Addressing Consumer Demands: A Manufacturing Collaboration Process Using Blockchain for Knowledge Representation *

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Abstract. BACKGROUND. In I4.0 the current definition of a MAS includes the representation of: equipment; transportation; products; and organisations. With the current manufacturing processes, industries will be able to produce faster and better products, in more quantity. However, we face a new challenge that results from the increasing demand for customised products, motivated by trends that can quickly shift.
PROPOSED SOLUTION. We propose the inclusion of the consumer, represented by an agent, directly in the manufacturing process. This agent represents the preferences and needs of the consumer in product customisation scenarios which, together with the other agents, negotiate criteria and cooperate with each other. In addition, this model also represents a network of entities (based on a MAS), and the knowledge representation using a blockchain.
DISCUSSION. In addition to addressing the customisation necessities, the model proposal allows organisations to collaborate in any manufacturing problem, through the usage of the network resources.

Keywords: Collaboration, Negotiation, Industry 4.0, Blockchain, Multi-Agent System

1 Introduction

Recent developments regarding Industry 4.0 (I4.0) definitions are commonly naming collaboration scenarios, and the urge to collaborate, as an essential characteristic for the success of the fourth industrial revolution. As a revolution that is destined to impact the overall performance, quality, and the control of the manufacturing process, is still facing some challenges. To answer its demands, organisations have a necessity to collaborate more efficiently, making faster and reliable decisions, and establishing transactions between the right partners.

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Organisations establish among themselves a collaborative principle, which typically operates in the supply chain, in order to introduce benefits to their activities, as well as the ability to respond to the needs of the most demanding consumer. With the introduction of I4.0, the manufacturing process must be able to meet the consumers needs, resulting in an increase in the demand associated with the supply chain, which represents a necessity to improve communication and supplier integration. In a set of entities, where all (or part of) services and/or products are highly dependent on the availability of services and/or products from other entities, it is difficult to execute quick and easy decisions. There will always be a set of dependencies between two or more entities that share a position in the supply chain, and problem is that in an environment where organisations need to make decisions assertively and quickly, there is no way of knowing which entity to depend on.

Such developments in the manufacturing processes are being supported by governmental agenda, being part of the several strategy plans for the future of the industry in many countries, including the European Union.

Collaboration is based on trust, but without social capabilities or characteristics, collaboration can be based on agreeable contracts that bound two entities. We evidence four necessities: (1) the decentralisation of the decision making process; (2) supporting collaboration; (3) include the consumer in the manufacturing processes; (4) and represent the generated knowledge. As result this work proposes the inclusion of the consumer, represented by an agent, directly in the manufacturing process. To achieve that, this work proposes the definition of a model for an industrial collaboration network, that includes the consumer in the manufacturing process (social manufacturing) and is composed by a collaborative network of entities (based on a Multi-Agent System), a reasoning and interaction layer, and the usage of blockchain to represent knowledge. Our proposal is based on the definition of a Multi-Agent System (MAS) to represent industrial entities in an environment where there is a necessity for collaboration, while maintaining competitive natures. This model can support decision-making processes regarding which entity should one rely on, to solve existing dependencies and is initially focused on the manufacturing of customised products.

This work is structured as follows. In Section 2 we present a background on the technologies and concepts included in this work, with special reference to the blockchain technology. This Section also includes related work entries that are the result of the combination of MAS and blockchain technologies; Section 3 describes our proposed solution, including the process that originated the proposed model and a description of its main components, namely: network of entities, reasoning and interaction layer, and knowledge representation; This work concludes (Section 4) with a discussion of the proposed solution, its strengths, limitations and future work paths.

2 Background

As a concept, Ambient Intelligence defines a vision of the Information Society with emphasis on greater ease of use, more efficient support services, and supporting human interactions, referring to a digital environment that proactively but sensibly supports people and their daily activities. The focus of this concept has been adjusted according to chronological needs [6], and a quantitative analysis of scientific publications in the field suggests that the term has been replaced by more popular terminologies appropriated to the area of application, including the I4.0 terminology that is typically associated with Ambient Intelligence in an industrial context (or an intelligent industrial environment).

First introduced by the German industry during the Hannover Fair event in 2013 [13], the I4.0 concept is impulsed by emerging technologies that are being adopted by manufacturing environments like the Internet of Things, wireless sensor networks, big data, cloud computing, and embedded systems. One of the main objectives is the creation of new values for the industry, through the creation of new business models, and the resolution of numerous social problems [12].

Cyber-Physical Systems (CPS) are defined as a transforming technology that provides innovative services to enable interconnected operations between physical assets, computing, and communication [14]. Shafiq et al. [23] define CPS as being "the convergence of the physical and digital worlds by establishing global networks for business that incorporate their machinery, warehousing systems and production facilities". Monostori et al. [18] affirm that CPS "are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its ongoing processes, providing and using, at the same time, data-accessing and data-processing services available on the Internet". With the growing usage of sensors and network connected machines, there will be a continuous generation of data that the CPS manage and leverage the connectivity between the machines, originating smart-machines. Also applying the concept of CPS in production, logistics and services in the current state of industrial practices, it would transform the factories of today into smart-factories with significant economical potential [14].

With an increasing usage of online social networks, and the adoption of new technologies, there is a demand to include consumers opinions on product manufacturing, customisation and delivery, requiring factories to become self-aware, self-maintenance, and capable of making market predictions and act accordingly [15]. Social Cyber-Physical Systems (SCPS) are an evolution of the CPS model, and combines the production services with the consumer, understanding consumer demands and offer personalised products and services on valuable time [28].

Agent-based technology is recognised as an important approach for the twenty-first century manufacturing systems. The suitability of agent technology is a unique factor to consider in the real world applications, particularly in I4.0, since it can bring a major improvement in the decision making processes and in the collaboration of different systems [3]. Is an entity that senses the environment and acts on it, performing a task continuously, with a strong autonomy, in a shifting environment, while coexisting with other entities and processes.

Multi-agent Systems (MAS) aim to provide both principles for construction of complex systems involving multiple agents and mechanisms for coordination of independent agent behaviour [24]. While an agent ins any individual entity that is making decisions independently, MAS are a network of agents that work together to solve a specific problem (where agents work together) implying a certain level of cooperation among the agents involved, that can be explicit by design, or adapted. MAS are a particular type of intelligent systems, where autonomous agents dwell in a world with no control, or persistent knowledge. This infrastructure has been studied as a solution to manage widely distributed systems, particularly industrial applications, and aim to provide both principles for construction of complex systems involving multiple agents. MAS, which consists of a multiple autonomous agents with distinct goals, are especially suitable for the development of complex and dynamic systems. Agents communicate with each other and with the environment with a focus on understanding the latter and reason upon intelligent models, coordinating their efforts to achieve their goals and the one of the ecosystem where they are inserted in.

2.1 Blockchain

Since the publication of "Bitcoin: A Peer-to-Peer Electronic Cash System" by Nakamoto [19], and the follow announcement of the first public version of the bitcoin client, blockchain has started its journey to become one of the most popular topics today. Since then, blockchain has being commonly associated with cryptocurrency and accompanied its success, which intrigued and triggered the curiosity of researchers from different academic backgrounds for the pursue of all the different scenarios of application for the blockchain technology [4]. Despise the current success in digital currencies and financial assets, the potential application reach is still a work in progress [1]. Blockchain is the generic designation given to transaction persistence protocols, which are based on different algorithms and cryptographic principles that ensure the integrity and traceability of all transactions within the system, without the need to place trust in a central entity, thereby maintaining it, decentralised and distributed. The successor of the initial blockchain protocols (Blockchain 1.0), whose implementation is restricted to ensuring that a predefined set of validations were respected, is Blockchain 2.0. This new designation is associated with the new generation of blockchain protocol implementations designed since its inception to support the definition of business rules and custom validations through Smart Contracts. As a direct response to the increasing demands from the industry, anxiously expecting a framework that allowed the full exploration of this technology for the most different ends.

Smart contracts were introduced as a concept by Szabo in the 90's [25], whose definition was defined as a computerised transaction protocol that executes the terms of a contract [8]. This definition was based on the necessity to translate contractual clauses into code, and embedded into hardware or software that is capable of self-enforce them, resulting in a decrease for the need of a trusted intermediary between transacting parties. In Blockchain, smart contracts are self-enforcing scripts that represent a digital contract [16]. They work as a software protocol that performs an action when certain conditions are met, reducing the amount of human involvement required to create, execute, and enforce a contract. Since there is no necessity for the contract partners to fully trust each other, blockchain, as a distributed system, is suitable for this type of application by removing the intermediary and simplifying trustless protocols between multiple parties [27].

2.2 Related Work

The combination of this technologies (namely blockchain, MAS, and smart contracts) is not a novel concept. There are existing proposals based on the combination of some/all previous described technologies in the described domain (intelligent industrial environment), namely:

- The work of Casado-Vara et al. [7] presents a model that uses a combination of blockchain, smart contracts, and a MAS to coordinate the tracking of food in the agriculture supply chain. The proposed model uses blockchain to store a record of all transactions, and this decision was justified by the authors due to security and decentralisation necessities. The coordination of all the members of the supply chain is performed using a MAS, where agents verify the fulfilment of smart contracts for each transaction between entities.
- Abeyratne and Monfared [2] main objective was to define a blockchain based system to facilitate the vast amount of data that is required about the products and respective consumers in a manufacturing domain. Their approach is composed by a decentralised distributed system that uses blockchain to collect, store and manage the data related to the product life cycle, where the authors claim that this solution allows consumers to access information related to a specific product at any given time, resulting (theoretically) in better buying decisions.
- Ghadimi et al. work [11] proposes a MAS approach as solution for the automation, and process facilitation, of sustainable supplier selection and order allocation, which results in a more cooperative partnership. Their proposed model is composed by two sub-models: a supplier evaluation model; and a order allocation model. The first sub-model uses three types of agents: a database agent, a supplier agent, and a decision maker agent. The second sub-model uses a order allocator agent, a database agent, and a supplier agent. According to the authors, their model can improve the order fulfilment rate, decrease demand uncertainty, and eventually can lead to improvements in the performance of a supply chain.
- The work of Wang et al. [26] proposes the definition of a MAS to represent an Industrial Network where they define the following agents: Machine Agent (MA) which represents all the equipment that performs any production or

test activity; Conveying Agent (CA) which represents all entities that move a product, like robots, conveyor belts, and others; and the Product Agent (PA) which represents the products that are or will be processed by MA, and transported by CA. In addition, they propose an intelligent negotiation mechanism for agents to cooperate with each other, as well as preventing deadlocks by improving their decision making and coordination behaviour.

3 Proposed Solution

The current list challenges that industries face today, includes the necessity for the collaboration between different organisations and/or partners including suppliers, service providers, shipping providers, and even other competing organisations. While this collaboration might prove to be an improvement to the previous unidirectional communication channels that different organisations had, there is still a necessity to include and create communication channels to the consumers to answer the shift in the paradigm of production: from the mass production towards mass customisation.

With reports [9] affirming that the frequency that consumers will ask for more complex or personalised products is increasing, only with collaboration organisations will be capable of answering such exclusive demands. Collaboration occurs when organisations work jointly on the development of products, where the distributed returns are sufficient for all the collaborating parties [21], witnessing a free flow of information between collaborating organisations, which in turn provides faster decision-making and can enhance the effectiveness of internal processes.

With an increase of productivity efficiency under I4.0, manufacturing flexibility and the integration of different processes and activities are guaranteed, due to the intelligent manufacturing environment. The problem is how, besides handling manufacturing and processes flexibility, industries will be able to fulfil personalised demands by their consumers, and be capable to offer better response to the needs and preferences of them. I4.0 assumes its operations in a computerised and intelligent manufacturing environment, assuring flexibility and high production efficiency, which allows a faster communication between costumer and producer, with consumers being much more demanding and requesting more personalised products. As result, is even more important to include the consumer on the manufacturing process (social manufacturing). Therefore, this work proposes a model definition for an industrial collaboration network that includes the consumer in the manufacturing process. A visual representation of this model is illustrated in Figure 1, which is divided in three main components: (1) a collaborative network of entities based on a MAS; (2) a reasoning and interaction layer; (3) knowledge representation using blockchain.

The proposal is based on the definition of an MAS in an industrial context for the representation of different entities that decentralise decision-making processes and aid the manufacturing process by using agents to represent entities included in an industrial environment, where there is a necessity for collaboration.

Is designed to be capable of representing and supporting the complex structure of dependencies created between entities, improve decision-making processes, and to facilitate the relationships through collaboration. Organisations need to look at the individualisation of customer's requirements, where the goal is to deliver various goods to fulfil small customer groups with specific needs while reducing production costs and focusing in customisation, flexibility, and responsiveness.

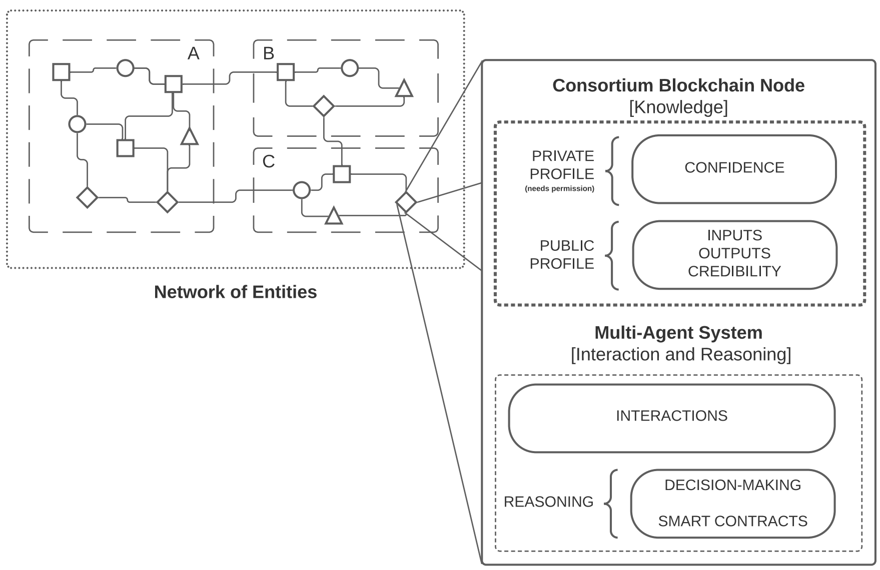

Fig. 1. Industrial collaboration model that includes the consumer. On the left: entities network from different organisations (A,B,C) based on a MAS. In this network the MA are represented by $\Box$, CA represented by $\Diamond$, PA represented by $\bigcirc$, and the CsA are represented by $\triangle$; On the right: reasoning and interaction layer and a consortium blockchain node representation, used for knowledge representation.

Despite their presence in the collaboration network, it does not mean that an organisation is associated or is part of other organisation. Instead, that organisation is allowed to use the resources that are available in the network. As result, organisations A, B, or C, might not have any form of business relationship between them, or even any past interaction/transaction. Despite the initial definition of this model being oriented to solve the increase in demand for customised products, the model can work as a collaborative network for every manufacturing process.

3.1 Collaborative Network of Entities

This initial part of the model is achieved through the creation of a network, as suggested by the work of Schuh et al. [22], where entities can collaborate towards a stronger cooperation and each can achieve its targets. We achieve this network of entities in a similar approach proposed by the model present on the work of Wang et al. [26], where they define a MAS that includes:

- Machine Agent (MA): represents all the equipment that performs any production or test activity;
- Conveying Agent (CA): which represents all entities that move a product, like robots, conveyor belts, and others;
- Product Agent (PA): which represents the products that are or will be processed by MA, and transported by CA

Our model proposal, represented in Figure 1, includes the previous agents in its network of entities including a visual reference, namely: MA are represented by $\square$; CA are represented by $\Diamond$; and PA are represented by $\bigcirc$. The objective of this network is not to create an idea that the entities belonging to the network appear and operate like a larger unique entity. Instead the point of the network is to encapsulate the different entities and their relationships in the same environment to allow the other components of the proposed model to be applied in an organised setup. Each entity has knowledge of all other entities present and the network and knowledge regarding their function, and inputs, outputs, and credibility (to be discussed in section 3.3). A new type of product is created through smart manufacturing: intelligent product. These products contain embedded sensors, identifiable components, and processors that carry information and knowledge to convey functional guidelines to the production system, including information about your production requirements and the equipment required for this. In this way, each PA knows, at any given moment, all the steps it has already taken, all the MA it has passed through, the remaining steps, and which MAs are needed for its completion.

The main contribution of this proposal is the introduction of a new actor (the consumer), represented by an agent, who assumes criteria representing his preferences and needs. This Consumer Agent (CsA) is represented in the model by $\triangle$, and represents a consumer (our a group of consumers). In customisation scenarios, the needs and preferences represented by the CsA will have to be negotiated with the other agents. This cooperation is essential to understand the feasibility of the product taking into account the existing raw material and the current processes performed by the MA and other entities present in the network. The MAS systems already contemplate negotiation processes between agents, and the inclusion of the CsA, and its integration into the system, creates a need for redefinition/adjustment of existing negotiation processes.

The goal that each CsA intends to achieve, is directly correlated to the consumer or group of consumers that is representing, more specifically, to their needs and preferences. The capture of this criteria is not the main focus of this proposal, but in future works we will address the possibility of including externals sources that can help the identification of consumer needs. At this moment, we are going to assume that this needs and preferences are known and being correctly represented by the CsA.

Additionally, the inclusion of the consumer is a direct response to the necessities for social manufacturing, and their inclusion on the entirety of the product life cycle. This model is initially focused on the inclusion of the consumer on the manufacturing process (design, manufacturing, disposal), but can be further extended to the other processes that can even include the decision making process regarding materials and suppliers selection.

3.2 Reasoning and Interaction

The second part that composes this model is based on the MAS and is intended as a solution to handle the reasoning and the interactions between entities, to decide which are the best entities, in the network, to interact with in each situation.

As a direct response to the diverse consumer demands (represented by the CsA), there is a necessity for each entity to connect and work effectively and efficiently with others, making the entity to entity relationship critical for the success of this model. The selection of the right entities for the manufacturing of a product (whose characteristics are represented by the PA as a result of a negotiation process with the CsA) is the main purpose of this layer.

The MAS proposed in the reasoning and interaction layer is based on the methodology presented in Nikraz et al. [20] and the work of Ghadimi et al. [11]. These works are focused on the key issues of the analysis and designing of a MAS, with a special attention to the analysis and designing phases, which are based on the Foundation for Intelligent Physical Agents (FIPA) standards. To design the system, is performed an identification, categorisation, and refinement of agent types during the analysis phase. It starts by making an initial agent type identification based on two rules: (1) add one type of agent per user/device; (2) add one type of agent per resource;

This step is followed by a responsibilities identification, where is created an initial list for each agent main responsibilities. In this proposal are included the definition of the following agents: Blockchain Agent (BA); Entity Agent (EA); and the Decision Maker Agent (DMA). For each one of this agents were defined the following responsibilities:

- Blockchain Agent (BA):
  1. Receives the entity data from the EA;
  2. Saves the data from the EA in a blockchain transaction;
  3. Informs the EA that data was saved;
  4. Receives a data request from the EA;
  5. Returns data results to EA;
  6. Receives data requests from DMA;
  7. Returns results to DMA;
- Entity Agent (EA):

1. Requests data from the BA;
2. Send data to the BA to add to its public profile;
3. Send data to the BA to add to its private profile;
4. Receive data from the BA;
5. Request results from DMA;
6. Receive results from DMA;

– Decision Making Agent (DMA):
    1. Start decision-making process;
    2. Request data from BA;
    3. Receives data;
    4. Evaluate entities involved;
    5. Send data to the BA;
    6. Inform all EA involved.

The process is then focused on the acquaintances identification, where there is a necessity to identify all the possible interactions. The analysis ends with the agent refinement where a set of considerations is applied:

– Support: what supporting information agents need to accomplish with their responsibilities, and how, when and where is this information generated/stored;
– Discovery: how agents linked by acquaintance relation discover each other;
– Management and monitoring: is the system required to keep track of existing agents, or if there is a need to create or demand other agents.

How each agent relates to another is defined in the form of communications and interactions, with messages being send between sender and receiver [49]. To perform a specification for the system interactions, Nikraz et al. [20] advise that a interaction table should be created, that considers each agent responsibilities, including:

– A description of the interaction;
– The responsibility (identified by a corresponding number);
– An interaction protocol to implement the interaction;
– The role played by the agent (Initiator or a Responder);
– The agent name of the complementary role;
– A description of the trigger condition that initiates the interaction.

3.3 Knowledge Representation

The final part of this model is responsible for handling the knowledge representation that supports its entirety. The model uses a blockchain to store entity and transactions data, providing a shared, immutable, and transparent append-only register of all actions that have happened to all the participants in the network. This is achieved through the adoption of a consortium blockchain (a middle ground between the low trust provided by the public blockchain, and the 'single entity that rules everything' of the private blockchain) [17], since it provides many of the benefits found in a private blockchain (like efficiency, transactions, and data access privacy) without consolidation the power in one entity, and maintaining the decentralisation of the decision making process. This unique strategy found in the consortium blockchain is highly beneficial for entities collaboration since it operates under a leadership of a group instead of a single entity.

Transaction and general data on the blockchain are also controlled using permissions, managed by the network. These overall system rules are easier to manage and are capable of achieving better protection results against external disturbances (when compared to other solutions).

Regarding the entity data, is created and registered for each entity that is inserted in the network, and is used for the identification of entities and the ease of the collaboration process. As result, each entity is represented by a public and a private profile. The public profile contains data that is accessed by the network participants, and is used to validate and evaluate which entities should be approached to collaborate in a specific manufacturing process. This profile aids the identification of an entity in a network and stores the following values:

- Inputs: represent the needs of the entity, namely what it needs from the network to fulfil its processes. These inputs can be raw materials, maintenance needs, transportation services, among others. This value can be read by each participant of the network, but each entity can only update its input values.
- Outputs: represent what an entity offers to the network. Each entity has a set of needs that wants to be fulfilled (inputs) and can have a set of outputs (what it can offer/produce) that can be used as inputs by other entity. Ultimately, an output of an entity might represent the input of other.
- Credibility: is a value attached to the public profile of an entity and represents how each entity is perceived by the other entities in the network. Defined as the quality of being trusted and believed in, this variable holds a range of values (from zero to one, where zero is no trust and one is absolute trust) that, based on previous interactions, represents how the network trusts a specific entity. Despise its presence on the public profile, this value cannot be adulterated.

In the specific case of the CsA, the inputs define the needs and preferences of the consumers or group of consumers that they are representing. Initially this needs can be related to a product they want to be manufactured, but in further expansions of this model can also be related to specific preferences like processes, suppliers, or even raw materials.

The private profile stores data regarding the level of confidence that a single entity has in every other entities of the network. In our proposal, one entity can have a certain level of confidence in other entity, regarding what the level of confidence of the others entities is. This confidence is represented by a range of values (from zero to one, where zero is no trust and one is absolute trust) and is only accessible by its entity. The update of this value occurs each time a transaction is performed between entities.

This combination of confidence and credibility values are critical for the success of this model. Credibility can be described in four axis [54]: trustworthiness;

expertise; reliability; and quality; where the first two axis can be related to the credibility of the entity itself, while the latter are related to the credibility of the transaction performed. In this model credibility is used to provide a mean for an entity to be individually classified by others, while the simpler and direct approach of confidence is used to provide an entity with a way of storing their evaluation for each entity, based on their previous interactions. For example: MA_1 has a low level of credibility, but due to previous successful collaborations with a PA_1, it has a high value of confidence in MA_1 which allows PA_1 to trust in MA_1 to establish more transactions.

As for the blockchain that supports the knowledge representation layer for this model, it requires transparency and privacy features, and a necessity for a special infrastructure that can provide such characteristics. As result, this work relies on a Hyperledger Fabric (HF) for knowledge representation. Similar to other blockchain technologies, HF has a ledger, uses smart contracts, and is a system where participants manage their transactions. HF differs from other blockchains by not being an open system that allows unknown entities to participate in the network, instead, its members need special authorisation and validation to be part of the network [10]. Is an implementation of a distributed ledger platform for running smart contracts, leveraging familiar and proven technologies, with a modular architecture that allows pluggable implementations of various functions [5].

This peculiar blockchain architecture introduced by HF is called "execute-order-validate", and a distributed application for Fabric consists of two parts:

1. Smart Contract (Chaincode): is the central part of a distributed application in Fabric, with special chaincodes existing to manage the blockchain system and maintaining parameters. Chaincode is invoked by an application external to the blockchain, when there is a need to interact with the ledger;
2. An endorsement policy that is evaluated in the validation phase. This policy acts as a static library for the validation of transactions, which can only be parameterised by the chaincode. A typical endorsement policy allows the chaincode to specify the endorsers for a transaction in the form of a set of peers. This set of peers are defined as the smallest set of entities required to endorse a transaction to be valid. To endorse, an entity endorsing peer needs to run the smart contract associated with the transaction and sign its outcome.

In HF, a ledger consists of two distinct parts, a world state and a blockchain. The world state is a database that holds the current values for the ledger state, making it easy to access them, while the blockchain works as a transaction log that registers every change that lead to the current world state. The world state is implemented as a database, providing a rich set of operations for the efficient storage and retrieval of states. When a transaction that implies changes to the world state is submitted, by invoking a smart contract, ends up being committed to the blockchain, where a notification about the validity of the transaction is later sent to its committer.

In addition to represent and register every transaction performed in the network (and its participants), this knowledge representation layer is also capable of representing a product life-cycle by analysing each transaction performed by a PA.

4 Discussion

While the manufacturing processes are evolving under I4.0, by taking advantage of the amount of data produced and the digitalisation of manufacturing pipelines, organisations are still facing a variety of challenges. On of those challenges is the increasing demand of customised products by their consumers, that are shifting the manufacturing paradigm towards mass customisation. This specific challenge requires organisations to adapt their manufacturing process, to produce multiple products (or the same product but with different variations) without having to make significant changes to their production line while minimising their downtime. Besides the necessity for the manufacturing of customised products, organisations will need to gather the necessary conditions to ensure their quick adaptation to a changing environment (motivated by trends and social influence), and assuring that they have the required materials and services to answer the manufacturing needs.

One solution to this problem can be found in collaboration, that besides providing a solution to the increase in demand for customised products, can also act as a solution for many other challenges in I4.0. Collaboration is an open and transparent environment where information is shared, and each actor can work together to solve a common problem. The proposed model present in this work is our solution to the necessity for collaboration between organisations, and the satisfaction of customised demands by the consumers. We proposed a model definition for an industrial collaboration network composed by a network of entities, reasoning and interaction layer, and knowledge representation using blockchain. Despite the combination of MAS and blockchain not being a novel process, and existing works that proposed a similar base infrastructure, the novelty of this proposal is found in the inclusion of the consumer.

The initial portion of our model is found in a network of entities, based on a MAS, where each agent represents an entity that is directly related to the manufacturing process of a product, namely: Machine Agent (MA); Conveying Agent (CA); Product Agent (PA); and the Consumer Agent (CsA). This network of entities is composed by different types of agents, belonging to different organisations, that are a common objective: collaborate to solve an existing problem, which in this scenario is the manufacturing of a product.

The knowledge representation uses Hyperledger Fabric and is the entry point for all the information in the network. By creating a solid way of structuring and saving the data, creates the possibility that for each entity and its interactions, the data is stored and shared with all the entities, while keeping the information secure and making sure that stored information cannot be tempered with. Entities information contains data that helps create each organisation's profile and helps in the decision-making process, creating a way for network participants to evaluate and classify each other's performance when collaborating. The decision making portion, relies on a multi-agent system that interacts with the Hyperledger Fabric blockchain in order to gather the necessary data to handle decision making processes regarding choosing the right entity to collaborate. This is crucial, to help stakeholders and decision makers streamline their decision-making process, that can be the difference between acting in a useful time and solving a problem or failing.

As for the limitations of this work, the first that should be addressed is the usage of blockchain. Is the right solution for this model? Despite the current success with cryptocurrencies, and the combination of MAS and blockchain being well documented in literature, this application of this technology is still limited in real world, often associated with a certain level of distrust. However, blockchain aligns with our proposal, and the consortium blockchain provides a way to create interactions among a group of entities that exchange funds, goods, or information, while none are willing to agree on a trusted third party. Also, the usage of smart contracts can simplify trust-less protocols between multiple parties, while the details of the contract remain hidden to other network entities, and providing the decentralisation of the decision-making process.

However, there are some limitations. The MAS developed still lacks maturity in some areas, namely when it comes to the actions of the agents. An entity that can potential affect the operation of the model is the Decision Making Agent (DMA) behaviour and actions, where is important to consider what decision making model framework/algorithm, such has the Markov decision process and a fuzzy inference system, should be used and how it could affect the model. This would enable the developing of the model even further. It is also noted that since different organisations will be sharing their resources, where sensitive data can be available, there is a concern for security and privacy. At the moment, this work relies on the underlining concepts of privacy that come attached to the blockchain technology.

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