Fostering consumer bargaining and e-procurement through a decentralized marketplace on the blockchain

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Abstract

In most products and services markets, some firms reach multinational status either by organic growth or through mergers and acquisitions, which brings about economies of scale and additional market power. While acting as buyers, firms can also come together and form purchasing cooperatives to gain bargaining power. Customers, however, have few mechanisms for collaborating, leading to an unbalanced buyer-supplier relationship and economic surpluses shifting from consumers to producers. Some group buying websites helped alleviate the problem by offering bulk discounts, but more advancements can be made with the emergence of technologies such as the blockchain. In this paper, we propose a customer-push e-marketplace built on top of Ethereum, where customers can aggregate their proposals, and suppliers try to outcompete each other in reverse auction bids to fulfil the entire order. Furthermore, smart contracts make it possible to automate many operational activities such as payment escrows/release upon delivery confirmation, increasing the efficiency along the supply chain. The implementation of this network is expected to improve market efficiency by reducing transaction costs, time delays and information asymmetry. Furthermore, concepts such as increased bargaining power and economies of scale, and their effects in buyer-supplier relationships, are also explored.

Keywords

Blockchain; Decentralized marketplace; Reputation system; Buyer-supplier relationship; Supply chain management

1. Introduction

Individuals cooperate and associate when they find it convenient and to their best interest. For instance, employees join labour unions to gain more bargaining power; small producers establish cooperatives to share resources and benefit from economies of scale; firms use purchasing centres to get discounts by placing larger orders. Consumers, however, are more fragmented, lacking the tools or vehicles for coordination due to high transactional costs. Initiatives such as consumer associations do exist, but they are fundamentally concerned with protecting the customers' rights and interests, and not necessarily with fostering bargaining power. Group buying websites, on the other hand, appeared to be a promising start for joining consumers, and in this way obtaining bulk discounts, but their success was short-lived, at least in most Western countries (in China and Taiwan the case is quite different). The focus on services, especially life & spa or restaurants, did not appeal to a broad range of consumers. Group buying was limited to whatever offers suppliers put on the market, not necessarily reflecting the customers' immediate needs. As a consequence of this limited syndication, economic surpluses are often transferred to producers at the expense of consumers.

Firms may also face these constraints, especially when they are acting as buyers. The procurement process is still very cumbersome, as reaching suppliers and negotiating quotes are often time-consuming tasks. Besides the difficulty in managing buyer-supplier relationships, coordinating suppliers also puts a drag on operations and supply chain management. Market participants still rely on old-fashioned but somewhat reliable supply chains to operate their businesses. However, in a flat world, where supply chains run through multiple geographies back and forth and serve thousands of customers worldwide, managing such chains has become a challenge on its own (Baker & Steiner, 2015; Abeyratne & Monfared, 2016). Limited visibility and transparency over third-party supply chains often lead to scandals with severe consequences to firms. For instance, in 1996, the Nike child labour scandal could have been avoided if Nike had visibility over the subcontracting done by their contractors; or in 2013, in the case of the horse meat scandal, it took six months for the Irish Food Safety Authority to map the whole supply chain network (Brewster, 2015). This type of occurrences could have been prevented by increased transparency and visibility over the supply chain, namely in terms of provenance and traceability of goods (Abeyratne & Monfared, 2016).

In both cases, there is an evident lack of coordination. While consumers have to undergo considerable transactional costs to come together and thus gain bargaining power, which would hardly compensate for any bulk discount obtained through these means, firms lack the technologies to connect geographically-sparse supply chains. Blockchains may, however, help to overcome these limitations. We envision a decentralised marketplace (DM) for B2B and B2C transactions, which facilitates consumer bargaining and e-procurement operating on top of a blockchain. Moreover, the use of a blockchain may also help to address some of the limitations currently identified by Operations/Supply Chain Management researchers, in particular those related to lack of visibility, aggregation, validation, automation, and resiliency (Babich & Hilary, 2019a, 2019b).

This work studies the design and specification of a DM, operating on top of the Ethereum blockchain, where buyers can come together to gain bargaining power. This is achieved by developing a proof-of-concept that demonstrates how a Blockchain-powered platform may be used by consumers—individuals and institutional buyers alike—to buy and sell goods in a more efficient way. Contracts automatically enforce the agreed rules, and a distributed trust network (i.e., a reputation system) is built on top of contract compliance to improve the market players' confidence. The aim is to extend typical buy-and-sell platforms by exploiting the capabilities of the blockchain, therefore introducing features once hard to attain. In particular, our work contributes to two of the research gaps identified in the literature of SCM (Babich & Hilary, 2019a, 2019b): (i) how to aggregate individual needs and repackage them to other market participants; and (ii) how to provide incentives for SC participants to share information.

The DM rests on two critical features that make customer bargaining possible: (i) it allows users to merge orders for similar products, in this way increasing the order quantity; and (ii) it implements a sealed-bid auction system, inviting suppliers to present their best offers. All the activities performed in the platform were implemented resorting to smart contracts, which are self-executing pieces of code. Smart contracts are a tenet of blockchains, having unleashed promising use cases, as they allow activities such as order fulfilment to be processed automatically, including payment and shipping.

At first glance, one could argue such DM could be provided by a centralized operator, such as Amazon or eBay. Transparency, however, as well as collaboration in the supply chain, raises questions about trust, privacy and vulnerability. The control of information by a single partner or a mediator is a highly delicate matter, as it requires a great deal of trust by every participant (Weber et al., 2016). The information holder has the power to misuse the data, possibly extorting or damaging the other parties. Even if trusted not to abuse its power, this entity becomes a single point of failure (e.g., for being hacked, losing data, or simply going out of business), leaving the whole system vulnerable to failure (Abeyratne & Monfared, 2016). Additionally, disintermediation and automation provided by blockchain results in substantial reductions in transaction costs and time. It shortens payment periods from days (sometimes weeks or months) to minutes or even seconds. These two factors no longer restrict smaller, more casual transactions (Nakamoto, 2008) between small scale producers or taking place in developing countries (Brewster, 2015), reducing the barriers to establish new business relationships or even enter new markets.

The remainder of the paper is organised as follows. Section 2 provides some background on both economic/managerial issues, such as bargaining and auctioning, and technological solutions, including decentralised marketplaces, reputation systems and blockchains. Section 3 presents the scope and conceptual requirements of the platform. Section 4 details the platform and the technical choices made, while Section 5 discusses any limitations and presents the conclusions.

2. Background

2.1 Buyer bargaining power and buyer-supplier relationship

From the viewpoint of the buyer, holding power over suppliers comprises the ideal setting to leverage the supplier's performance on quality and/or cost improvement (Cox, 2001). On the one hand, alliances between risk-averse buyers generate such power, since participants can split evenly the negotiation surplus (Chae & Heidhues, 2004). On the other hand, risk-averse sellers tend to offer lower prices to larger customers to offset the additional risk associated with larger orders, increasing the probability of a successful sale. Although the presence of larger buyers may reduce suppliers' profits, incentives can be built into purchasing contracts to induce suppliers to consider synergistic and complementary innovation investments, leading to a subsequent increase in total industry profits and welfare (Inderst & Wey, 2007; Nair et al., 2011).

In this context, some solutions were developed in the late 1990s, such as online group-buying, that resort to the use of technology to foster grouping among buyers. The premise is that individual consumers can band together and obtain the same discounts as retailers who buy in volume (Van Horn et al., 2003). However, many of these initiatives either ceased operating or changed their business models a few years later (Kauffman & Wang, 2002). A decade later, the online group-buying model has become very popular in several countries, such as the USA (e.g. Groupon and Massdrop), China (e.g. Lashou and TeamBuy) and Taiwan (e.g. GOMAJI). Nowadays this minor bubble of investment activity seems to have burst in some of the western markets, as evidenced by the fact Groupon acquired its main rival, LivingSocial. Meanwhile, some group-buying apps have proven to be effective in engaging younger-generation online shoppers in Asian markets (Williams, 2018).

2.2 Auction theory

Auctions are a critical tool for driving prices up or down, depending on the way it is set up. In the field of auction theory, the survey by Klemperer (1999) addresses the use of auctions in the context of procurement in which auctioneers seek lower prices. Primary auction types can be summarised in open ascending-bid, open descending-bid, first-price sealed-bid and second-price sealed-bid. In open ascending or descending bid auctions, prices are respectively raised or lowered until one bidder remains, winning the auction at the final price. In sealed-bid auctions, bidders submit their bids independently without knowledge of other bids. The difference between first-price and second-price is relative to the price paid by the winner, which is determined by the highest (or lowest) bid in the first case, or by the second highest (or second lowest) bid in the latter scenario.

Risk-aversion and risk-neutrality are, among other aspects, at the basis of the difference in optimality between auction types, namely regarding second-price and first-price sealed-bid auctions. Indeed, while in the former risk-aversion on the bidder side does not affect the bidder's strategy, in the latter risk-aversion increases aggressivity from bidders at the cost of reducing the potential value of winning for these. Therefore, an entity faced by risk-averse bidders has a preference for first-price auctions (Coppinger et al., 1980; Klemperer, 1999).

2.3 Decentralized marketplaces and reputation systems

Until now, few applications have been specifically directed at decentralised marketplaces. The primary electronic commerce marketplaces such as eBay and Amazon operate in centralised setups, providing weak privacy guarantees to users in the maintenance of confidentiality of sensitive information or the correctness of their reputation systems. Academia has started introducing formal models for decentralised marketplaces. For instance, Soska et al. (2016) have idealised a decentralised anonymous marketplace (DAM) using distributed ledger technology (DLT), displaying a design resistant to Sybil attacks. In practice, some decentralised marketplaces are emerging, such as BitBay and Particl. Yet, none of these platforms provides group buying, which is a non-trivial feature in the context of decentralised marketplaces.

The growth of this kind of marketplace models is accompanied by an increasing need for reputation systems, as more people and services interact online. Currently, despite the existence of various solutions originating both from academic and real-world environments, each reputation implementation faces its own issues. A widely used solution is the implementation of reputation systems that rank users in function of their trustworthiness (Ratnasingham, 1998; Gefen, 2000; Einav et al., 2016). Electronic markets such as eBay adopt an informal yet explicit reputation system through user feedback, allowing parties to leave positive, neutral or negative feedback about the transaction, and rate also other order parameters (e.g. accuracy, shipping time). Other online markets such as Amazon allow its registered users to write reviews on products and rank them using a 5-star scale (Liu & Munro, 2012).

Regarding academic reputation systems, ReGret was designed to operate within an electronic marketplace setting, using multiple contextual attributes and classifying information as coming from an individual, social, or ontological dimension (Sabater & Sierra, 2001). Lin et al. (2014) sought to filter unfair feedback and evaluate the trustworthiness of suppliers through a multi-criteria decision-making framework based on trust and reputation. Dennis and Owen (2016) proposed a new reputation system applicable to multiple networks, where the system quantifies reputation in peer-to-peer networks by removing the human opinion from the transactions and storing instead a single dimension reputation value (i.e., 0 or 1) from the completed transactions. Valls et al. (2017) introduce a privacy-preserving reputation system that enables anonymous ratings, making sure only authorised users can issue ratings and the good raters are rewarded. Other reputation models focus on personalized computation of reputation of service providers in an online marketplace, in which the users can dynamically adapt the underlying computation mechanism resorting to visual analytics (Sänger and Pernul, 2018). This can be performed in a decentralized way without a central trusted party learning individual user feedback (Bag et al., 2018). Notwithstanding their effectiveness in meeting the trust related design requirements, reputation systems are often vulnerable to manipulation strategies by users, such as the Sybil attack (Lian et al., 2007), which comprises the creation of several fake identities in the system in order to manipulate the rank of users.

2.4 Blockchain and smart contracts

Notwithstanding the advantages of reputation systems, trust requirements in DMs can also be addressed by distributed ledgers and smart contracts (Fairfield, 2014; Babich & Hilary, 2019a, 2019b), which often feature increased resistance to manipulation. Indeed, the type of access and restrictions to certain core features of a blockchain can be permissioned or permissionless. On the one hand, if the identity of participants is known and authenticated by some process, economic incentives for reaching consensus are not required, thus making it simpler, faster, less costly, and more easily scalable (e.g. Hyperledger). On the other hand, the lack of a centralised authority responsible for authentication, access and modification control in permissionless blockchains (such as Ethereum) can be advantageous in situations where trust is paramount. As an additional benefit, permissionless blockchains resort to cryptocurrencies as incentives for appending information to the ledger which facilitates the creation of novel business models.

Intrinsically connected to the concept of blockchain is the existence of smart contracts enforced by coded rules, which can convey trust in multiple applications without resorting to third parties (Wüst & Gervais, 2018). Smart contracts permit for instance issuing digital tokens for the creation of new decentralised markets, such as ERC-20 in Ethereum (Vogelsteller & Buterin, 2015), and can become highly advantageous if connected to digital information technologies in the physical world (e.g., bar codes, RFID). They can also be used to model the primary functions of DMs, such as orders and auctions. Implementations of this kind leverage on the blockchain's transparency and security to do escrow or winner verification. Strain is a platform making use of these properties in sealed-bid auctions to protect the confidentiality of bids and securing malicious bidders attacks (Blass & Kerschbaum, 2018). A different implementation utilises a set of cryptographic protocols that provide bid privacy and bid binding, public verifiable correctness and financial fairness in the system (Galal & Youssef, 2019). The Hainan Airlines (HNA) group has implemented an internal, decentralized, cryptocurrency-based e-commerce platform to manage employee benefits as a way to eliminate institutional intermediaries while protecting sensitive information (Ying et al, 2018).

Another field in which a significant trend to adopt blockchain solutions can be observed is supply chain management. Although its adoption has been more noticeable in countries that feature higher development in the IT and internet infrastructures (Kamble et al., 2018; Queiroz and Wamba, 2019), which may introduce some bias in its observed impacts, the blockchain has been shown to significantly impact aspects such as cost, risk reduction and flexibility (Kshetri, 2018), traceability of transactions and other interactions (Abeyratne & Monfared, 2016; Biswas et al., 2017; Lu and Xu, 2017), provenance of products (Kim & Laskowski, 2016) and anti-counterfeits (Toyoda et al., 2017), and disintermediation (Weber et al., 2016). Blockchains themselves are also effective at providing the foundation for decentralised and anonymity-preserving reputation systems that allows customers to submit ratings and textual reviews (Bazin et al., 2016). Indeed, most organizations can benefit from the enhancement of processes and operations spanning through the entire supply chain, as well as from safer, transparent and efficient transactions, and from the improvement of trust and reliability across the network (Kshetri, 2018; Ying et al., 2018; Zamani and Giaglis, 2018; Hughes et al., 2019). These aspects transform and evolve the relationship between stakeholders (Wang et al., 2018; Queiroz and Wamba, 2019; Queiroz et al., 2019; Wang et al., 2019), namely cooperation and trust, among others, and as such are relevant in the scope of this work.

3. Requirements of the decentralised e-marketplace

3.1. Scope and economic rationale

The platform proposed in this paper was envisioned for serving both B2B and B2C relations. Contrarily to other marketplaces such as eBay or Amazon, the proposed DM is “buyer-push”, enabling users to insert their particular proposals instead of selecting through a list of available items. One of the main drivers behind this implementation is to promote increased buyer bargaining power by allowing proposals to be aggregated and undergo auction listing, thus potentially reducing prices.

From the suppliers’ perspective, this model can comprise an incentive for small and medium businesses, since they can sell directly large quantities of products/services to final consumers without the need for retailers or any other intermediaries. In addition, different versions of the platform can cater to different product scopes, ranging from consumer electronics to service brokerage, e.g. insurance brokers can aggregate the needs and interests of many users, thereby offering better contract conditions (which can be automated), resulting in improved surplus for players with less purchasing power. Transporters and trusted mediators can also operate in the system to automate order fulfilment and expedite conflict resolution.

Other advantages of this type of implementation can be accounted for in the broader context of operations and supply chain management. Even if suppliers tend to lose power and reduce their margins, their inventory turnover will potentially increase. Moreover, the DM platform allows participants to buy and sell goods efficiently and turn cumbersome ad-hoc business relations into a seamless, trustful and interconnected network, ensuring anonymity where needed. Its usage can reduce transaction costs, time delays and information asymmetry, increasing coordination among participants and the possibility of establishing new business relationships. Finally, the implementation of a transparent yet private preserving network should significantly increase visibility over the supply chain and allow for provenance ascertainment, thereby directly contributing to a reduction of the Bullwhip effect, and thus the operating costs of a business.

In the context of ensuring fairness in the transaction process, while boosting the aforementioned potential economic surplus for buyers, first-price sealed-bid (FPSB) auctions feature several desirable characteristics. Indeed, this auction typology is advantageous from the standpoint of buyers, assuming that bidders (i.e., suppliers) will have a particular aversion to risk, and thus a lower fulfilment price should be obtained in comparison with other alternatives such as second-price sealed-bid (SPSB) or Vickrey auctions (Coppinger et al., 1980; Klemperer, 1999). Moreover, the increased bargaining power provided by demand aggregation should yield a lower price than a conventional purchase, contributing to a theoretical higher preference from buyers regarding the use of this platform. Despite the fact that sellers may not be able to extract as much value from winning the auction in comparison to a SPSB auction, one can argue that the system will nonetheless be fairer, as rational suppliers can bid a price that is economically viable to them and still have access to a more substantial portion of the market than before given the demand aggregation property.

3.2. Aggregation approaches

In order for buyers to gain bargaining power, their individual needs need to be aggregated into one single order. Several alternatives were considered, each with its own set of advantages and challenges. A first and more intuitive alternative is characterized by the automatic aggregation of buyers according to the procured goods. In this approach, each buyer specifies a maximum price that they are willing to pay for a given procured good. Buyers are automatically aggregated into listings that feature similar maximum prices for the same procured good. As the listing is created, any supplier is able to post bid values and available good quantities, bearing in mind that the winning bid must account for all the demand. Drawbacks of this alternative include the definition and calibration of buyer aggregation and supplier matching parameters throughout the process of creating aggregated contract listings (e.g., the definition of the aggregation threshold). Moreover, the uncertainty of the outcome of the matching process may also comprise an obstacle.

A second alternative expands on the automatic aggregation and matching of the previous one by focusing on the maximization of supplier fulfilment conditions. In this context, this approach adopts a multivariate and thus more complex means of buyer aggregation. Indeed, while buyers can submit orders with different maximum prices, they can also specify other features such as maximum admissible lead time. A single listing is created encompassing all the orders of a single product, regardless of the variation in maximum prices and/or admissible lead times. At this point, suppliers are able to bid for partial order fulfilment, attempting to “capture” demand. For instance, Supplier A submits a bid that satisfies the conditions of 50% of buyers in an aggregated listing. Should a Supplier B submit a better bid (e.g. lower prices, or lower lead time) that captures 80% of the buyers in the listing, this supplier would take up a part of Supplier A’s customers. It is important to note that even though suppliers have access to the information regarding the amount of buyers that may be captured with their bid, the bids of other suppliers are not known. Only one bid per supplier can be active in each listing. Given the characteristics of this approach, the orders of some buyers with lower maximum prices/lead times may not be fulfilled on the range of orders captured by the bids from suppliers. Concurrently, this approach inherently implies a higher level of complexity concerning not only the usage of the platform, but also its conceptualization and implementation, e.g. in terms of dealing with multivariate-related aspects, such as the priority level imparted to each auction parameter (i.e., maximum price, maximum lead time). Additionally, the efficiency and ease of integration with transport companies may also be hindered, especially in what concerns buyers from the same area “captured” by different suppliers.

A third alternative is aimed at addressing the drawbacks from the two previous approaches. In this approach, any single participant has the ability to create and define a listing for a good, to which other peers may be allowed to aggregate or not according to the creator’s preference. The creator of a listing defines all features and properties to which all other participants must abide to, such as maximum price per item, or maximum lead time. Should the aggregation feature of the listing be set as open, buyers may then join this listing, committing to the specified conditions while doing so. Suppliers then submit blind bids for satisfying the entire order quantity. On the one hand, this approach enhances fairness in the system, while simplifying its usage. In fact, the multivariate problematic of the second alternative is eliminated, as well as the issues associated with the forced automatic aggregation and the calculation of the prices to be paid by buyers from the first alternative. On the other hand, this approach cannot guarantee features such as the maximization of bargaining power, though buyers are given the option of not joining a specific listing (e.g., should they disagree with the listed conditions beforehand) and create a new one according to their own requirements. However, in cases when a high number of listings for a single good are created, the resulting search by new participants looking to join one may become cumbersome, as it is essentially a manual process. Table 1 summarizes the advantages and drawbacks of all considered alternatives.

Table 1 – Aggregation approaches, as well as associated advantages and drawbacks

Approach	Description	Advantages	Drawbacks
1	Aggregation according to single parameter	· Increased bargaining power	· Uncertainty regarding the outcome of the matching process · Definition and calibration of buyer aggregation and supplier matching parameters · Dealing with multiple requirements in the aggregation process
2	Multivariate aggregation	· Increased matching rate	· Dealing with the transport logistics in cases of buyers captured in the same zone by different suppliers · Higher complexity regarding the bidding process · Definition and calibration of buyer aggregation and supplier matching parameters · Dealing with multiple requirements in the aggregation process
3	Aggregation according to user preferences	· Platform usage is simple and intuitive · Higher freedom for buyers to create listings according to their own requirements	· Potential partial loss of bargaining power by the buyers in comparison with other alternatives · Searching for listings may become a cumbersome process for new participants · Risk of getting a lower match rate between participants due to the more rigid nature of the listings

3.3. Properties of a decentralised marketplace

Given that the scope of the marketplace elaborated in Section 3.1 is non-trivial, this brings a series of additional challenges in order to achieve decentralization. Indeed, according to IJzendoorn (2017), one of the leading characteristics of a decentralised market is the inexistence of intermediate parties. A direct implication of this fact is the subsequent need for a trust system, capable of conveying the trustworthiness of peers. However, this can pose a challenging problem in many cases not only in terms of its implementation but also regarding potential security issues and resilience against the use of strategies to cheat or manipulate the technology (Wigand, 1997; Lucking-Reiley & Spulber, 2001). In particular, the proposed platform should be able to resist manipulation and collusion attacks by malicious participants, such as ballot-stuffing attacks (e.g., participants voting more than once to manipulate reputation scores), bad-mouthing attacks (e.g., participants colluding to force negative feedback on a third party), or whitewashing attacks (e.g., participants resetting a poor reputation by re-joining the system with a new identity) (Schaub et al., 2016).

The underlying technology should have the least possible number of entry barriers and, in theory, should be a system in which anyone can participate. Information inputs for transactions should come from various sources and in different formats, potentially overlapping one another. As such, given this heterogeneity of information, it is crucial to provide self-sustainable means to reach consensus over a single source of truth with high finality assurance. It should be possible to verify the occurrence of transactions, even if its inputs are unknown, in order to ensure transparency over the DM processes, thus making them auditable. This is especially critical regarding design considerations for the chosen auction method (FPSB auction), in which bids must be concealed, but the result should be publicly verifiable and consensual.

Ultimately, the proposed DM aims to reduce waste in supply chain interactions by automatically triggering actions according to predefined conditions. Taking into account the fact that the auctions in the platform imply holding funds in escrow, it benefits greatly from reducing the involvement of intermediaries to a minimum. Such disintermediation entails strong trust, transparency and security requirements, enabling open verification by users and preventing a black-box effect.

4. System design

Having established a clear definition of the scope and requirements of the DM, we can now detail the technological and design choices of the platform. In short, the technology underpinning the DM must be able to aggregate orders, provide seal-bid auctions, integrate with shipping companies, and provide a feedback system to users in order to harness trust in the use of the platform, while automating as much as possible all operational activities related to payment, order fulfillment or delivery.

To this purpose, our DM relies on a smart contract framework where orders are placed and managed (cf. Figure 1). In this framework, each auction corresponds to a *listing contract* and their creators may customise the type of orders according to their own business rules. Special clauses can be used to trigger automatic events such as releasing escrow upon confirmation by the courier that the order was delivered (Weber et al., 2016). Thus, processes such as *order aggregation* and *auctioning* result in the generation and execution of smart contracts, which, as events unfold, lead to the *fulfilment* of the customers' needs. In turn, the data resulting from this process, together with the degree of *fulfilment* (if any) of contracts as well as the feedback from buyers, is fed into a *reputation* system.

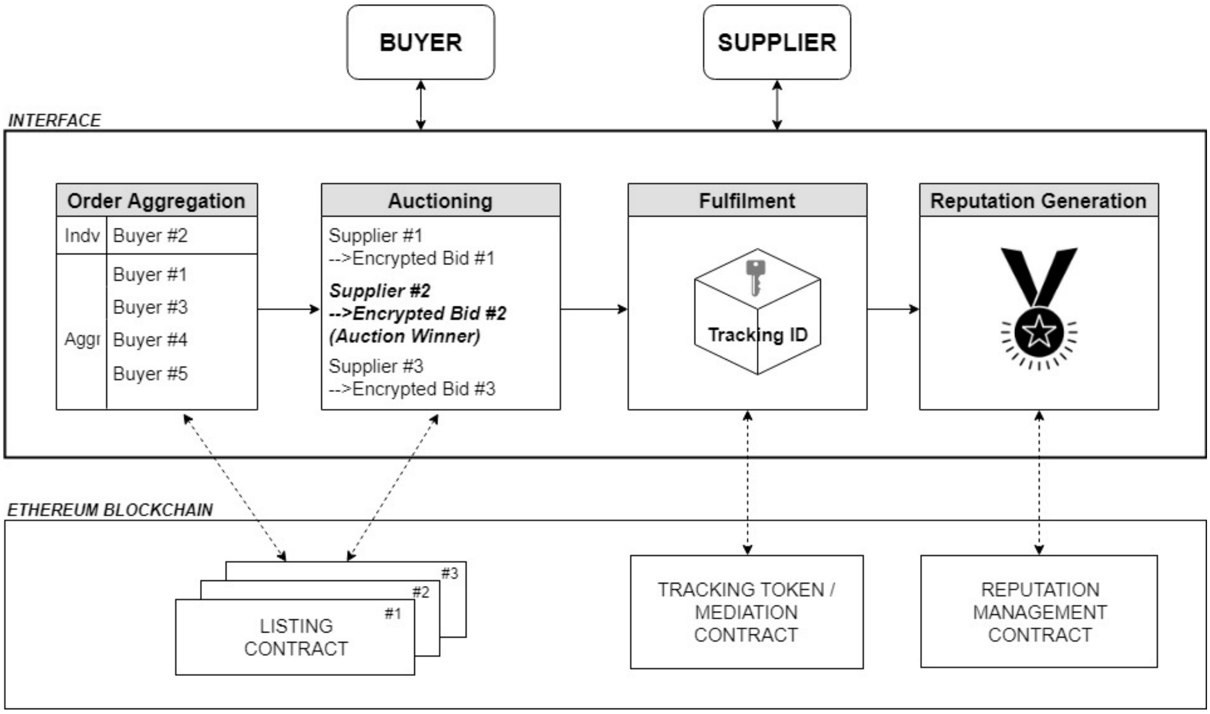

Figure 1 – Overview of the DM

4.1. Blockchain solution

Smart contracts are a central tenet of most blockchains, which is the technology upon which the DM was implemented. Yet, for a blockchain implementation to be successful in an untrusted environment such as a pseudonymous e-marketplace, a set of limitations inherent to this technology must first be addressed. These include the lack of privacy, the lack of standardisation, the “garbage-in garbage-out” (GIGO) problem, the black-box effect, and inefficiency-related issues. Notwithstanding these well-known challenges and limitations associated with a blockchain, the potential of this technology for DM implementations is still noteworthy, especially in applications in which trust and robustness are paramount (Babich & Hilary, 2019a, 2019b).

Considering the available platforms, as well as the analysis regarding their features and limitations, we have opted for a public and permissionless blockchain, such as Ethereum. The main reason behind this choice lies in an attempt to minimise the barriers of entry to the network, theoretically maximising the number of participants. As a “decentralised world computer”, Ethereum features smart contracts that enable the creation of fungible and non-fungible tokens via community tested and agreed standards, which will comprise a vital part of the proposed reputation system, as well as a means to ascertain product provenance. Despite the lack of formal security verification associated with Solidity (Ethereum’s primary programming language), its extensive use across the Ethereum development community, acceptable learning curve, and the existence of great documentation make it a compelling option for the implementation of the proposed DM.

The architecture of the DM takes into consideration several factors: the base amount of Gas required for every transaction in Ethereum; the economic incentive for the miners to append transactions to the blockchain; whether or not data and executable code should be kept on or off-chain (cf. Figure 2); and how should the contracts be conceptually organized in terms of hierarchy and linkages. In the proposed DM, listing contracts are created in an on-chain re-usable factory contract that guarantees the consistency of the contract definition. A factory contract is similar to a class and the smart contract instances are generated by calling a function (Xu, Pautasso, Zhu, Lu, & Weber, 2018). This function call requires an extra cost to deploy the factory since we are using a public blockchain. In order to reduce this cost and optimize function calls between contracts, we use a proxy contract, “listing interaction”, to interact directly with the other smart contracts and reduce contract instantiations.

Furthermore, in lieu of enabling encrypted computations over the bidding system and mitigating some privacy limitations in blockchains as described by Babich & Hilary (2019a, 2019b), we have further opted for employing “secret contracts” in conjunction with the aforementioned Ethereum smart contracts. Enigma, created by Zyskind et al. (2015), is one of the few permissionless blockchains with privacy-preserving characteristics and features a direct connection to Ethereum, therefore embodying a viable choice for the DM. Indeed, this platform is capable of maintaining stateful encrypted contracts, allowing encrypted data to persist between tasks, and enabling full bid privacy for blind auctions through the entire lifecycle of the DM.

Since some external data interaction needs to be connected to the closed execution environment of smart contracts, we use a decentralized oracle network, Chainlink. The latter has the ability to act as a bridge to Ethereum and source data securely and automatically, thus effectively extending the tamperproof property of smart contracts to the end-to-end operation with external APIs (Juels, Ellis, & Nazarov, 2017).

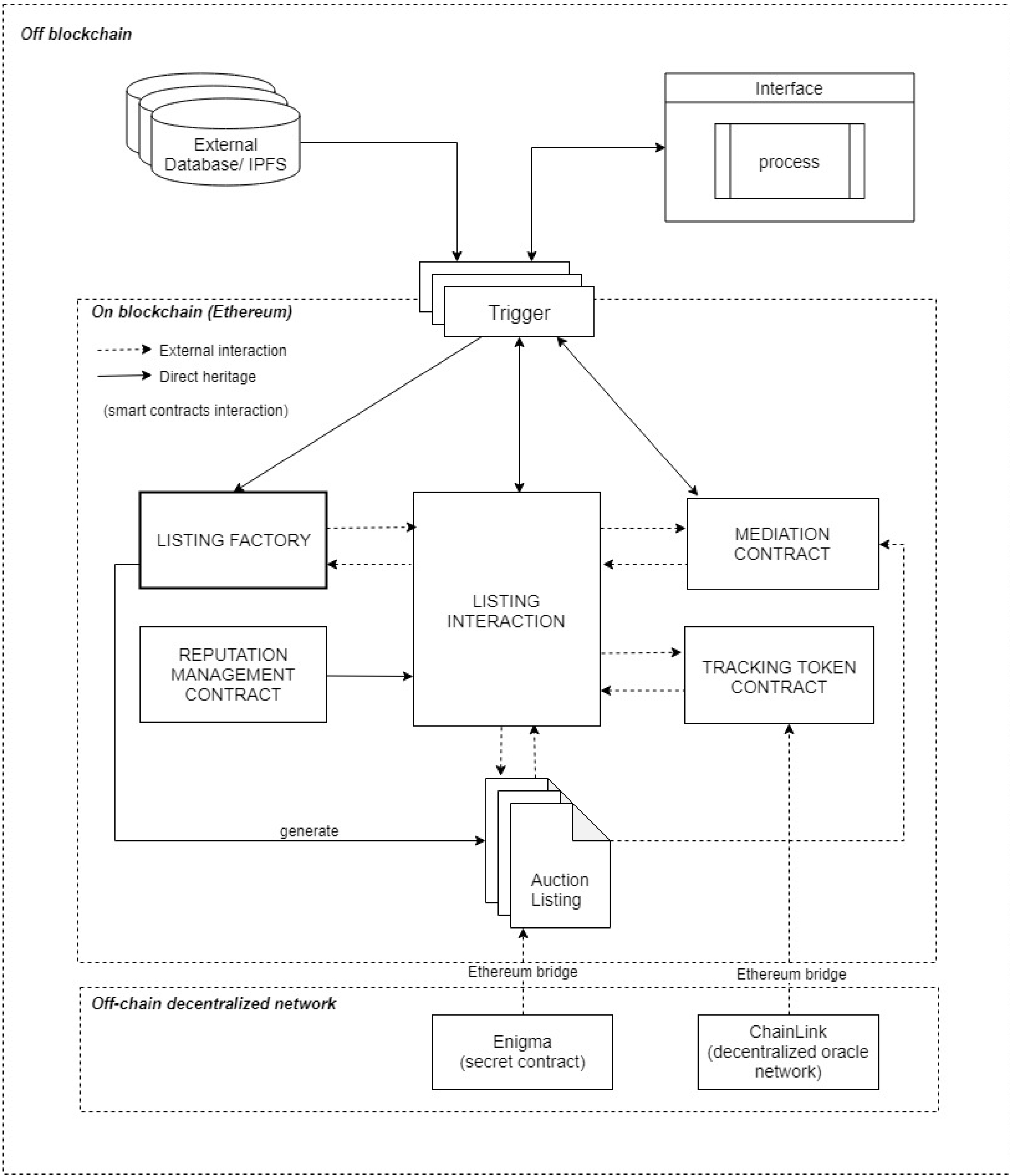

Figure 2 - Smart Contracts Architecture

4.2. Order aggregation

In this phase a participant can create a listing in the DM platform that satisfies his needs. When a participant submits a listing in the platform, it triggers the creation of a new auction listing generated by the listing factory contract (cf. Figure 3). The ability to create new auction listing contracts is granted not only to buyers, but also to suppliers, since they could want to signal the availability of a product they intend to sell. Each listing is associated with six parameters (besides time restrictions): a product identifier; the region the contract is associated to; a flag setting whether the auction is groupable or not; an indication of minimum reputation for suppliers to join and bid in the auction; a lead time that users are willing to wait for the fulfilment of the purchase contract; and a maximum value that users are willing to pay for the item.

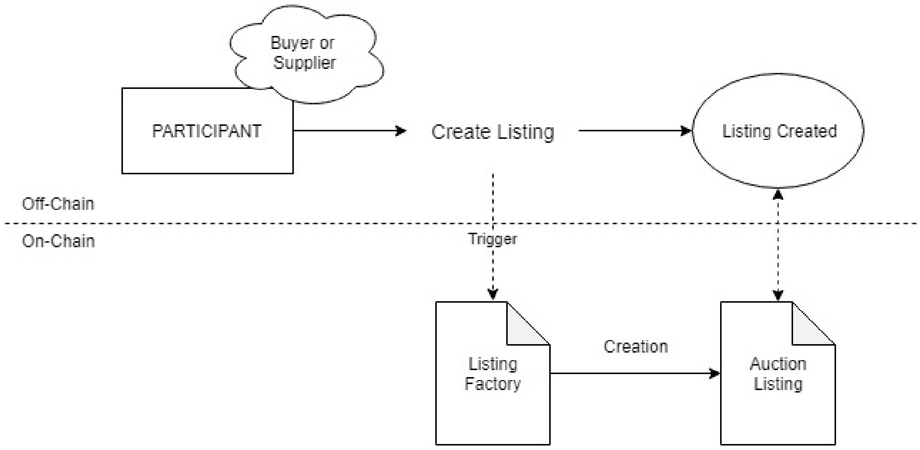

Figure 3 - Listing Creation Process

In order for buyers to be able to explore quantity discounts, they must search and join an already existing listing for the procured item. Every time a new participant intends to join an existing listing contract, a trigger will be sent to the listing interaction contract, aggregating the desired quantity in the smart contract associated to the auction. In view of preventing buyers from committing to several simultaneous auctions in a way that exceeds their total available funds, the full amount of capital corresponding to the procured products or services in each auction is put in escrow at the time of aggregation. This aims to both disincentivise buyers from exploiting the platform and automate payments to suppliers once contract conditions are fulfilled. A deadline is associated with each proposal, giving additional buyers the opportunity to join or cancel their proposals. After the timer to join an existing auction ends no more participants can join the auction listing and the aggregation period is over (cf. Figure 4).

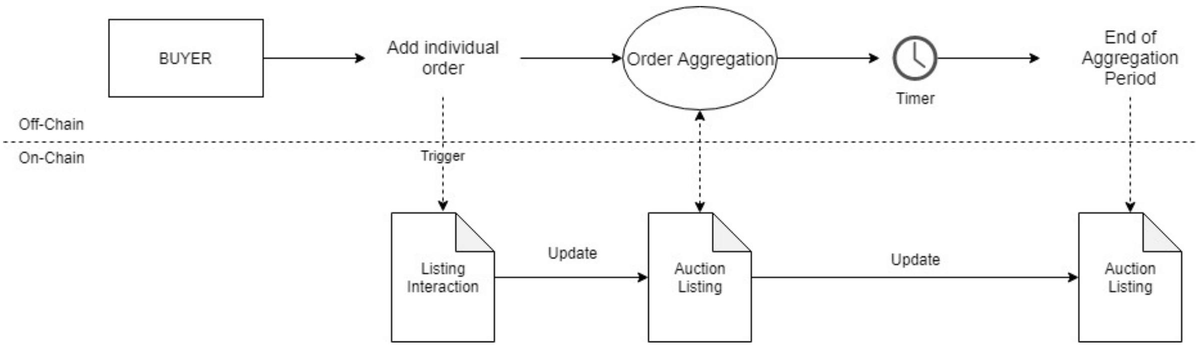

Figure 4 - Aggregation Process

4.3. Auctioning

To maximise buyer bargaining power, we implemented a FPSB auction where suppliers must bid for complete order fulfilment. Other participants can see that a particular supplier has joined but not their bid value. All suppliers deposit a fee (fBid) in escrow in a given listing contract. Bid inputs are encrypted in the platform to allow for a blind auction.

To further explain the reasoning behind the fBid fee, it can be regarded as a measure of credibility in the system, representing the lowest bound on the cost for an adversary to generate reputation from product fulfilment, thus imparting trustworthiness (Soska et al. 2016). It acts by deterring malicious suppliers from running sybil attacks with buyer and supplier accounts in order to leave fake reviews to influence his reputation, since the fee value depends on the total product quantity in a listing and on the category of the items.

Following the end of the period to submit a sealed bid, the smart contract will automatically send the encrypted bids list as a task to an Enigma node to determine the winner (cf. Figure 5). The completion of this private computation will result in a callback to our Ethereum auction listing smart contract, updating the winner and the winning bid, and allowing any ensuing withdrawals by the suppliers to take place.

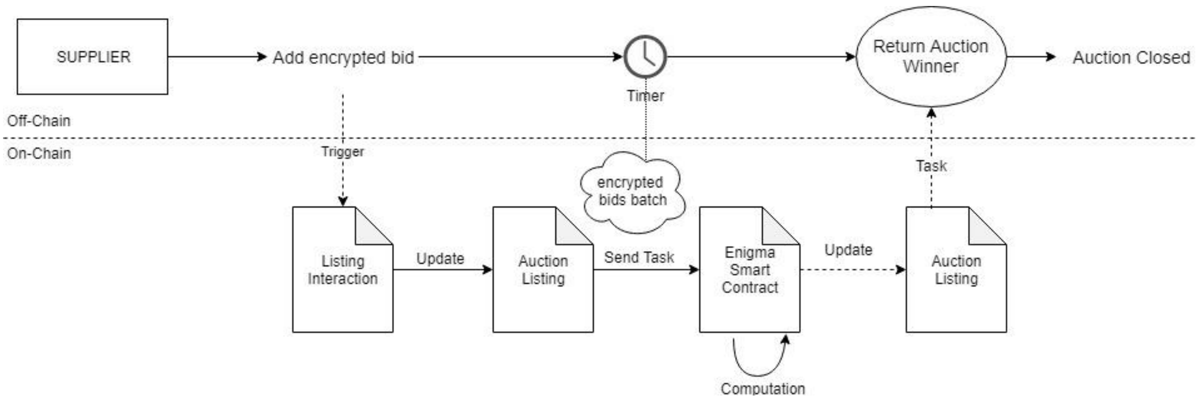

Figure 5 - Auctioning Process

4.4. Fulfilment

This phase represents the physical integration of the different platform stakeholders and provides a solution to many transparency problems identified in OM/SCM. The winning supplier should initiate the delivery for each buyer by selecting a transporter in the platform. We assume that transporters are integrated in the platform for selection and can be added in cases when suppliers want to use other transport services. After the transporter accepts the shipment, the listing interaction contract will be triggered, providing the shipment information, setting a unique transporter identifier, and minting unique digital tokens that represent the products being shipped. These tokens permit the storage of tracking information, allowing after-sales proof-of-ownership, and are based on the ERC-1155 multi token standard for increased interoperability and efficiency of deployment (Radomski et al., 2018). They can be customised to attach delivery events, effectively providing an immutable trail of provenance of the shipment starting from the first timestamp.

Attached to the shipment information, both transporter and buyers exchange a public key, generated from previous off-chain generated private keys that will be used to validate the shipment between both parties (cf. Figure 6). This key transaction scheme is based on Diffie-Hellman key exchange method, (Kaur & Nagpal, 2014; Rescorla, 1999) and each participant can securely exchange keys over a public network.

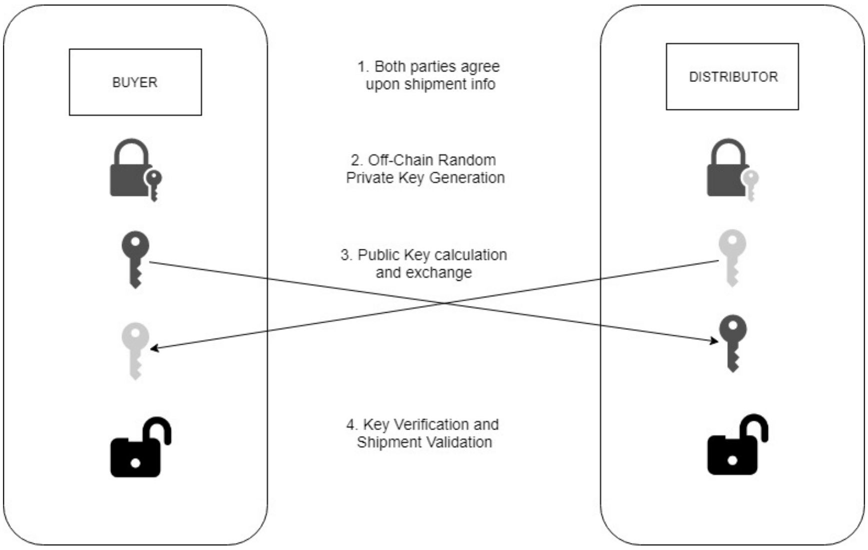

Figure 6 - Key exchange scheme; based in Diffie-Hellman key exchange method

During the shipment process, information might be required from external systems, such as GPS data and ERP supply chain systems information. IoT devices integration are also expected to boast great benefit in reducing the GIGO problem elicited before, given their ability to collect information without human intervention and thereby increasing the trustworthiness of the information sought from external systems. As more of these devices are used across supply chains, they can be leveraged upon instead of relying on human typed information. In order for smart contracts to interact and get information from the external world, a decentralized oracle network is used to provide these with shipping information every time it is requested (Xu, Pautasso, Zhu, Lu, & Weber, 2018). The Chainlink platform is a network capable of acting as a bridge to Ethereum and providing data securely, automatically and in a tamper-proof manner. (Juels, Ellis, & Nazarov, 2017). Hence, together with the fact that it is at an advanced production stage, these reasons provide the grounds for the adoption of this platform.

At the end of the process, a transporter exchanges the shipment key with the buyer for verification and releases the shipment if successful (cf. Figure 7). The fulfilment is thus deemed complete, and any post-fulfilment condition should trigger at this point, e.g. releasing payment to the supplier.

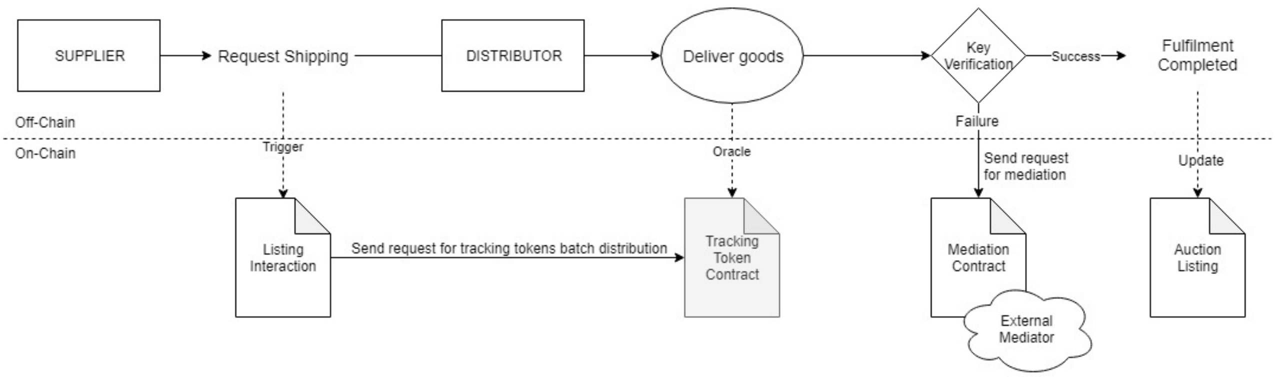

Figure 7 - Fulfilment Process

In cases where the verification procedure is unsuccessful, the buyer's funds are transferred to a mediating smart contract controlled by trusted third parties agreed by both the buyer and the supplier. Such entities are able to analyse the log of transactions and claims reports by both parties to determine the origin of the failure. According to the decision taken, the smart contract will then transfer the amount in escrow to the rightful beneficiary and deem the transaction complete.

4.5. Reputation generation

The goal of the reputation system in the DM context is two-fold: to reduce the effects of asymmetric information between buyers and suppliers, signalling the high value of agents that consistently comply with the agreed terms; and to create disincentives to act fraudulently. Thus, the reputation system was oriented towards suppliers, since buyers have less interest and or opportunity to act distrustfully, as they have to pre-commit with a lump sum to register their interest in the purchase.

The reputation system collects metrics originating from transactions and also from feedback left by the users. However, contrarily to typical e-commerce websites, this information lasts in the blockchain and does not require a central point to be maintained and shared. By leveraging on the availability of this data, the reputation management system can be integrated into the platform, both as a measure of performance of each supplier and as a quality assessment metric for goods and services.

Yet, the proposed reputation system extends beyond perceived social value (e.g., typically conveyed in the form of stars or rating). Through the use of the decentralised ledger' s capabilities, the platform awards a digital token – Merit – that acts as a financial incentive for professional and ethical behaviour. Only suppliers own Merit (though anyone can query a supplier's Merit), which provides exclusivity tiers (e.g., normal, gold, or diamond suppliers) corresponding to different platform benefits. Merit is exclusively controlled by smart contracts and is not transferable between users, since reputation cannot be transferred. Nevertheless, the platform may allow Merit to be burned in exchange for economic rewards or perks (Orlovsky & Sobol, 2018).

Merit is earned or lost immediately after fulfilment is confirmed, though not immediately transferred to the supplier to discourage attempts at users rapidly inflating Merit to participate in other listings. Moreover, since reputation is a point-based system, it is essential to correlate good and bad behaviour to certain amounts of Merit. Fulfilment metrics calculation is based on a function of different metrics, e.g. the actual fulfilment lead time versus the maximum lead time associated with the order and or the supplier response rate during the listing. Ensuing this calculation, a window of time in which buyers are economically incentivised to leave feedback will open. The feedback is input in the form of a 1 to 5 rating, which can then be verified against the fulfilment metrics, potentially resulting in additional merit for the supplier. When the time for users submit feedback is over, all Merit is transferred to the respective suppliers and the reputation score is set (cf. Figure 8).

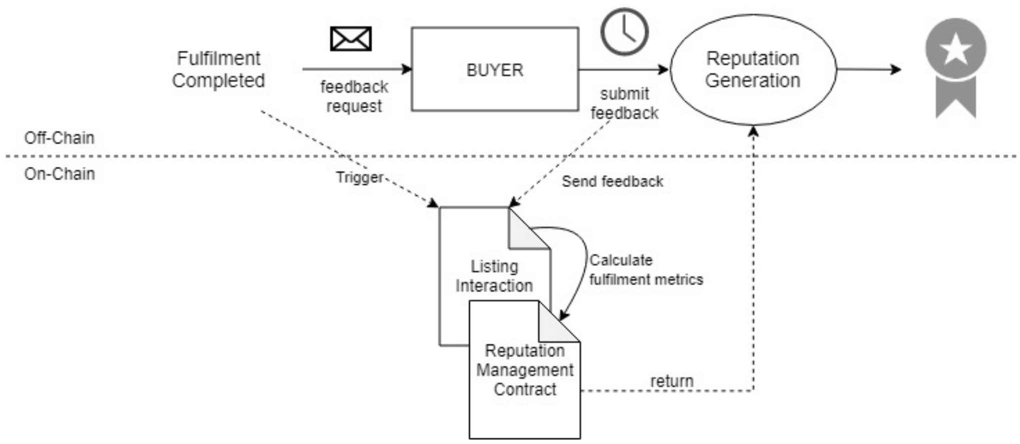

Figure 8 - Reputation Generation Process

4.6. Example of Solidity implementation

In order to demonstrate the capabilities of smart contracts in Solidity for the topic at issue, we demonstrate a possible implementation of a support procedure: the withdraw function (cf. Algorithm 1). This code snippet was developed taking into consideration the checks-effects-interactions pattern to build safer functions and help prevent attacks such as reentrancy (Consensys, 2019). It assumes that the calculation of the amounts to withdraw is carried out before the user has a possibility to extract value in escrow via this function. A participant can withdraw under one of three conditions: (i) if the address is a buyer and the auction has been cancelled at any time before the aggregation deadline ended, the full amount committed when entering the listing is withdrawn; (ii) if the address is a non-winning supplier that participated in the auction, in which case the fee deposited is withdrawn; or, in the case of a winning supplier, the amount corresponding to the fee and payment after fulfilment of a buyer order; or (iii) if the address is a buyer that has had an order fulfilled, any funds assigned to that address are withdrawn.

```
/**
* @dev Withdraw function according to checks-effects-interactions solidity pattern
* @param _beneficiary The address of the beneficiary account
*/
function withdraw(address payable _beneficiary) external
{
    require(msg.sender == owner);

    require(uint256(listingMode) == 3);

    require((supplierParams[_beneficiary].isParticipating && !buyerParams[_beneficiary].isParticipating) ||
    (!supplierParams[_beneficiary].isParticipating && buyerParams[_beneficiary].isParticipating));

    uint256 withdrawalAmount = 0;
    bool buyer = false;
    bool supplier = false;

    if (buyerParams[_beneficiary].isParticipating){
        buyer = true;
    }
    else if (supplierParams[_beneficiary].isParticipating){
        supplier = true;
    }

    if (lData.canceled){
        withdrawalAmount = buyerParams[_beneficiary].weiAmount;
    }
    else{
        if (supplier){
            withdrawalAmount = supplierParams[_beneficiary].weiAmount;
        }
        else if (buyer && buyerParams[_beneficiary].canWithdraw){
            withdrawalAmount = buyerParams[_beneficiary].weiAmount;
        }
    }

    require(withdrawalAmount > 0);

    if (supplier){
        supplierParams[_beneficiary].weiAmount = 0;
    }
    else if (buyer){
        buyerParams[_beneficiary].weiAmount = 0;
    }

    _beneficiary.transfer(withdrawalAmount);
}
```

Algorithm 1 - Example implementation of the withdraw function in Solidity

5. Conclusion and future work

In this paper we presented a decentralized marketplace built upon a blockchain that serves three purposes: (i) allowing buyers to aggregate in a transparent and open way, enhancing bargaining power; (ii) fostering digital broking, as it allows middlemen to act as buyers; and (iii) augment traditional OM/SCM processes, improving activities such as shipping and payment. Emphasis has been put on the conceptualisation of such network, as well as on to what extent it influences market efficiency, supply chain coordination, and buyer-supplier relationships. In this context, aspects inherent to the blockchains, such as automation, immutability and disintermediation, play a critical role in improving market efficiency, with a substantial effect on reducing transaction costs and time delays. Moreover, the additional features related to visibility, transparency, and the subsequent reduction in information asymmetry, propel the projected ecosystem towards evolving buyer-supplier relationships in an unprecedented way. Not only does the network enable the direct connection between customers and suppliers, removing mediators, but it also does so while providing a permanent auditable trail of every transaction and product movement from origin to destination, reducing opportunities for fraud. Even more remarkable is the additional existence of a ranking based on reputation that enables and fosters the establishment of new business relationships, transforming the current paradigm in which mutual trust is exclusive to long-term relationships.

The smart contract-based platform provides aggregation of individual needs of DM participants into collective listings, effectively comprising a response to need to enhance customer bargaining in markets where suppliers still hold the upper hand and large mark-ups. The subsequent benefits related to enhancing bargaining power and enabling economies of scale, as well as the introduction of the tokenized reputation system, comprise an effective incentive for participants to share information, directly addressing the possibility of implementing digital broking of services.

Many of the considerations made in previous sections aimed at improving trust and security. The current DM platform is resistant to several network and blockchain attacks, though not fully attack-proof. Ballot-stuffing attacks are tackled by implementing a sealed bid auction system, discouraging suppliers from adopting multiple buyer sybils and risk winning the auction, thus forfeiting fees associated with the total required product quantity in a listing. Bad-mouthing attacks are discouraged by the fact that an attacker loses 100% of the money in escrow to the supplier once fulfilment is complete. Thirdly, resistance to whitewashing attacks is achieved by the introduction of the Merit metric, which rational suppliers will strive to build, as it potentially enables participation in more listings. The amounts of Merit could be differently awarded to suppliers, being higher for longer participation time and exemplary behaviour, thus making whitewashing attempts counter-productive. Further overall resistance to sybil attacks could be achieved by the implementation of a decentralised and privacy-preserving identity system (Liu et al., 2017).

Moreover, additional limitations involve the introduction of third parties in the DM, e.g. trusted mediators in the claims process and transporters in the shipping process. Such less automated setting may contribute to wrongful inputs which may affect smart contract outcomes. Nevertheless, it is expected that the intervention by these two third parties, and thus the GIGO issue, can be reduced by, respectively, the implementation of an advanced means of decentralised governance and the integration of the DM with transporter's sensors and APIs. Ultimately, the study of the type of metrics to use in the calculation of Merit can contribute to a heightened refinement of platform incentives, together with the creation of other novel types of rewards for information sharing.

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