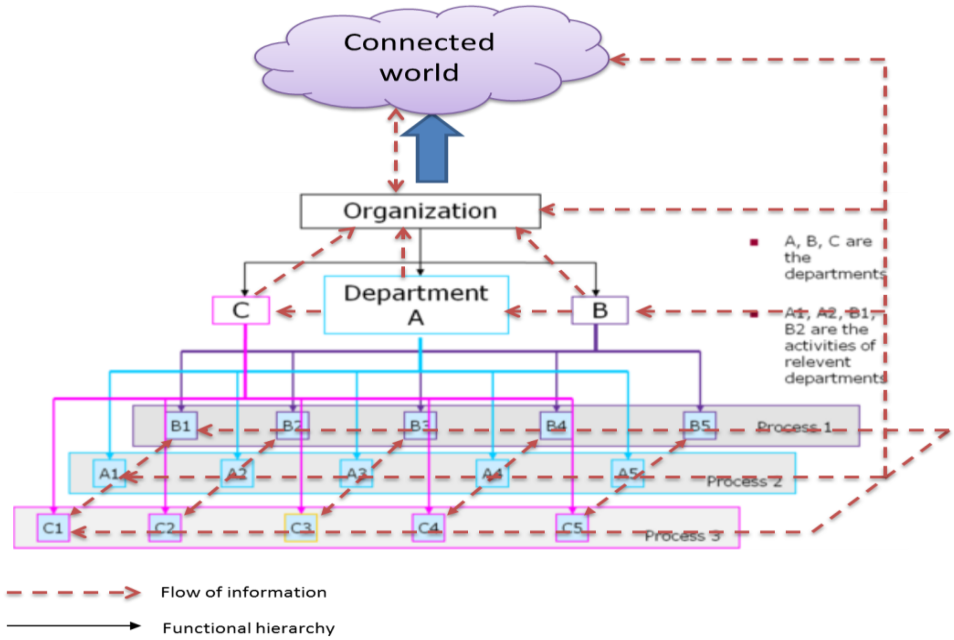

Figure 5: Pictorial representation of a smart factory connected with the real world through integration of information throughout the product life cycle value chain of the product. Source. Self-created.

Implication for Knowledge Intensive Manufacturing Concerns

The execution of business processes within and across business organizations can be done in a trustworthy manner, even without mutual trust among nodes (end-to-end business transaction partners) (Mendling et al., 2018). The above discussion, in fact, reflects on the use of smart contracts and blockchain applications, which can play an important role in knowledge-intensive manufacturing concerns in the ongoing regimes of RAMI 4.0 and Big Data. The key research question raised in this paper is how knowledge and information are shared within and across the organization's boundaries in a trustworthy way by linking various processes and activities in a smart factory.

The answer to this question probably lies in using blockchain technology through the smart contract concept. Smart contracts are famous for their self-executing characteristics. Although research is in progress to decide the legal aspects of these smart contracts (Staples et al., 2017), in a fully automated world, these small conditional computer codes written on an underlying distributed ledger are executed automatically by nodes on the network. A smart contract could theoretically run any instruction that a computer could execute. Thus, these smart contracts can be used to develop new communication protocols for industry 4.0

components. “Smart contracts’, in the context of DLT, are programs written on the underlying distributed ledger and executed automatically by network nodes. A smart contract could theoretically run any instruction that a computer could execute. Transactions or data recorded on the distributed ledger trigger the smart contract, and the actions taken are recorded in the ledger. Smart contracts “allow for logic to be programmed on top of the blockchain transaction” (Natarajan et al., 2017)

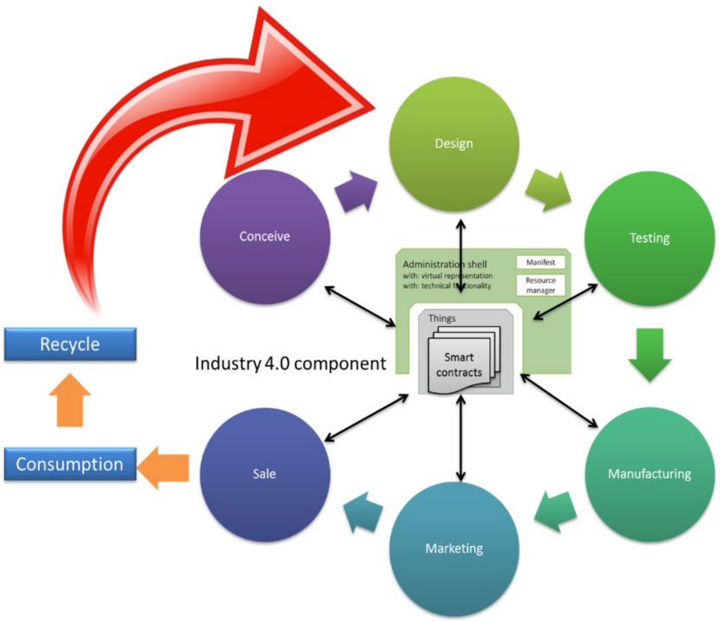

Figure 6: Role of smart contracts integrated with Industry 4.0 component throughout Product Life Cycle Management (PLCM)

The use of smart contracts through the distributed ledger technique can help achieve the integration of blockchain into RAMI 4.0 architecture. Since RAMI 4.0 is based on the cyber-physical space concept, the crucial data from the product at any stage of the product life cycle value chain can be filtered, and high-value data can be stored in blockchain. Based on this high-value data, auto-executable smart contracts, various functions can be performed throughout PLCM, from idea generation to recycling and disposal. The inherited property of immutability and traceability of blockchain makes PLC a sustainable business model in knowledge-intensive manufacturing organizations.

Figure 6 represents the closed-loop manufacturing system or sustainable product lifecycle management. All stages of sustainable PLCM, from the generation of ideas to its disposal and recycling through consumption, are virtually connected through smart contracts. These contracts are proposed to be part of industry 4.0 components (see Figure 4) which consists of an administrative shell and any “thing,” aka a product, machine, or computer. Data generated at each phase or stage of PLCM can be selectively stored (chronologically) in distributed ledgers (blockchain). Using computer codes via smart contract, each step is linked within PLCM.

Many critics of blockchain highlighted flaws like cost, speed, privacy, and trust, but it could still be a vital technology that helps to bring industry4.0 to widespread acceptance. In their paper, (García-Bañuelos et al., 2017) argued that blockchain technology can be used through a spaced-optimized data structure, which can reduce the number of operations to perform a process by using an optimized BPMN process model. Concerning ongoing research (García-Bañuelos et al., 2017), this can be a promising technique to settle down the flaws of blockchain and help companies keep them within the race of the Industry 4.0 regime.

Conclusion

The current paper addresses two agendas: 1) the Knowledge-related function of an organization can be linked with the outer world within the RAMI 4.0 framework, and 2) blockchain technology via smart contract can be used to link various processes within a smart manufacturing factory. The first agenda of this paper is to link knowledge-related functions with the outside world within the RAMI 4.0 framework. Manufacturing factories are stacks of various processes and activities accumulated in different functional units. In the regime of Industry 4.0, these functional units can be interlined through various layers and levels. The business models of knowledge-intensive manufacturing concerns are mainly linked with the first two layers, i.e., the business and functional layers; however, these layers are further connected with the asset layer through the information, communication, and integration layers. Organizations are also considered knowledge repositories consisting of three hierarchical layers: the strategic layer, the business model layer, and the business process model layers. Thus, most RAMI 4.0 layers can be mapped with the knowledge repositories layers respective to different functionalities and processes. The first two layers of RAMI 4.0 can easily be mapped with the strategic and business model layers. The rest of the RAMI 4.0 framework layers can be mapped with the business process model layer of the knowledge repository hierarchical structure.

The second agenda of this paper is to discuss how blockchain technology via intelligent contracts can be used to auto-execute various processes within an organization. The reference architecture model for Industry 4.0 comprises RAMI 4.0 and Industry 4.0 components. Industry 4.0 component consists of administrative shell and the “thing” which could be a product, a machine or even software. The administrative shell stores all relevant hardware or software data in production environment enterprises throughout the lifecycle value chain. The data available through the i4.0 component can be used to design various programs for self-automating various functions within knowledge-intensive organizations. The use of smart contracts to perform auto-execution based on relevant and critical data available through Industry 4.0 components can be vital for knowledge-intensive manufacturing organizations in the current scenario of Industry 4.0 and Big Data regimes. Using smart contracts through blockchain-based DLT technologies radically improves knowledge-related functions and automates knowledge repositories. Since knowledge-related functions are key parts of business model concepts, using smart contracts leads to sustainable business models for knowledge-intensive manufacturing companies.

Various efforts are being made to develop a value chain for connected organizations through various frameworks (IVRA NEXT, RAMI 4.0). The implication of using smart contracts will be another perspective that will lead to utilizing the latest technological developments in industrial automation and creating new business models.

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